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A S P H A L T   P A V I N G   C O N F E R E N C E

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MICHIGAN COLLEGE OF MINING AND TECHNOLOGY
Houghton, Michigan
May 18 and 19, 1960

ASPHALT PAVING CONFERENCE

SPONSORED BY

Department of Civil Engineering

WITH COOPERATION OF

Michigan State Highway Department
Michigan Asphalt Paving Association
The Asphalt Institute

Michigan College of Mining and Technology
Houghton, Michigan
May 18 and 19, 1960

FRONTISPIECE - THE PROGRAM

1960 ASPHALT PAVING CONFERENCE
Michigan Tech Ball Room - Memorial Union
First Session - Wednesday, May 18, 1960

1:00 P.M. - REGISTRATION
Ball Room

2:00 P.M. - PRESIDING
Howard E. Hill, Managing Director
Michigan State Highway Department

WELCOME
Frank Kerekes, Dean of Faculty
Michigan College of Mining and Technology

2:30 P.M. - HISTORY OF ASPHALT
Ladis H. Csanyi
Professor in Charge
Bituminous Research Laboratory
Iowa State University

3:30 P.M. - TYPES AND USES OF ASPHALT IN PAVEMENTS
Claude F. Skidmore
District Engineer
The Asphalt Institute

4:30 P.M. - BUILDING THE VELVET CARPET - Movie
Scott A. Baker
Executive Secretary
Michigan Asphalt Paving Association

CONFERENCE BANQUET

6:30 P.M. - Douglass House, Houghton

"AMERICANISM"

Dr. Ronald C. S. Young appears through the courtesy of General Motors Corporation.

1960 ASPHALT PAVING CONFERENCE
Michigan Tech Ball Room - Memorial Union
Second Session - Thursday, May 19, 1960

9:00 A.M. - PRESIDING
Wilfrid C. Polkinghorne
Professor and Head, Michigan Tech
Department of Civil Engineering

CHANGES IN CONSTRUCTION PRACTICES
Walter P. Tervo
Construction Engineer
Highway Survey
Michigan State Highway Department

10:00 A.M. - COUNTY AND LOCAL ASPHALT PAVEMENT PROBLEMS
Henry L. Shroeger, Engineer
Marquette County Road Commission

11:00 A.M. - THE IMPORTANCE OF BITUMINOUS BASE CONSTRUCTION
Gerard O. Kerkhoff
Head of Soil Testing Section
Michigan State Highway Department

LUNCHEON - BALL ROOM - MEMORIAL UNION

1:30 P.M. - PRESIDING
Frank Kerekes, Dean of Faculty

RESEARCH IN ASPHALT TECHNOLOGY AND DESIGN OF BITUMINOUS MIXTURES
Paul J. Serafin
Bituminous Testing Engineer
Michigan State Highway Department

2:30 P.M. - A NEW METHOD OF ASPHALT MIXING
Ladis H. Csanyi

ADJOURNMENT

FOREWORD

The 1960 Asphalt Paving Conference held at the Michigan College of Mining and Technology on May 18 and 19 was highly successful because it provided an opportunity to assemble representatives of all phases of this important type of highway education, design, research and construction.

The educational and professional environment of the Michigan Tech campus and the high level of professional programs developed a strong feeling of accomplishment among those in attendance including both the audience and program participants. There were 190 in attendance; of these 75 were practicing engineers and 115 were students in the Department of Civil Engineering. The keen interest of the students in professional engineering programs is a further reason for conducting programs of this type on the Michigan Tech Campus at Houghton.

Special acknowledgment and genuine appreciation goes to the program participants for their excellent presentation of topics; to the Michigan State Highway Department for their contribution in planning and in program participation; to the Michigan Asphalt Paving Association and The Asphalt Institute for their promotion and support of the Conference; to the Department of Civil Engineering for effective assistance in all phases of the Conference activity; and to the Institute of Extension Services for providing the necessary registration, housing, and operational services.

Frank Kerekes

Frank Kerekes
Dean of the Faculty

August 1960

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HISTORY OF ASPHALT
by Ladis H. Csanyi

Asphalt is probably one of the earliest materials known and used by man. Archeological evidences indicate that the Cave Men, before the dawn of history, had found the natural asphalt lakes and had used their material for cementing the stone head upon the shafts of their spears, and also for treating wounds. At the beginning of recorded history, it appears that asphalts were fairly well known because it is found that the Sumerians in the year 4,000 B.C. were using it to waterproof boats, cementing building blocks and in ornaments. As time passed its uses were expanded, for in 2900 B.C. it was being used for waterproofing baths and drains, for weatherproofing building blocks by saturating them with asphalt, and as a trowelled surfacing for floors and pavements. Later, the Egyptians developed its use for the preservation of their mummies, while the Babylonians were mixing it with aggregates in the preparation of asphalt paving and building blocks and using it as paints and roofing seals. King Nebuchadnezzar's famous hanging gardens, one of the seven wonders of the world, shows asphalt used extensively in its construction, in waterproofing drains and waterways, saturated bricks for buildings and bridge abutments, also paving of walks and paths. The Assyrians at about 1000 B.C. were using it for medicinal purposes, while at the same time the Swiss lake dwellers were using it to coat piling to prevent decay.

The Greeks and the Romans, who used asphalts extensively, apparently did not discover new uses for the material other than a presumed ingredient of the devastating Greek Fire used in warfare. They did, however, apparently refine the manner and techniques of application.

During the Dark Ages, in Medieval Times, although bitumens were well known, they were not used extensively for any purpose other than pouring it upon the heads of the enemy attacking the castle walls. The Arabs, who preserved the knowledge of the ancients during this period, seem to have used it widely. Bitumens, nevertheless were so widely known that Columbus immediately recognized the material in the asphalt lake when he discovered the Island of Trinidad.

Historically, it seems that the ancients had discovered almost every conceivable use of asphalt. The extent to which they developed these discoveries and applied the knowledge gained appears to have depended upon the demands of the existant society and the times. Although asphalt was used for pavements in antiquity, it was not until the nineteenth century that the demands of transportation started its wide use in this field as we see it today. In 1835 and 1836 mastic asphalt pavements on foot paths were laid in Paris and London, respectively. Then in 1852 the first Macadam type asphalt pavement was laid in Paris.

The discovery of rock asphalts, sandstones and limestones impregnated with asphalt gave impetus to the use of asphalt in roads. The first rock asphalt used as a compacted pavement was tried in Paris in 1858. This type of asphalt construction of roads was so successful that it spread rapidly in France. It spread to London in 1869, to Newark, New Jersey in 1870, and to Washington, D. C. and New York, N. Y. in 1871. Rock asphalt roads are still being built today, not only in Europe but also in the United States in and around Kentucky, where Kentucky Rock Asphalt is available. This material makes excellent durable pavements.

Although the ancients had used asphalt aggregate mixes for pavements, the first sheet asphalt pavement using a mixture of sand and Trinidad asphalt was laid on Pennsylvania Avenue in Washington, D. C. in the year 1876. This type of mix and construction became quite popular and was used extensively for city streets, until the use of petroleum asphalts displaced the natural asphalt. Considerable natural asphalt is still being used in Europe for paving purposes.

At the beginning of the twentieth century, as the refining of petroleum asphalts improved, they came into more common use. About the same time cut-back asphalts and emulsified asphalt came into being. These developments widened the range of asphalt paving mixes and provided both hot and cold mix types. Asphaltic concrete mixes also began to appear and gain favor for rural highway pavements. The use of asphaltic concrete on highways brought about a rash of patented mixes. The first of these, known as the "Topeka Mix", appeared about 1910, and soon after was followed by Ammesite, Coldprovia, Bitulithic, and a host of others. Almost every contractor in the business had his own private mix. A large number of these "mix" mixes were excellent, as attested by the fact that some of them are still in service after 40 years. Many others, unfortunately, were poor and these failures placed a stigma upon the industry. They, however, did serve a useful purpose in establishing the need for specifications, controls and the development of some means of testing the physical properties of the mixes.

The first significant test devised around 1930 was the Hubbard-Field Stability Test. This was followed by the Marshall, the Triaxial, the Hveem and other methods of testing the physical properties of a paving mixture. These tests provided not only a means of designing and evaluating mixes but also a means of ascertaining the effects of asphalts, aggregates and their proportions upon the character of the mixes. This opened the door for detailed research for mix design and composition, giving us invaluable information and the assurance of durable mixes.

The various tests of the physical properties of mixes also provided a means of evaluating mixing techniques and plant production operations. At the turn of the century, asphalt plants were small and quite crude in operation, yet they possessed the basic elements still used today. They had a cold mix blend, such as it was, produced by a combination of wheel barrows, a dryer, a rotary screen, hot bins and a pug mill mixer. Modern plants still have the same basic elements, highly refined for better control and operation. They are much larger, with tremendously increased production capacity. One major change, brought about by the demands of high production, has been the development of the continuous mixer. A comparison of the old plants with the modern plants clearly shows that tremendous improvements have been made in refinement of operations, reduction in manpower needed to operate them, closer controls, and the introduction of automation to some degree. Yet, in spite of all this, very little change has been made in basic procedure during the past sixty years.

Asphalt is an exceedingly complex material. Man has observed, studied and catalogued its physical properties until a tremendous amount of information has been accumulated. Asphalts today are tested and classified mainly on their physical properties. Strange as it may seem, even though asphalts have been known for thousands upon thousands of years, we still know but little about their chemical composition. No doubt the alchemists studied its chemical composition in efforts to transmute it to gold. Yet the first treatise on the chemistry of asphalt was published in 1837 by J. B. Boussingault. In this treatise are found references to asphaltenes and petrolenes which are still in use today. Many investigators, such as Richardson, Marcusson, Nellynstein, Krenkler and many others, have studied the chemical composition of asphalts. They have compiled a tremendous amount of information. Yet today we know but little about the molecular character of the material, what happens in the process of polymerization and changes effected by aging, exposure to heat, light and traffic. Considerable research is being directed to this phase and it is hoped that new instrumentation, such as infra-red, ultra violet, and mass spectroscopy, will materially assist in shedding more light on this subject. Since asphalt is the basic ingredient in an asphalt mixture, a better knowledge of its composition is essential if asphalt technology is to advance with modern needs.

Asphalt paving has gained considerable popularity recently and is being used ever increasingly to meet modern traffic demands, not only on major highways and city streets but on local roads and in soil stabilization. Asphalt paving has served the public well and it will continue to do so if it maintains its progress in relation to traffic demands.

As one reviews the history of a development, one just cannot help but glance at the future as reflected by the past. We are living in a scientific age that is developing new theories, concepts, techniques and materials that are fantastic. There is every indication that the future will bring forth new materials and developments which will make commonplace things that are undreamed of today. How does this affect the future of asphalt? Even today, with the tremendous development of the plastics, there are plastics that may seriously compete with asphalts tomorrow, as indicated by the epoxy resins. Who can predict that a material may not be found that need only be sprinkled on the earth to yield a good pavement? Considering the advances made recently in the plastic field, asphalt technology must not rest upon its laurels but must advance swiftly if it is to retain its popularity in the paving field.

TYPES AND USES OF ASPHALT IN PAVEMENTS
by Claude F. Skidmore

There may be some confusion resulting from deletion of the word "in" from the subject as printed in your program, which I understood previously to be "Types and Uses of Asphalt IN Pavements."

As Professor Csanyi has so ably presented the history of asphalt it seems quite logical that I should consider what comprises an asphalt pavement design and take a look at the types of asphalts that may be incorporated in its construction.

Asphalt pavements or wearing surface is not new or untried even here in Michigan as Woodward Avenue in Detroit was paved with asphalt in 1868. Sheet asphalt pavements were placed in several cities along the East Coast, as New York, Washington, D. C. and others before the turn of the century. Until sometime after the turn of the century all asphalt paving was accomplished by the use of lake or natural asphalt imported from the island of Trinidad or Venezuela. Petroleum refined asphalt followed shortly thereafter and was used as a dust layer and surface treatment on existing gravel and stone roads. Existing gravel and aggregate surfaces were improved then by use of liquid asphalt seal coats, road mixes, cold plant mixes. However, hot plant-mix asphalt was not used to any degree until after the development of the paving machine by the Barber-Greene Company in the 1930's. Increased use of higher type hot plant mix asphalt has followed since that time. Developments have lead to what I would term the maintenance use of asphalt as contrasted with a total structure design involving asphalt. As a result, not only has the public, the user of asphalt surfaces, come to think of asphalt as a maintenance product, patching material or the like, but many engineers associated with road construction find it difficult to conceive of asphalt as having a primary function in a design of pavement structures. There is no reason why we should not consider asphalt every bit as much a product for new construction as Portland Cement for rigid construction. Asphalt continues to be the one product most effective for highway maintenance, therefore, I would not discount its importance in this respect. However, in thinking of types and uses of asphalt in pavements we will need to think clearly as to whether its use is strictly for surface and wearing course or for the total pavement structure design.

We might ask the question, what is a pavement? Turning to Webster's Dictionary we find that it is the artificial covering of a road or street. You or I will hasten to add to this definition, the quality and functions which it must perform.

There are two types of pavements, a rigid or slab type that is designed to spread the traffic load over the subgrade as a beam carries a load between points of support and the other a non-rigid, or shall we call it, the asphalt design composed of successive layers of compacted selected mineral aggregates of increasing stability near the asphalt-aggregate roof and wearing course. If the non-rigid pavement structure is to support the traffic over it, it will need be so constructed that the layers of the structure will transmit and spread the load in such a way that the unit pressure reaching the foundation soil does not exceed the soil's ability to support it, and this must be true for all seasons and weather conditions. The keying action or supporting ability of the component aggregate courses must be such that they will not decrease during periods of greatest moisture, such as immediately following winter or spring thaws. This is just another way of saying that drainage must be of great concern and adequate steps taken to assure that all free water will be carried off before reaching the pavement structure, that capilary water will not rise within the structure so as to accumulate or reduce its strength, or that vapor moisture will not condense at some point within the structure wherein it will be accumulative and reduce the structural capacity of any portion of the component parts.

As we look about us from state to state it is observed that the design of the asphalt pavement structure varies considerable, particularly with respect to the ways and degree that drainage is built in. Where frost penetration is to be dealt with, especially as in this area, a deep free-draining pavement structure is essential if the newly completed pavement surface is to retain its constructed smoothness for many reasons. The rule-of-thumb design, that is, total pavement structure, must equal or exceed half the greatest depth of frost penetration, certainly does not mislead us in our problem. I am convinced that Michigan's asphalt pavement structure design is planned to meet the requirements just mentioned.

The 40 inches plus of structure depth for the Interstate Expressway pavement with the improved free-draining sub-base extending from ditch to ditch, that is, completely through the shoulders, allows a much greater freedom for moisture movement from the structure than those incorporating more impervious subgrade materials. In order that this asphalt pavement structure is to perform to its maximum, the component layers will need be consolidated to such a degree that subsequent traffic loads will not develop further consolidation or deformation. Vibratory compaction of granular materials, heavy proof-rolling with large pneumatic tired rollers along with new and improved means of spot density checks are rapidly finding their place in the achievement of these standards. Too many miles of roads and streets have asphalt surfaces where not that first thought was given as to whether the existing structure was adequate, properly drained or so constructed as to carry the traffic to be attracted to it by the addition of an all-weather surface. Asphalt is not magic. A thin asphalt surface is little more than a roof and wearing course on a pavement structure and surely should not be expected to add miraculous values to the structure when it comes to carrying the loads over it. Deep strength asphalt design, however, should incorporate quality asphalt-aggregate mixes into the base area of the structure. Increased thickness of high quality asphalt-aggregate mixes increase greatly the structural ability to withstand the shock and beating of high speed, heavy-wheel loads.

Here it may be said that stage construction is often times recommended and highly desirable but it is only when the total structure was designed and built for the traffic it is to serve. Costly surfaces applied to poorly drained inadequate base structures can be considered only as an emergency measure and not as a desirable practice. In some areas where presence of high quality aggregates required for the component layers are not in abundance, the use of materials of lesser quality may be effectively made by the ad-mixture of asphalt or waterproofing by the use of asphalt, thus resulting in a structure of greater strength and service and possibly at savings in cost.

Now, having in mind the fundamental concern for adequate drainage, consolidation and placement of the subgrade and sub-base in the asphalt pavement structure, we will discuss in more detail, the use of asphalt in the base and surface courses which are to receive the most rugged treatment by traffic. Asphalt cement is the basic material of the asphalt industry and is obtained by further distillation of the heavy residual oil after the removal of gasoline, kerosene, fuel oils and lubricating oils that comprise lighter fractions of crude petroleum. The temperature to which asphalt cement need be heated for spraying and mixing generally exceeds 275° F. This fact makes difficult the use of asphalt cement except in plants designed to heat the aggregate as well as the asphalt before the mixing process. In the beginning, asphalt was used as a part of the heavy residual oils before sufficient refining to reduce them to the present grades of asphalt cement. These oils were known as road oils and could be applied at atmospheric temperatures or with a small amount of heating to make them fluid. These road oils could not function as do asphalt cements, due to the oil component in the product which remained soft and plastic. It was found, that by reducing the heavy asphalt oils to asphalt cement by further refining, that the cement then could be made liquid at atmospheric temperature by the cutting back with lighter solvents such as gasoline or kerosene. These cut-back products, when used on a road surface, would give off fairly readily the volatiles within them and leave the residue with the high cementing qualities natural to the asphalt cement. This process of diluting the asphalt cement with a lighter, more volatile product developed materials with many characteristics and uses depending on the amount and kind of diluent used, so some standardization became necessary.

The flow chart which you see upon the screen simulates the refining process of the crude petroleum as it leaves the wells and goes to the refinery. By heating and vacuum distillation, the lighter ends are removed, including gasoline, kerosene, fuel oil and lubricating oils, leaving the heavy portion to be further refined by steam to the road oils and paving grades of asphalt. At first there was no limit to the number of grades of paving asphalt that was considered desirable. As late as December, 1957, the Asphalt Institute adopted a reduction in the number of paving grades of asphalt from nine to five. This simplified the problem of choosing the asphalt with the desired consistency to fit the need for the pavement of concern.

A confusion often exists in the selection of the grade of liquid asphalt most suited to the application involved. With six grades each of the slow curing asphalts, medium curing asphalt cut-back and rapid curing asphalt cut-back it may be debatable as to which grade will work with ease and give the desired performance. This has lead to efforts by the Asphalt Institute to reduce the six grades by half, however, conflicting practices from one area of the country to another has made agreement difficult.

To add to this confusion of grades and products we have liquid asphalt emulsions that serve well certain types of use. Asphalt emulsions being a suspension of fine asphalt particles or globules in water by the aid of chemical agents are of three general types: (1) Quick breaking or rapid setting-(RS), (2) Medium breaking or medium setting-(MS), and (3) Slow breaking or slow setting sometimes referred to as a dense mixing type. These you see on the chart as RS-1, RS-2, MS-2 and SS-1. In the Michigan Highway Department the former nomenclature of AE is still retained for asphalt emulsions.

AE-1 is essentially same as RS-1.

AE-2 is rapid setting as is RS-1 except that the penetration of the asphalt is from 60 to 110 that is harder than the RS-1 being made from an asphalt with 100-200 penetration.

Our AE-3 conforms to AS-TM - requirements for RS-2. The AE-5 is a medium setting asphalt emulsion about the same as MS-2, and the SS-1S listed for mulching is identical with SS-1.

How are we to choose the correct grade of asphalt for the particular job in mind? Perhaps it is not in error to state that the choice may be varied and still result in quite satisfactory results.

Shall we discuss then, the various types of work to be performed and consider the choice of asphalt product the use of which we can expect to secure desirable results.

Asphalt Prime - First Application - Dust Palative

A wide choice confronts us immediately, so let's be more specific as to our purpose. If it is a traffic bound road surface for which we desire only to control dust and consolidate the surface the choice of an SC grade or road oil will likely serve best this purpose. The slowly volatile oils in the SC products will be absorbed by the finer particles of aggregate and dust and provide for a few weeks a desirable matting together of the surface fines. The grade of SC to use will be determined by the density of the aggregate surface. As an SC-0 contains only about 50 per cent asphalt it is most fluid of the six grades and will penetrate the more dense surface such as a traffic bound crushed limestone surface. On the other hand a loose gravel or sandy surface with little or no clay content may require a grade with less oil and more asphalt so as to hold the particles together and prevent corrugation. In this latter case an SC-2 may serve best the need. In such an instance some blading of the surface after the oil application will likely improve results. With heavy traffic use, SC dust treatments may result in pot holes in areas deficient in fines and require sacrifying to restore a smooth surface.

Where traffic warrants more than a dust treatment, and providing the aggregate base is adequate to support the year round traffic a surface treatment with a liquid asphalt may be considered desirable. Again, the loose aggregate on the traffic bound base will need be held together by an adhesive that will penetrate the depth of the loose layer and cure to form a solid layer to which a heavy grade of binder can be applied for holding an aggregate cover. This application is generally termed a prime. For this we would do well to choose a medium curing cut-back asphalt grade MC-0 or MC-1 depending on the density of the surface to which it is applied. A 22-A road gravel base compacted by the aid of salts or chemicals may become so dense that a 2/10 gallon per sq. yd. application of MC-0 will be the maximum that can be applied without runoff. A gravel base having a small amount of fines content may require as much as 4/10 gallon per sq. yd. of MC-1 as a prime and still not be as firm as desired. In such extreme cases of porosity an MC-2 might be desired, however blading and increased application rate will be required. Where traffic is to be maintained over the primed surface a light cover of 5 to 10 lbs. of small chips or pea gravel is often advantageous to prevent pickup on the wheels of vehicles as the material cures and becomes tacky at the surface before it cures within. The kerosene content of the MC product must be allowed to evaporate completely before placing the surface course so that the trapped volatile will not soften the new surface. Forty-eight hours is usually considered sufficient for a light prime to cure, however cloudy, humid weather or a heavy application may extend this period to a week. A prime application to be most effective requires a volatile content to carry the dilute asphalt and penetrate the surface fines. The asphalt residue after the vehicle has evaporated becomes the adhesive. An extremely dry or dusty surface is more difficult to penetrate due to surface tension of the particles, so a partially damp surface may result in deeper penetration of the prime. Likewise, an asphalt emulsion prime, if used at sufficient rate of application may give improved penetration.

Seal Coats - Seal coats may be classified as two types. One is the placing of one or more applications of a viscous or liquid asphalt and aggregate cover over a primed surface so as to provide an all-weather wearing course for light to medium traffic. The other would be one or more applications of a fluid grade of asphalt covered with suitable aggregate to serve as a seal to an existing asphalt-aggregate surface to prevent infiltration of surface water into the base structure and to provide improved surface qualities.

The size of cover aggregate to be used for the cover should be taken into account when fixing the rate of application of asphalt. On a single seal application one aggregate particle comprises the depth of cover to be held by the asphalt. There needs be sufficient asphalt to inbed the aggregate approximately half its vertical dimension when pressed in place by traffic. Too heavy an asphalt application may result in a fat, slick surface. The smaller the size of the cover aggregate, the lighter the rate of asphalt application should be. The asphalt for a light or thin application needs be fluid so that it will cover the pavement surface uniformly. Use of a highly viscous asphalt cutback, asphalt cement or asphalt emulsion in small rates of application usually contribute to ridges or drill rows as it may be called. In the northern states little use of paving grades or penetration grades of asphalt cement is made for seal coats. In a few cases 200-300 penetration grade is used with satisfactory results.

MC-3, 4 and 5 grades are possibly most universally used for single seal coat applications for less care in their use is required for reasonably satisfactory results. Excessively heavy applications of MC-3 or SC-5 in seal coats tend to retain the volatiles in the surface only to be flushed to the surface to be tracked about in hot, humid days. Bleeding of MC and SC grades of asphalt cut-backs make them less desirable for use on city streets and roads carrying heavy volumes of traffic. For seal of roads and streets having heavy traffic the RC-4 or 5 grades or RS-2 (AE-3) are usually recommended. As the RC grades provide an asphalt with a penetration range of 80 to 120 whereas the asphalt emulsion has a penetration of residue of 100 to 200, the RC may be preferable to asphalt emulsion for extremely heavy traffic. Careful workmanship and know-how developed with experience can produce an asphalt seal coat to provide excellent service and appearance with about any of the grades of asphalt cut-back or asphalt emulsion. With nice concern for aggregate sizes incorporated and rates of application double and triple seals can provide excellent service. And, in some areas where hot-mix plants are available, a high type hot plant mix surface may be applied at equal or less cost than a triple seal.

Road Mixes - Road mixes serve well many areas and conditions. Liquid asphalt cut-backs or asphalt emulsions provide the asphalt binder in order that the mix can be performed at prevailing road temperatures. That grade of liquid asphalt which will provide just adequate mixing time is desirable, as to attain the best adhesive properties the diluent needs evaporate completely. This fact usually prevents effective use of dense aggregates as they trap the volatiles and the mix remains too soft to serve its purpose and tends to bleed. RC-2 or 3 grades are desirable for dense mixtures where positive mixing equipment is to be used. However, on local roads where traffic is to be light the SC-3 to 5 grades may be used to allow for blade mixing or remixing and MC-3 is often used for blade mixes. Frequent rains and difficulties involved in drying the aggregate affords a real difficulty in the affective use of road mixes.

Cold Plant Mix - Cold plant mixes serve best as repair materials that can be used over a period of time before setting. Every cold plant installation by trial can establish the grade of cut-back asphalt most suited to the aggregate gradation performance desired. The higher SC grades and the lower MC grades are used most.

Cold plant mix is not to be preferred for a pavement surface if a higher type, dense hot plant mix can be secured for the gradation of the mix needs be open to allow the volatile to pass off and this will allow surface water to filter in. Even with seal applications the cold plant mix seldom provides service to be compared with higher quality hot plant mixes.

Asphalt Treated or Stabilized Aggregate

For base course construction it is in some areas desirable to incorporate granular soils or low quality aggregates into the asphalt pavement structure design by water-proofing the softer particles or by binding the mass together to develop greater bearing value by making it into a lean asphalt mixture. Effective use of this procedure has met with difficulties due to the failure of the weather to cooperate. Rain and excessive moisture in the soil or aggregate not only makes difficult the proper mixing and coating of the particles, but delays curing and consolidation. Most effective is the treating such soil or low quality aggregates by a central plant whereby moisture can be controlled and uniformity in asphalt content can be maintained. The most outstanding projects of this sort have been on the East Coast. South Carolina has used hot-mix beach sand with 3.5 to 4.5 per cent of 85 - 100 penetration asphalt to construct 10 inch bases on expressway construction. Oklahoma and other states west of the Mississippi River have used lean sand mixes for base construction. A surface of high type asphalt concrete is required over this base course construction.

<u>Hot Plant Mix Asphalt</u> - Hot plant mix asphalt provides the highest type of surface for highway and street pavement construction as well as base course material with greater capacity to withstand impact and give needed support to the heaviest traffic loads. Refinements in mixing plant controls and late improvements to paving or lay down equipment makes possible the highest quality of pavement construction ever attained.

Asphalt technology is advancing and general recognition and concern for the importance of maintaining uniformity throughout mix composition, preparation and placing is resulting in real progress. Use of the thin film oven test is leading to improved grades of asphalt. Recognition, that viscosity or film thickness of asphalt incorporated into a hot-mix affects the loss of penetration during the wet mix cycle thereby affecting the service life of the mix is leading to concern for limiting the top temperature at which a mix is made.

Generally, the greatest service life can be expected from the mix that is made at the lowest temperature at which proper coating can be secured, and still provide sufficient heat for paving and desired consolidation.

The extent to which the consistency of a given asphalt cement changes with temperature identifies its character. This relationship is called, "Temperature Susceptibility".

The choice of penetration grade of asphalt for a mix is usually determined by the use to which the pavement is to be placed. Heavy, dense traffic can best be served by a mix made with 60-70 penetration grade and 85-100 grade or softer for lighter traffic. However, low penetration grades should not be expected to replace the need for a well designed and controlled mix.

As a concluding observation it seems well to say that uniformity in every phase of the mixing, paving and asphalt construction will contribute greatly to improved work. The best possible mix design poorly combined and placed will be disappointing.

Good control and careful work becomes excellent advertising for asphalt pavements.

CHANGES IN CONSTRUCTION PRACTICES
by Walter P. Tervo

In spite of the general belief that we, in Michigan, are still specifying and producing bituminous mixes in the same old way we have been doing things for some 25 years, changes have taken place and new equipment and new methods are being studied to make further changes. Here are some of the changes we have seen in the past 5 years. These are not in any particular order of occurrence or importance -- simply some of the changes that have taken place.

1. Asphalt cement delivery by truck. Previous to truck delivery of asphalt cement, it was necessary for the contractor to erect his plant on railroad siding which restricted his plant to urban areas. Many contractors ran into legal difficulties because of zoning ordinances and it always meant a dirty and dusty condition for the area in which the plant operated. With truck delivery, contractors can place their plants at locations advantageous to haul, to construction site, and to source of materials.

2. Asphalt cement from local refineries. Until only recent years all the asphalt cement delivered into the State of Michigan came in by railroad cars from refineries outside the state.

3. A new mixture was introduced -- levelling course. Previous design for two-course bituminous concrete construction consisted of either binder course and wearing course, or two layers of wearing course. Now the standard design two-course work consists of binder base, or what we call levelling course plus wearing course. This levelling course has a gradation similar to the large binder course material except that top course stone 25A is used. This is an attempt to stop rutting and shoving.

4. We will start paying for removing old bituminous patches. Previous to the 1960 Specifications removal of existing old bituminous patches or pot poured patches was incidental to the work. Therefore, the practice employed throughout the 10 districts was different depending upon direction of the area engineer.

5. We set up planing of the lane near the curb on some of our municipal work.

6. We saw edge failures on old bituminous roads -- and pay for it.

7. We are specifying 85-100 penetration asphalt on bituminous aggregate as well as 150-175. We are experimenting unofficially with a bituminous aggregate for a top size stone normally 100 percent passing the one-half inch sieve with a high crushed content. This makes an excellent bituminous aggregate surface especially for small communities.

8. We are increasing the proportion of bituminous aggregate tonnage.

9. We are slowly changing from using 60-70 penetration asphalt out-state.

10. We use DC 200 -- or perhaps -- we now approve its use by authorization. DC 200 is a silicone chemical which, when added to bituminous mixtures, inhibits segregation. Unfortunately, the chemical has no beneficial effect unless the plant drying process is efficient. It is not a cure-all for the drying process.

11. We now specify 200 pounds per square yard of 9A binder, a change from 170 pounds.

12. We have a Design Committee who study all proposed work and advise on thickness, penetration, and type.

13. We have built one expressway-type of asphalt highway and will build some 200 miles more at 460 pounds per square yard.

14. We are increasing asphalt content in our mixes - up to 5.7 and 5.8 percent. We have only had a couple of years of visual inspection of these mixes with an asphalt content higher than 5.5 percent but what we see, we like. Until only recently our standard mixture contained 5.5 percent asphalt.

15. We are changing our visual acceptance of our mats -- today, almost everybody wants to see a tight, sandy, closed surface. We know these sandy tops are more skid-resistant. Our research laboratory has an instrument to measure skid resistance of all types of surfaces and they have been studying our bituminous mats for several years. A preliminary report from them indicates that we should have sandier asphalt mixes.

16. We are getting back to 31A tops in our cities -- last year we had six such jobs -- we'll get more.

17. We are substituting and studying 2NS modified for our standard 3BC -- with success so far.

18. We will blend 3BC mechanically from now on rather than shovel-blend on the ground.

19. We are using continuous-mixing plants on bituminous concrete.

20. We have increased haul limits for both bitimunous aggregate and bituminous concrete.

21. We are getting truck boxes with built-in insulation -- and also specifying insulation for haul at any time of the year over 20 miles for bituminous concrete and 25 miles for bituminous aggregate.

22. We will see less 1-foot binder widening 9 inches deep -- and see more gravel widening with 1 course of binder.

23. Automatic proportioning with interlocks are specified for bituminous concrete advertised after May 1.

24. Fluidometer - or volumetric metering is now approved, with exact controls.

25. Controls are now specified on the oil heating lines in an attempt to stop one of the possible sources of contamination.

26. We have seen some new pavers introduced:

1. Blaw Knox
2. Pioneer
3. Cedar Rapids
4. New Barber-Greene
5. We are examining a new machine called "Trac-Paver"

27. We will require three standard 8-10 ton rollers for 90 tons per hour or more plant production.

28. We will see pneumatic rollers in use - we will specify them as soon as we know enough about them. Many of the states are already specifying pneumatic rollers for bituminous concrete. We have tested them on a small scale for three years. We will set up a research project this year and from this study hope to arrive at a specification.

29. We will construct bituminous mat shoulders this year to learn whether they are feasible and economical.

30. We are experimenting with the density of our mats.

31. We have a mobile laboratory to study densities and to trouble-shoot at plants.

32. We are considering thin mats to correct slippery conditions of dried-out, pitted surfaces.

33. Shaping of bases and shoulders will be under more rigid control of grade and crown.

34. There is a trend toward one-course construction.

35. Extraction test specimens are now prepared representing the total days production - not just the first hour's work.

36. We already have two or three 8000-pound batch plants.

37. We had one year when we exceeded two million tons.

38. Our plants have increased in number from 55 to 85, of which continuous mixing plants increased from 8 to 18.

39. Our contractors are increasing in number each year.

40. Our unit price per ton has decreased each year.

41. In collaboration with the Michigan Asphalt Paving Association, we have a committee to study jointly the problems of quality control of mixtures and good construction practice. Each organization inspects the construction of the previous year, and makes a report.

COUNTY AND LOCAL ASPHALT PAVEMENT PROBLEMS
by Henry L. Shroeger

To fully discuss the problems faced by the road commissions of the State of Michigan with regard to providing asphalt paving surfaces on county roads, a brief review of the county road systems and the financing of these systems will be necessary. It must be recognized that each road commission, in its operation, financing and management, is somewhat different than the others. Any statements or remarks made in this discussion should not be construed as being typical for any one road commission unless stated as so.

For many years prior to 1930, the road commissions enjoyed the unusual position of having sufficient finances to adequately construct and maintain their county road systems. However, shortly after 1930, all the township roads were turned over to the county road commissions and, since that time, there has never been sufficient amount of money to ideally construct, improve and maintain the systems. Under Act 51 of the Public Acts of 1951, of the State of Michigan, the county roads were reclassified into two groups, namely, the primary road system and the local road system. Under this Act, the Legislature not only reclassified the system but also provided the bulk of the finances now available to the road commissions of the State.

By definition, a primary road is one that is described as being of the most importance to the county in general. Any road in the county road systems that did not fit this classification became, automatically, a local road. The determination of the primary road system was not the privilege of the Board of Road Commissioners entirely, as the final selection of the primary road system was subject to the approval of the Michigan State Highway Commissioner.

In the State of Michigan today, there are approximately 23,400 miles of roads in the county primary system and 62,300 miles of roads in the county local systems. By surface types, and based on the 1958 annual reports, the primary road surfaces are the following types:

Earth - 1,211

Prime and seal - 4,564

Concrete - 790

Gravel - 7,763

Bituminous Aggregate - 9,089

The local road system, by road types are as follows:

Earth - 18,630 | Gravel - 37,128

Prime and seal - 3,521 | Bituminous Aggregate - 2,653

Concrete - 379

We wish to point out that the bituminous aggregate surface, as mentioned, is not necessarily plant mix, as these figures include road mix surfaces. In the main, the improvement and maintenance costs for these systems are financed from funds obtained from the Motor Vehicle Highway Fund. Monies for this fund are raised from the license plates or weight taxes, as well as the taxes from the sale of gasoline and diesel fuel. The 83 road commissions of the State share approximately 70 million dollars from this fund. (Losses to fund, $20,000,000 since 1951.)

Many of the road commissions have other sources of revenue, such as township contributions, county road taxes and federal aid funds. It must be pointed out that all the road commissions do not obtain money from these sources, as this is a matter that is arranged for at the county level and need not be the same for all counties. In fact, the road commissions that obtain funds from county road taxes are relatively few. All road commissions are eligible for federal funds, however, these funds are obtainable only on an equal matching basis and further, this money may be used for construction purposes only. These construction projects can be carried out only over the approved federal aid secondary road system in each county. In general, the federal aid secondary road system is confined almost exclusively to the primary road system. Often times, many people have labored under the misapprehension that monies obtained from the state trunk lines, as a result of maintenance carried out by the road commission over the state trunk lines, are revenues that are available for the maintenance and construction of the county road system. This is not true, because the funds paid to road commissions by the Michigan State Highway Department are reimbursement for actual expenses incurred on the state trunk lines when maintaining the same. Under no circumstances has there ever been monies available for the county road systems from this source, as these are "no profit" type of contracts.

From this brief discussion, it is obvious that most of the road commissions of the State must depend almost solely upon the MVHF for its finances. Act 51 of the Public Acts of 1951 of the State of Michigan also provided that, at a state level, 75% of the entire road commissions share of the MVHF must be spent on the primary road system and the remaining 25% shall be spent on the local road system. The Act reserves the right to the Board of Road Commissions of the respective counties to transfer 10% of these monies from one fund to the other and an additional 15% may be transferred with the written approval of the Michigan State Highway Commissioner. However, under the original provision of the Act, the road commissions have approximately $52\frac{1}{2}$ million dollars to spend on 23,400 miles of primary roads and only 17.5 million dollars to spend on 62,300 miles of local roads, unless additional funds are obtained from other sources. Subsequent legislation also provided that no money from the MVHF could be spent on local road construction unless matching funds were obtained from other sources. It is because of these financial conditions that it is practically impossible to schedule construction projects of any type on the local road system. This, particularly pertains to those road commissions who depend almost solely on the MVHF as its financial source.

For many years, the road commissions have recognized the need of a better type of road surface and for as many years, they have been continuously plagued by the lack of funds when trying to provide these better type surfaces. The past years have witnessed a gradual change in county road surfaces from earth to gravel; from gravel to prime and seal construction; from prime and seal to bituminous road mix surfaces. It has been only within the past 10 years that any amount of bituminous plant mix road surfaces has been placed on the county road system. This does not mean that the entire earth surfaces and the entire gravel surfaces have been replaced as such. As stated earlier in this discussion, there are many types of road surfaces within the county road system, and, under the present financing, it is safe to state, particularly with respect to the local road system, that gravel and prime and seal will be a part of this system for many, many years to come. There is no doubt in our minds that this gradual change from the poor to the better type surfaces would have taken place at a faster rate, had funds been available. The rate of change in the future, and for this same reason, will, of a necessity, be slow. Many of you will possibly agree that it will be some time before the state legislature will grant another increase in weight, gasoline and diesel fuel taxes, and it is practically impossible to obtain sufficient funds from any other source. The recent raises in gasoline tax, made by the federal government, will have its effect for some years to come, insofar as additional revenue from these sources at a state level are concerned.

The ironic position the road commissions find themselves in is the fact that these poor types of road surfaces have resulted in higher maintenance costs and poor riding qualities, but our immediate problem also rises in the fact that enough money is available for patching existing surfaces, whereas it is a tremendously difficult problem to budget enough money to plan the construction projects that would eliminate the high maintenance factor that accompanies the poor type of road surfaces. Another feature that these constant patching operations introduce is the strained public relations with the motoring public. Many of us, too, realize that these patched roads produce a very uncomfortably slow ride and often justify the strong objections and complaints made by the motoring public.

We have shown that, without funds raised at a local level, it is practically impossible to provide plant mix road surfaces on the local road system. The problem of constructing this type of surface on the better financed primary road system is not without its difficulties, when the standards provided are such that good engineering practices dictate. On the primary system, good bases, as well as adequate drainage should be provided before the bituminous aggregate surface is considered. Traffic counts on this system are relatively high and the percent of heavy truck loads is increasing from year to year. Inadequate bases with this type of traffic will result in almost immediate failure of the surface. Needless to say, these failures bring justified criticism and do not improve public relations, insofar as the road commissions are concerned. In Marquette County, and on the primary road system, we have concentrated on these base corrections before constructing the bituminous road surface. The magnitude of these corrections depends on the soil conditions in each case. Weakness in road grades are corrected with a lift varying from one foot to five feet, depending on the soils in any one particular section of the road grade. In addition, and where limitations with reference to the vertical alignment warrants such treatment, the so-called frost heave materials are excavated to a minimum depth of 4 and 1/2 feet and replaced with good granular materials. The actual depth of the lifts, as previously stated, depends upon the actual soil conditions where the lift is to be made. When the soils are of the impervious heavy loam and clay types, a minimum 4-foot lift is then provided. Particular attention to the ditch construction is also given to those road sections over the poorer type of soils. Ditches in these areas should be of an adequate depth so that a bleeding process of the road grade may be made into the road ditches. It follows that, when these standards are maintained, construction costs per mile increase greatly and here again, out of pure economic necessity and, despite the fact that it is the better financed primary road system, few miles of this type of improvement can be made each year.

Insofar as the local road paving problem is concerned, very little money is available for either base correction or paved surface construction. Marquette County has been able to provide paved surfaces on these roads, because we are fortunate enough to obtain monies from a county road tax, as well as having the townships provide one-half the paving costs. However, despite the availability of additional funds, there is not sufficient funds to adequately correct the bases. We have constructed the paved surfaces and taken care of the isolated failures, due to the bases, as a part of normal maintenance. We do not wish to leave the impression that any section of a local road should be paved regardless of the base condition. Paving operations have been confined to road grades that are not obviously weak in base characteristics. This, we realize, is not good engineering practice, but it is the practical solution to the problem encountered when bituminous aggregate paving is placed on the local road system. We have further determined that the placing of bituminous surfaces on the local road system under the standards just mentioned, that our maintenance cost has been less than when the existing roads had either the gravel or prime and seal type of surfaces. Another factor, and possibly most important in its impact upon the public, is that we have succeeded in removing the motorist from the mud in the spring and the dust in the summer. One helpful reason why we were able to deviate from good standards and not have heavy consequent damages is the fact that on the local road system, traffic counts are low and heavy vehicle loads are few. There is no doubt that on some of these local roads that we have paved and not taken any steps to correct the bases, immediate failures would have resulted, if the traffic counts and truck loads were the same as on the primary road system.

The standards followed in constructing bituminous aggregate surface roads on the Marquette County road system are relatively simple. On the primary road system, a 210 pound per square yard single course mat, not less than 20 feet in width, is placed. On the local road system, 170 pound per square yard single coarse mat is provided. The width of the mat on the local roads depends upon the existing grade widths and varies from 16 feet to 20 feet. The bituminous aggregate mix used in our construction is produced in a continuous mixed type of plant using 120-150 penetration asphalt cement. Many experiments were made with other type of asphalts the first two years of our plant operation, using SC-5A, MC5 and 150-175 penetration asphalt cement. In general, all types did a fairly good job. The cut-back asphalts did not work out too satisfactorily in platted areas where traffic made many right angle turns. These mixes had a tendency to score or rut when opened to traffic. Because of the problem presented with storage when different bitumens were used, it was decided to simplify the storage problem by using one type of bitumen. Because of its overall satisfactory performance, a 120-150 penetration asphalt cement was selected.

Mineral aggregates used have the following grading requirements:

PASSING	PERCENT
3/4 in. screen	100
3/8 in. screen	65-85
No. 10 screen	40-60
No. 40 screen	18-35
No. 200 screen	2-10

Many of you will recognize this as a Michigan State Highway standard for 20-B aggregate. These specifications have been used in Marquette County for seven years and good results have been acquired. We feel, at this time, that any asphalt surfaces whose standards are higher than these specifications are superfluous and unnecessary for county roads construction. We base this opinion solely on the 7 years experience that we mentioned earlier and the present conditions of these mats that were constructed over the 7 year period. In fact, we feel that the results obtained from the bituminous aggregate produced under these specifications are in many cases as good as those obtained where bituminous concrete pavements have been constructed. We cite the case of the intersection of county roads 480 and 553. For those of you who are not familiar with this intersection in Marquette County, it is an intersection over which practically all commercial traffic routed to the K. I. Sawyer Airbase, must pass. At this intersection, we have a 4-way stop regulation, which, of course, means that every vehicle must stop and start at this intersection. The bituminous aggregate surface at this intersection has been placed over 7 years ago. In July of 1959, traffic counts show that this intersection has more than 3,000 vehicles per day, of which more than 50% are trucks. We invite any of you to inspect the surface at this intersection. We assure you there has been absolutely no movement of this surface, despite the stopping and starting of all these vehicles using this intersection.

In preparing existing surfaces for the application of the bituminous aggregate surface, we have found it most important to use bond coats on these existing surfaces. On hard surface roads to be resurfaced, we have used the asphalt emulsion AE2 and on existing gravel surfaces to be resurfaced with the bituminous aggregate material, we have used the asphalt prime AEP-1. Experience also has taught us that the omission of these bond and prime coats can prove most detrimental. On occasions where the bond or prime coat has not been employed, it has resulted in movement of the newly applied bituminous aggregate surface away from the old surface. When this takes place, it often necessitates the removal and replacement of large sections of the recently applied bituminous aggregate surface. Cost-wise, this may result in expenditures of 3 to 5 times the cost of the recently constructed surface. Needless to say, with such experience, we feel the application of these bond or prime coats are most important to the ultimate success of our bituminous aggregate surface construction programs.

In general, priority for bituminous aggregate surface construction projects are based on traffic count data. However, and in some cases, the geographic features of the county and township contributions have altered this procedure. When a township, at some extremity of the county, has indicated its willingness to cooperate and participate in a paving program, we have confined our operation to that particular section of the county for the entire construction season. Naturally, it follows that roads with much less traffic count are paved than roads located in a more populous and industrial portion of the county. In the 7 years that we have operated the black top paving plant, this condition has prevailed only on two occasions. Our program for 1961 will be the third occasion that this will happen.

In the past 7 years, Marquette County has averaged 33 miles of bituminous aggregate surface construction for each of these years. This has varied from a low of 26 miles of paving one year to a high of 38.6 miles for another year.

During this time, it has not been necessary to place a seal coat on any of these newly constructed bituminous aggregate road surfaces. From experience, and using the type of mix that we have in the past, we feel that these road surfaces will need very little maintenance for a period up to ten years after construction. At the end of this ten year period, it is our intention to provide bituminous aggregate recaps at an application of 150 pounds per the square yard.

Cost for this bituminous aggregate road surface construction, not including any base corrections or shoulder construction, has varied from $4,000 per mile on the local road system to as high as $7,500 per mile on the primary road system. The reason for this low cost per mile with respect to the local road system lies in the fact that on occasions the applied mat has been less than 18 feet in width. The average cost over the past 7 years for bituminous aggregate in place per ton has been $5.28. A further breakdown of this, and continuing on an average cost over the past 7 years is as follows:

Production per ton at the belt	$3.71
Transportation per ton	0.73
Prime per ton	0.36
Application or paving per ton	0.37
Rolling per ton	0.11

These costs are all inclusive and consist of direct cost to the plant, fixed costs which include an extraordinary reserve in the amount of 2% as well as depreciation and other factors, such as, overhead, insurance, vacation, sick leave, group insurance, workman's compensation and retirement. Cost of producing the mineral aggregate to be used in the plant for the past 7 years has averaged $0.64 per ton.

Overall results with this paving program have been most satisfactory to the people of Marquette County. In fact, it has developed a much better relationship with the people of the county and further produced a general feeling that the road commission has in recent years really built good roads.

In conclusion, we wish to point out that we firmly believe that all road commissions recognize the desirability of bituminous aggregate paving. However, the magnitude of this type of surface construction in each county is determined by the monies available and not because these road commissions do not realize the advantages of bituminous aggregate surface construction.

THE IMPORTANCE OF BITUMINOUS BASE CONSTRUCTION
by Gerard O. Kerkhoff

The importance of bituminous base construction is manifested by service behavior of pavements. Our laboratory has proven to be a field lab in the study of soils, base materials and pavements. The application of proven principals accumulated over the years resulted in the development of typical road cross-sections. More recent information indicates that the magnitude of load deflections are a major factor of the service life of bituminous pavements.

A great deal of basic knowledge was obtained from service behavior of bituminous surfaced roads during the 1930's. This came about through the Department's program to improve the large mileage of secondary highways having gravel surfaces. This program was intended to make these roads dust free with a bituminous mat. Usually the better gravel roads were selected for rebuilding by a method of stage construction. The first stage involved the rebuilding of known break-up areas, widening the grade, ditching and placing a stabilized gravel surface course over the entire project. This road was then observed under traffic for one year. This was called a seasoning period. If the road behaved satisfactorily during the seasoning period, it was covered with a bituminous mat (oil aggregate mat). This method of improvement of old gravel roads sometimes showed a considerable amount of spring break up. Investigations proved that the weakest subgrade support occurred during the frost melting period on loams and clay subgrades. Section of road over granular subgrade inevitably proved superior. This experience pointed out, in some cases, that a successful gravel road surface can fail when covered with a bituminous mat.

Through Michigan's Pedological Soil classification system, numerous road service experiences were associated with soil series classification. This method enables the correlation of definite pavement factors of failure and factors of success on a state-wide basis. This led to the development of a minimum road structure for bituminous pavements. The basic change in design at this time was the adoption of a sand subbase over loams and clay subgrades. To overcome climatic environment, it was found necessary that the minimum thickness of sand subbase should be 12 inches over frost susceptible soils. A general rule of thumb to estimate the thickness of subbase needed is that it should be equal to about one-half of the normal frost penetration.

In the last 1930's flexible pavement roads were constructed on the secondary state highways with a road structure of 4 to 6-inch base course and 12 inches of sand subbase over loam and clay soil textures. In general, this design proved satisfactory. However, occasional specific failures would develop. Investigations often proved that the use of 1 to 2 inches of top soil or loam soil to stabilize the loose sand subbase resulted in failures. This led to the adoption and the use of selected subbase gravels or crushed stone to stabilize the incoherent sand subbase. Another occasional source of failure was due to, what was considered, a high amount of fines in the base course aggregate. The physical property of the mortar portions of the aggregate is a laboratory determination of the material passing the No. 40 sieve. The test results are expressed as a Plasticity Index number. It represents the moisture range in per cent of the dry weight of soil in which the mortar portion is in a plastic state. Thru experience, the P.I. number has been decreased over the years to a specific requirement so that the plastic range of the mortar fraction is less than five (5). The gradation of the aggregate base materials has undergone some major revisions in per cent passing the No. 200 sieve. In order to control and obtain a low Plasticity Index, the amount passing the No. 200 sieve has been decreased to a range of 3 to 7 per cent. The P.I. control of aggregate base material is now not a direct requirement but is considered to be controlled within tolerable limits by gradation requirements. The materials used for sand subbase are usually clean sand or sand-gravels obtained from natural deposits. However, the sand subbase materials must meet the Porous Material "Grade A" specification requirement. The emphasis of this specification requirement is put on the Loss by Washing test. The maximum limit of fines permitted is 5%.

A very important and a most desirable factor of bituminous base construction is to use the aggregate base course as a roadway surface for a year or more. During this period traffic would affect additional compaction of the base course and the sand subbase. In addition, this method of seasoning can condition a road structure for the bituminous surface. Much credit for the success of early bituminous roads was due to this method of stage construction.

It is this background of experience that brought about development of the typical road cross-sections. In addition to the years of experience, factors of modern traffic loads and all weather service entered into the adjustment in thickness of base course material and sand subbase.

> <u>Slide 1</u> shows typical road cross-sections adopted by the Department. It shows that for a traffic volume of less than 500 vehicles per day, the thickness of sand subbase is 18 inches with a minimum aggregate base course of 6 inches. For a traffic volume of 500 to 2,000 vehicles per day, the sand subbase requires a thickness of

18 inches and the aggregate base course requires a minimum thickness of 7 inches. For the high type of bituminous pavement having a traffic volume of 2,000 or more vehicles per day, the sand subbase thickness required is 25 inches and with a minimum aggregate base course of 8 inches.

Slide 2 shows a design chart correlating the Highway Standards with equivalent C.B.R. values for Flexible Pavement Design. Due to the climatic environment the evaluation of clay subgrade in terms of C.B.R. values is between 2 to 4. The evaluation of sand in terms of C.B.R. is between 15 to 50. This is rather a broad range and the value selected is dependent upon the gradation of the material. The sand-gravel mixtures have the higher values. The examples show that for a clay subgrade the combined thickness of surface, base and subbase is 34½ inches. However, for a natural sand subgrade, the combined thickness of surface and base course is shown as 10 inches. In each case, this is for a 22,000 lb. axle load and 1,000 vehicles per day per lane. It is important to note in the second example that in areas of extensive granular soils only the base course aggregate is added to construct the road structure.

Slide 3 shows a description of Bridgman soil. Bridgman is a Pedological Soil classification name for dune sand formations. It is a deposit of deep, well drained, loose sands. This is ideal material for use as a subbase. In this case, the subbase requirement for a bituminous road structure is found in-place. Note that in its natural condition it is in a loose state.

Proper treatment during construction of the subgrade, subbase and aggregate base course is most important. The specifications require that the subbase be compacted to 95 per cent of maximum density. In granular cut sections, it is specified that this density be obtained to a depth of 18 inches. An adequate road structure in a condition of maximum compaction should result in a minimum roughness of the bituminous pavement surface. Such a structure should hold load deflection within tolerable limits. This is the basic requirement for a long service life.

Slide 4 shows two standard pieces of equipment used to measure density-in-place of soils, subbases and aggregates. The upper picture is a Rainhart apparatus and is able to measure the volume of a small excavated hole. This equipment is used extensively to measure densities. The lower picture is a new nuclear apparatus to measure moisture content and wet soil density by directly placing the nuclear pan on top of material. The Nuclear Method is still in the experimental stage, however, it does show considerable promise and, if proven to be satisfactory, it will provide a much faster method of checking density. The quality control of compaction work is a most important function of construction supervision.

Studies made in California since 1951 indicate a close correlation between cracking and fatigue type failures of bituminous pavements and measured deflections of the pavement under wheel load. Measurements indicate that the cracking and fatigue failures of most pavements are attributable to a large number of flexations when the effective magnitude is greater than 0.025 inch. This study also shows that clean sand and gravels subgrades exhibit very low resilience. The study concludes that the practical solution, in pavement design, is to provide a greater depth of granular bases and subbase. This additional requirement is necessary to reduce deflections to an acceptable limit.

Slide 5 shows a graph indicating the permissible deflection allowed to obtain long service life of a bituminous pavement. Note that the thin pavement is allowed a greater deflection and that the thicker bituminous mat is more limited in magnitude of deflection.

Profile surveys of pavement surfaces also provide information to substantiate the importance of bituminous base construction. Roughness surveys of selected pavements were begun by Professor W. S. Housel as early as 1952. In 1957 the University of Michigan built a new pavement profile measuring device, which is truck mounted. It is modeled after a design used by the State of California. This equipment automatically traces and records the profile of each wheel track on the surface of one lane of pavement. It is now possible to make a continuous record of service behavior of a pavement for each season of the year and over an extensive period of years. The measure of accumulative vertical displacement per mile of road is correlated to a rating of riding quality.

Slide 6 shows a table of pavement roughness rating in inches per mile. The rating in inches for the University of Michigan profile truck is shown on the right.

Slide 7 shows profiles of two pavement sections, representative of high type bituminous construction. Both are on superior types of subgrades of a sand outwash with excellent internal drainage. In both cases, gravel bases were constructed first and subjected to traffic for a sufficient period of time to be thoroughly compacted before paving with a bituminous mat. Note that the R.I. (roughness index) of 27 & 22 for M-37 and 39 & 40 for M-55 falls within the rating for exceptionally smooth riding quality. This indicates excellent construction practice as well as completely adequate carrying capacity. This profile also indicates good compaction in all portions of the supporting foundation. Also, deflections seem to be within the tolerable limit as indicated by the profiles.

Slide 8. In the lower half of the figure is an example of heavy duty flexible pavement, constructed on the Muskegon-Grand Haven Expressway. It is representative of the type of heavy duty flexible pavement proposed for use on the Interstate Highway System on certain selected projects. The riding quality of the pavement is exceptional because the roughness indexes is 18 and 15 is representative of two wheel paths of the expressway. The road is constructed in an extensive area of dune sand. This deposit of sand material makes an excellent sand subbase. Special effort was made to obtain compaction to a depth of 18 inches in all cut sections.

Slide 9 is reference to the same road as shown in Slide 8. Here is shown six comparative profiles registering seasonal changes. The profile shows that roughness increased in the late period of the winter of 1958-1959. This was followed by a decrease in roughness to an exceptionally smooth riding quality. The survey shows that a degree of roughness can be attributed to deep frost penetration of the road structure. This was not indicated in the more mild winter of 1959-1960.

In summary, the importance of base construction cannot be over emphasized. Even with adequate design thickness of the road structure, it is necessary that each component part be properly constructed. A major factor in the construction of the subbase and base course is compaction. This is essential in order to keep the magnitude of deflection to a tolerable limit. Building a road structure to give satisfactory performance and a long service life can be accomplished thru good engineering design and construction practices.

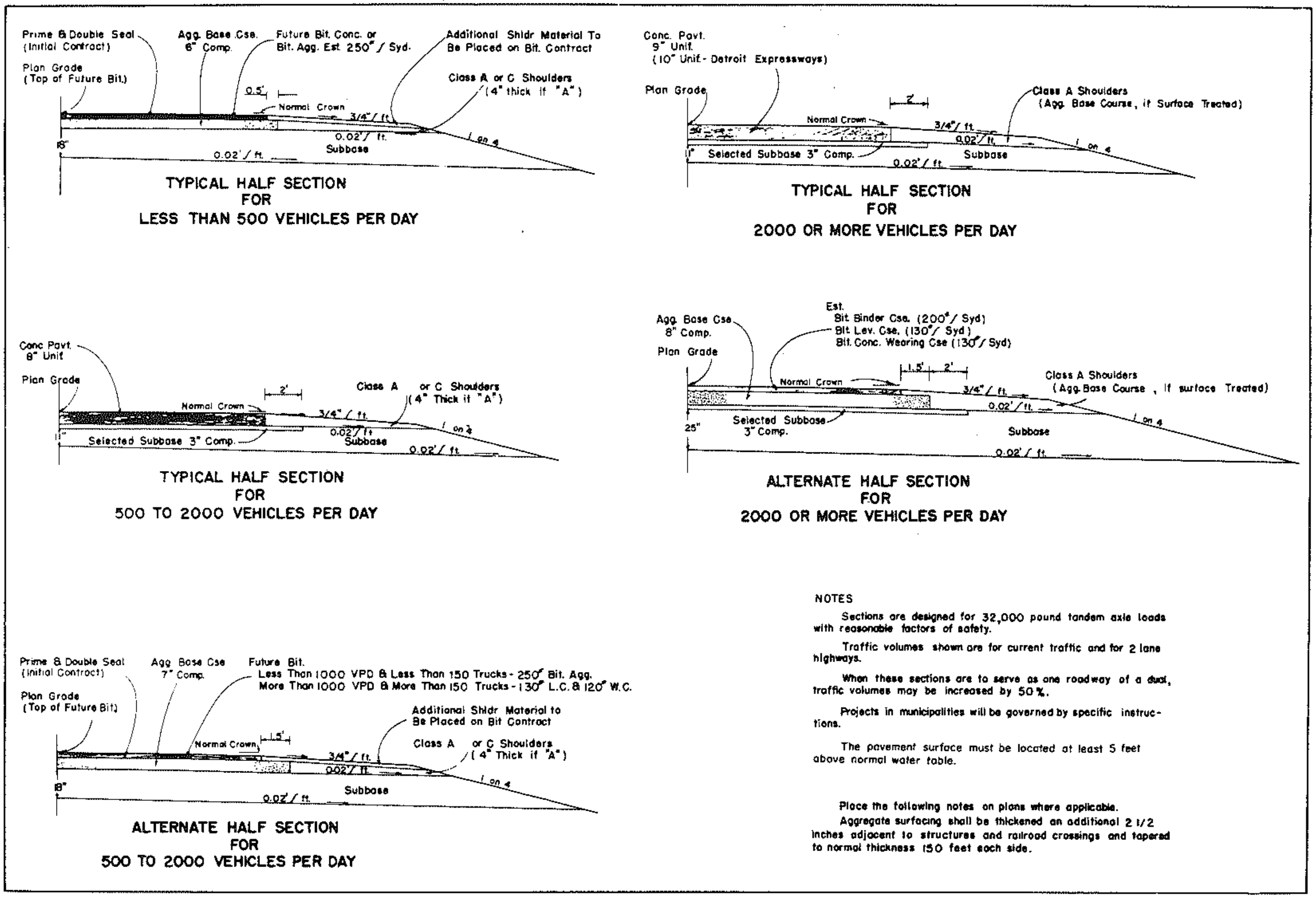
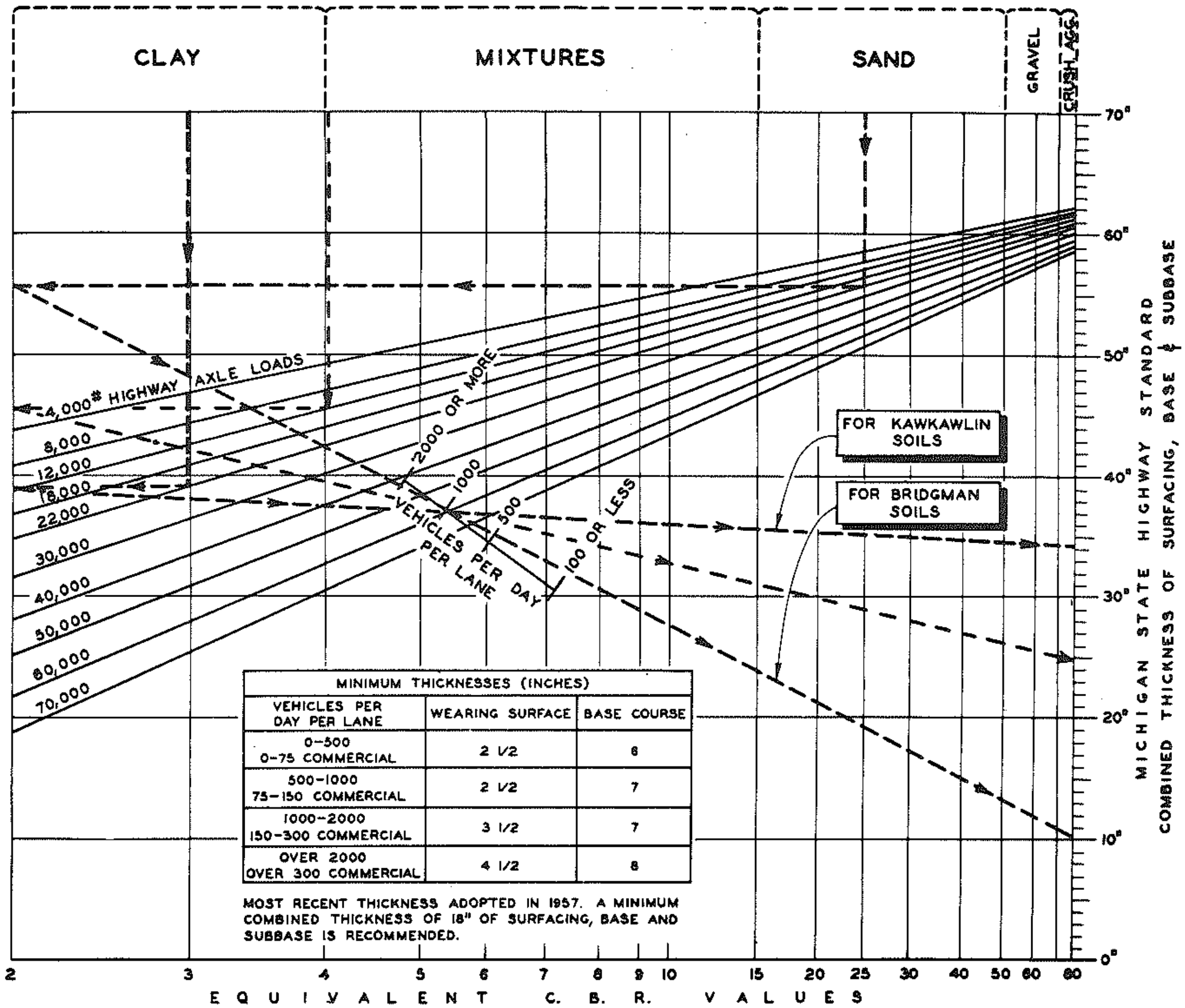


Figure 6. Typical Cross-sections as shown in book of design standards.

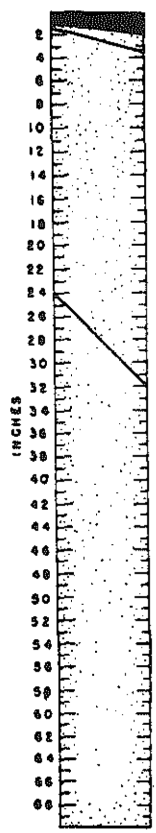
Slide 1



MINIMUM THICKNESSES (INCHES)		
VEHICLES PER DAY PER LANE	WEARING SURFACE	BASE COURSE
0-500 0-75 COMMERCIAL	2 1/2	6
500-1000 75-150 COMMERCIAL	2 1/2	7
1000-2000 150-300 COMMERCIAL	3 1/2	7
OVER 2000 OVER 300 COMMERCIAL	4 1/2	8

Figure 5. Equivalent C. B. R. values for flexible pavement design.

Slide 2



Litter, leaf mold and humus soil.

Leached gray fine sand.

Yellow fine sand, loose and incoherent.

Pale yellow fine sand, loose and incoherent.

SOIL DESCRIPTION

Gray-brown Podzolic Group	Bridgman Series	Fine Sand Class

Bridgman consists of deep deposits of a loose fine sand accumulated in dune form by wind action. It is free from stone and gravel.

It occurs mainly along the shore of Lake Michigan on the established dunes, knolls and winding ridges of loose fine sand. It is liable to shift under wind action where the vegetative cover is removed.

The original vegetative cover on the more stable dunes consists of mixed hardwood and pine.

Bridgman is very similar to Wallace. It differs by its occurrence on younger dunes and by the absence of a cemented "B" horizon.

The profile of Weare is similar to Bridgman. However, the greater age of the Weare is reflected in the profile by thicker weathered horizons.

The Deer Park series is very similar to Bridgman but has a thicker leached gray "A" horizon and a darker yellow color in the remainder of the profile. It occurs mainly along the shore of Lake Superior. The forest cover was mainly white, Norway and jack pine.

The Sauble series is also very similar to Bridgman but is recognized by the faint red color of the sand. It occurs mainly along the shore of Lake Superior. It has developed a faint soil profile. The forest cover was mainly hardwood.

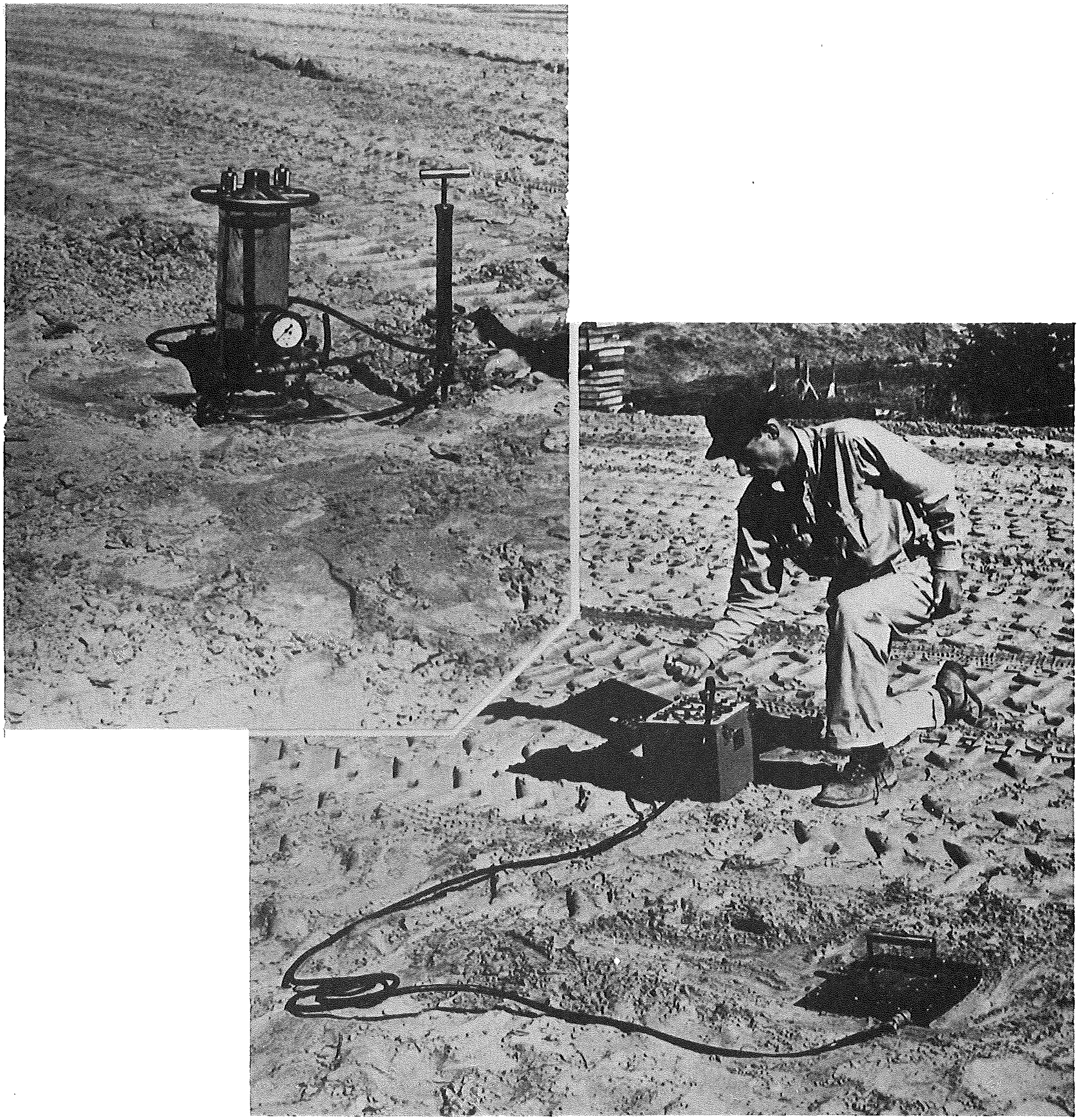
Since the Weare, Sauble, Deer Park and Bridgman series are all similar, combine them with Bridgman when mapping.

Along with the soil survey, study the natural vegetation with the object of using local shrubs and herbaceous vegetation for erosion control.

Construction Information

This material is considered excellent for grading operations during all seasons of the year. The loose character of the sandy material makes hauling difficult.

Figure 1. Description of Bridgman soil.



Equipment to Determine Density in Place Measurements

SLIDE 4

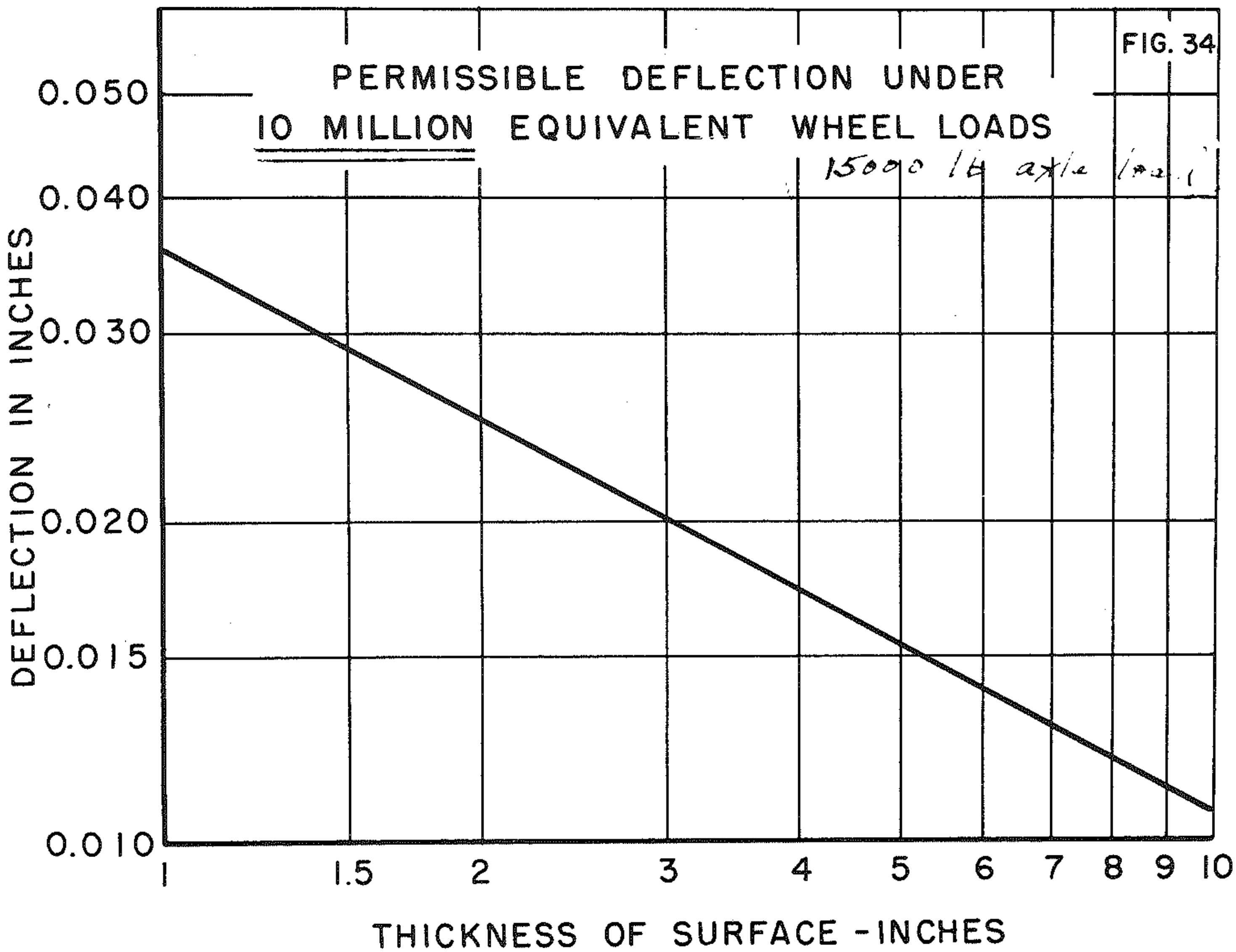


FIG. 34
PERMISSIBLE DEFLECTION UNDER
10 MILLION EQUIVALENT WHEEL LOADS
0.050
0.040
0.030
0.020
0.015
0.010
DEFLECTION IN INCHES
1
1.5
2
3
4
5
6
7
8
9
10
THICKNESS OF SURFACE - INCHES

Slide 5

TENTATIVE
PAVEMENT ROUGHNESS RATING
VERTICAL DISPLACEMENT - INCHES PER MILE

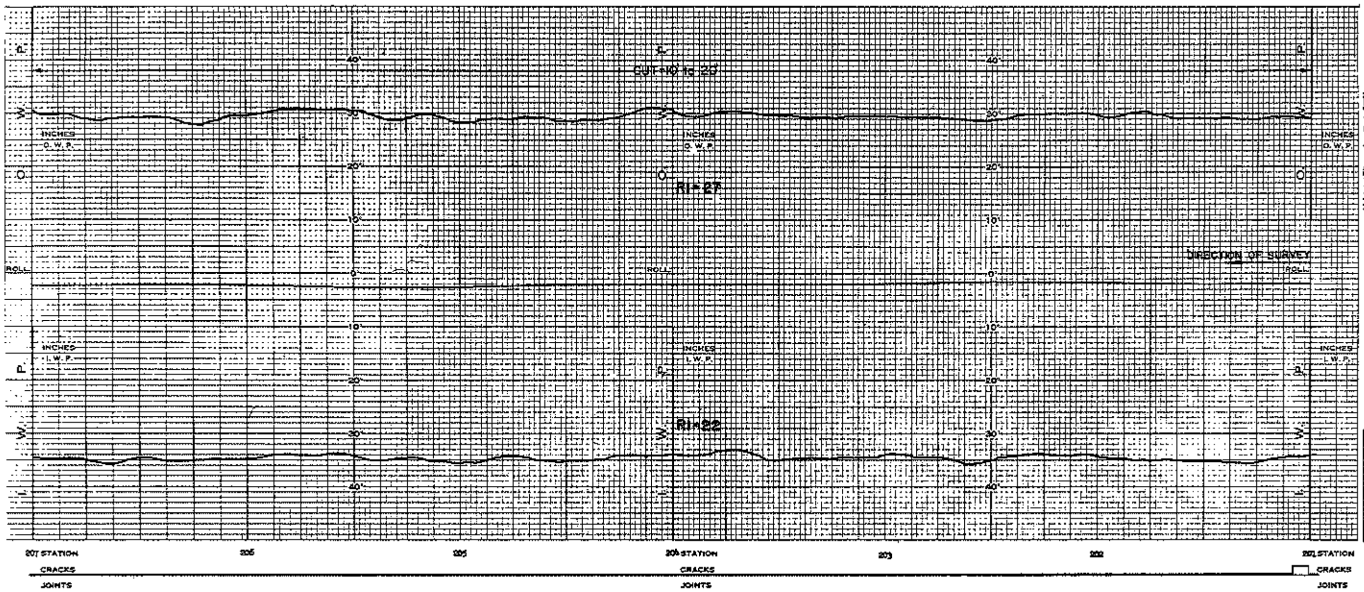
U.S. BUREAU OF PUBLIC ROADS[1] SINGLE WHEEL ROUGHOMETER	RATING	U. OF M. PROFILE TRUCK[2]
LESS THAN 100	EXCEPTIONALLY SMOOTH	LESS THAN 50
100-125	VERY GOOD	50-75
125 - 150	GOOD	75-100
150 - 175	FAIR	100-125
175 - 200	ACCEPTABLE	125-150
200-225	POOR	150-175
225-250	VERY POOR	175-200
MORE THAN 250	EXTREMELY ROUGH	MORE THAN 200

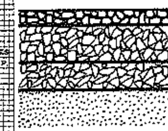
(1) OPERATED AT 20 MILES PER HOUR.

(2) OPERATED AT 4-5 MILES PER HOUR.

FIGURE-6

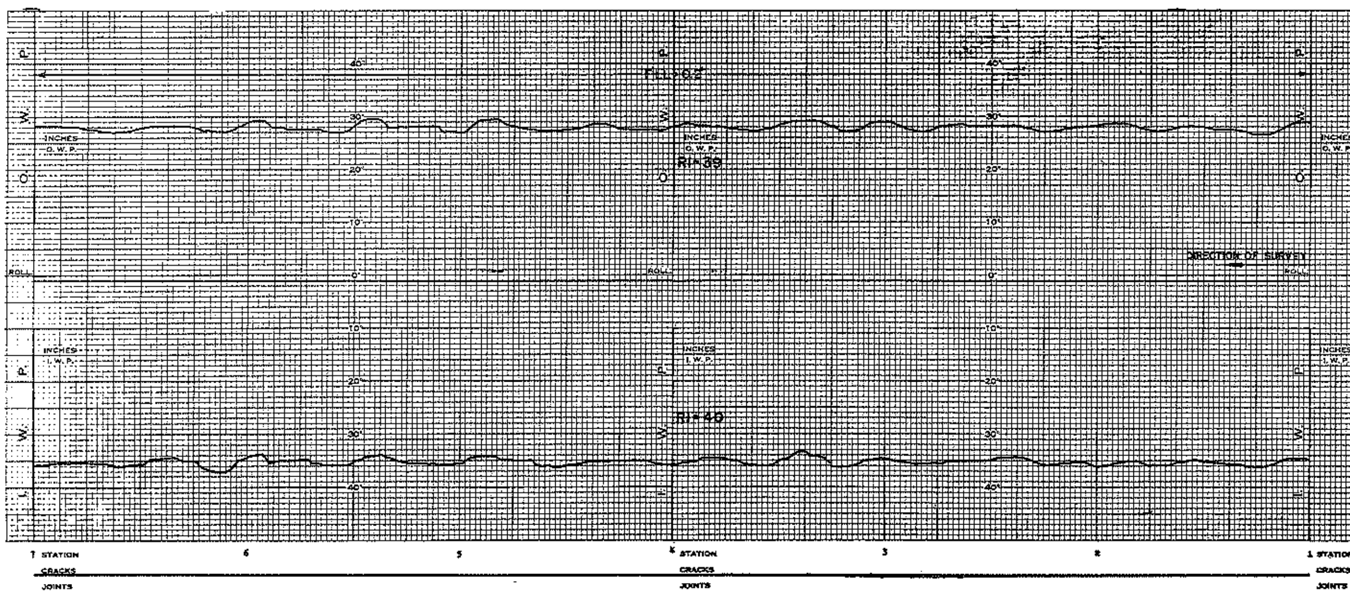
Slide 6

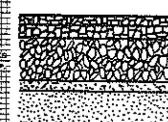




DRAINAGE: EXCELLENT

FIGURE-13A
CLASS-I FLEXIBLE
M-37, 1955 SERVICE 3 YEARS
TRAFFIC: TOTAL 500, COMMERCIAL 120, DHV 95
DATE OF SURVEY: SEPT. 11, 1958



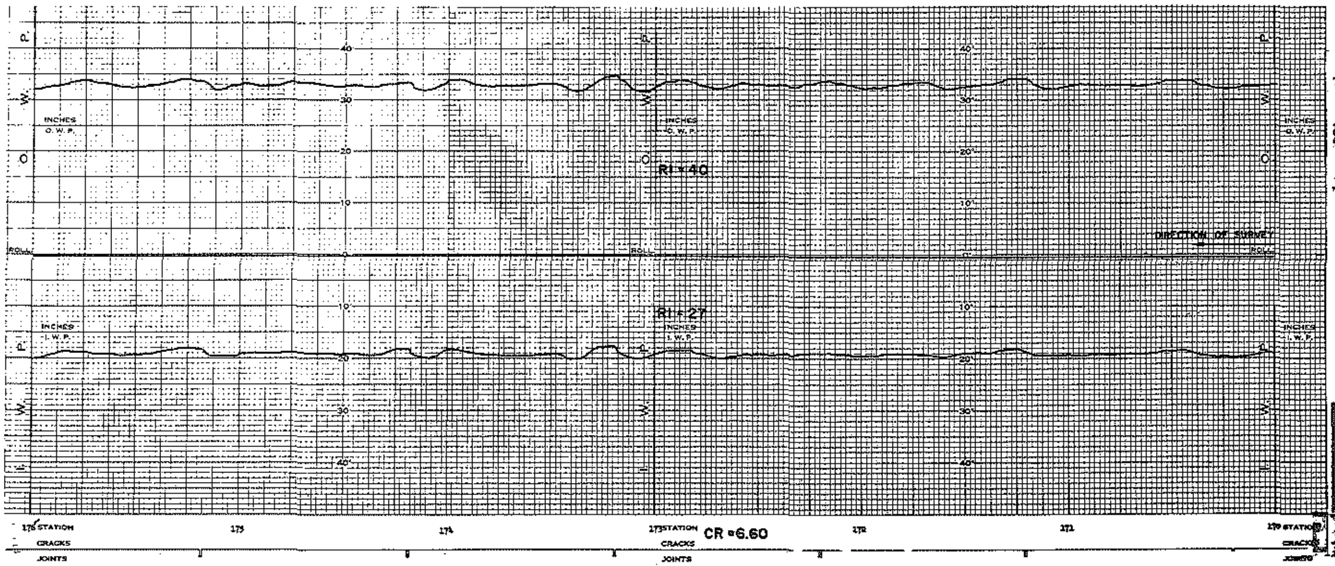


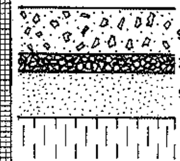
DRAINAGE: EXCELLENT

FIGURE-13B
CLASS-I FLEXIBLE
M-55, 1936 SERVICE 22 YEARS
TRAFFIC: TOTAL 900, COMMERCIAL 200, DHV 125
DATE OF SURVEY: SEPT. 12, 1958

FIGURE-9

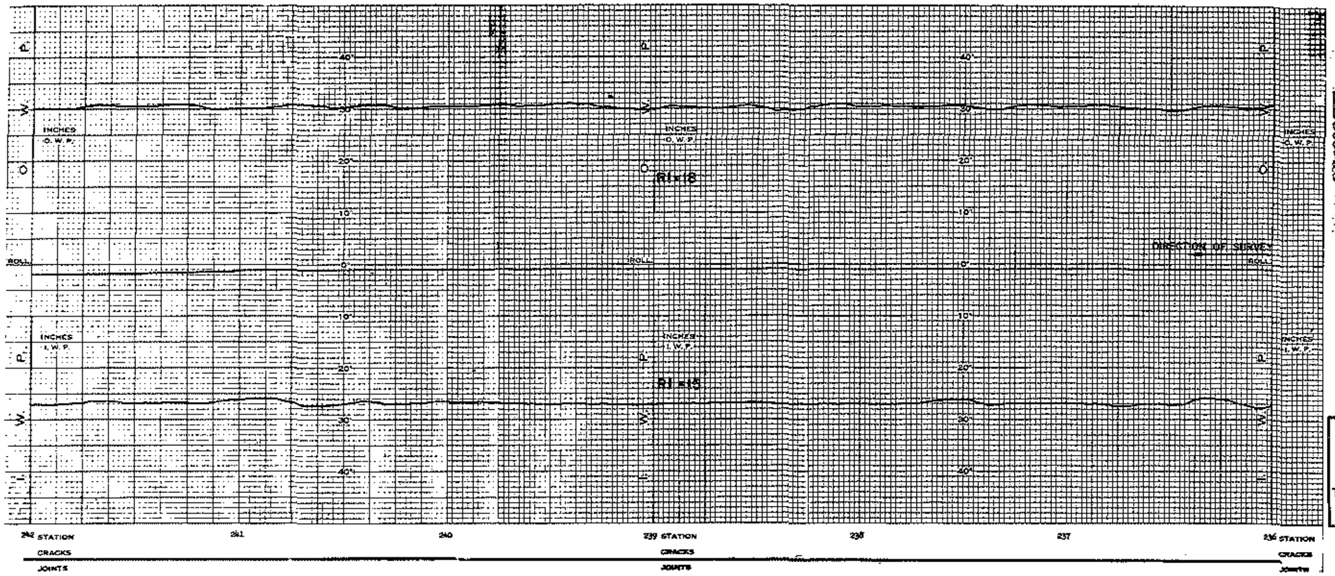
Slide 7

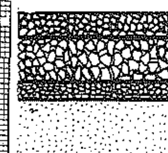




DRAINAGE: FAIR

FIGURE-18 A
CLASS-II RIGID
M-20, 1958 NEW PAVEMENT
TRAFFIC: TOTAL 5000, COMMERCIAL 875, DHV 785
DATE OF SURVEY: NOV. 18, 1958



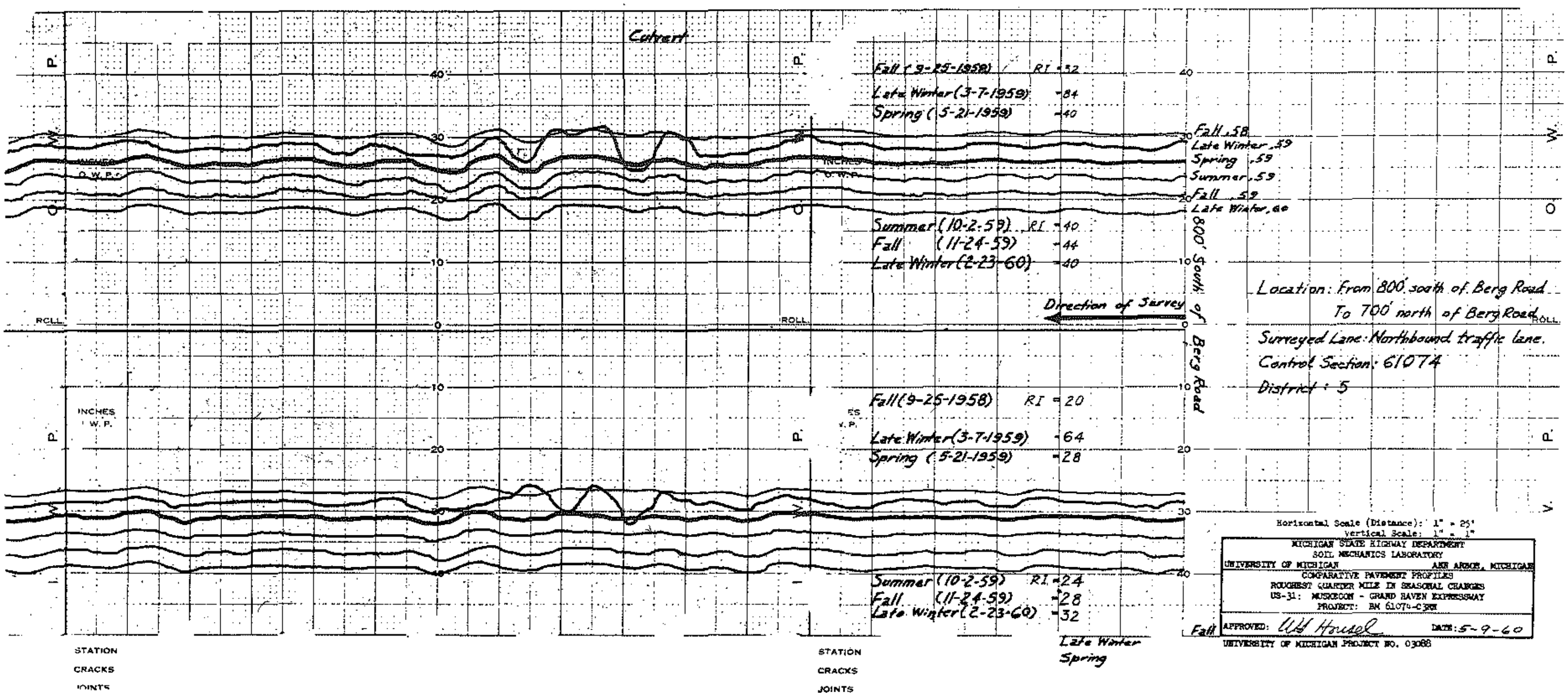


DRAINAGE: EXCELLENT

FIGURE-18 B
CLASS-I FLEXIBLE
US-31, 1958 NEW PAVEMENT
TRAFFIC: TOTAL 8200, COMMERCIAL 1625, DHV 925
DATE OF SURVEY: SEPT. 25, 1958

FIGURE-12

Slide 8


Culvert
Fall (9-25-1958) RI - 52
Late Winter (3-7-1959) - 84
Spring (5-21-1959) - 40
Fall .58
Late Winter .59
Spring .59
Summer .59
Fall .59
Late Winter .60
Summer (10-2-59) RI - 40
Fall (11-24-59) - 44
Late Winter (2-23-60) - 40
800' South of Berg Road
Direction of Survey
Location: From 800' south of Berg Road To 700' north of Berg Road
Surveyed Lane: Northbound traffic lane.
Control Section: 61074
District: 5
Fall (9-25-1958) RI - 20
Late Winter (3-7-1959) - 64
Spring (5-21-1959) - 28
Summer (10-2-59) RI - 24
Fall (11-24-59) - 28
Late Winter (2-23-60) - 32
Horizontal Scale (Distance): 1" = 25'
Vertical Scale: 1" = 1"
MICHIGAN STATE HIGHWAY DEPARTMENT
SOIL MECHANICS LABORATORY
UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN
COMPARATIVE PAVEMENT PROFILES
ROUGHEST QUARTER MILE IN SEASONAL CHANGES
US-31: MUSKEGON - GRAND HAVEN EXPRESSWAY
PROJECT: BM 61074-C3RN
APPROVED: W.S. Housel
DATE: 5-9-60
UNIVERSITY OF MICHIGAN PROJECT NO. 03088
STATION
CRACKS
JOINTS

Slide 9

RESEARCH IN ASPHALT TECHNOLOGY AND DESIGN OF BITUMINOUS MIXTURES

by Paul J. Serafin

Members of the Faculty, Fellow Alumni, Future Engineers, and Friends.

It has been twenty five years since I stood in these halls, trying to impress the professors that I was qualified to go out into the world and hang my shingle as a graduate engineer.

Today it is my pleasure to have been asked to return here to discuss a subject I am deeply interested in, that of Bituminous Research and Bituminous Mixture Design.

About nine years ago when I return to the Michigan State Highway Department, I was assigned the job of Bituminous Testing Engineer in the Testing Laboratory Division in Ann Arbor.

One of the first big problems that confronted us at that time was the matter of moisture in bituminous mixtures. It was causing no end of headaches, resulting in flushing of the asphalt to the surface, and also segregating the fine mortar from the coarse aggregates, thereby causing ravelling and premature failures of the bituminous surfaces.

One of the first things we did was to develop a method for precisely measuring the amount of moisture which was causing this trouble. To the surprise of many, it was found that instead of the moisture being in the neighborhood of one percent, as so many thought, the difficulty occurred with actually only about 0.05 percent moisture in the finished mixture. Steps were taken to encourage the contractor to dry his aggregates more thoroughly. However, the contractor, ever striving for more production, obtained larger asphalt plants and other larger equipment. This has caused an increase in the drying problems instead of correcting them.

Last year a committee was organized to study this moisture problem, and make measurements of dryer efficiency as a step towards improving drying of the aggregates. Preliminary work was conducted on the Wayne County Road Commission asphalt plant at Wayne. A preliminary report was made on this investigation which offers some valuable data on heat balance, and moisture balance. This data should become a valuable tool for analyzing where the problems exist and as a first step to make corrections in the drying systems. It is planned to continue this type of research during the current year with contractors equipment on actual projects under construction.

Paralleling this drying investigation, we have conducted several studies in possible changes in bituminous mixture design as a possible aid in relieving this moisture problem. Before I get into this subject it might be well to review the subject of bituminous mixture design and the different types of mixtures used in Michigan.

Two general types of wearing course surfaces are used here in Michigan. The bituminous concrete mixture, which is our high class pavement, is basically a mixture of crushed stone, sand, mineral filler, and asphalt cement, while bituminous aggregate, which is strictly a local designation, is basically a mixture of gravel mineral filler, and bitumen.

Three types of mixtures of bituminous concrete are available under the 4.12 specification for use on high class construction. A binder course may be used as the first course, where it is necessary to correct extreme unevenness of grade, or more commonly a leveling course is used as a first course, on top of which is placed a wearing surface. All of these use asphalt cement as a binding agent.

Bituminous aggregate mixtures are classed under two specifications, the 4.11 type which is used on state secondary construction and utilizes gravel, filler, and asphalt cement; while the 4.09 type is used on county road construction and utilizes gravel and liquid type asphalts.

In addition we use a finer type of wearing surface covered under the 4.13 specification. This is a sheet asphalt which is a mixture of sand, mineral filler, and asphalt cement.

These mixtures, although well covered in our specifications, require considerable thought for proper design. Some of the important factors in bituminous pavement design are listed as follows:

1. Proper base preparation
2. Economical availability of materials
3. Surface texture desired
4. Workability of the mixture for proper handling
5. Stability of the pavement against deformation from loads

Too often we strive to get higher and higher stabilities in a bituminous pavement, to the point where stability can be overstressed. Inasmuch as a bituminous pavement is considered a flexible pavement, it must necessarily take the shape of the base it is laid upon as it does not provide the rigid structure strength necessary to bridge over deflections caused by insufficiently prepared bases. A county road built with SC-3A oil and gravel serves very satisfactorily for the light traffic that it is subject to, yet if we were to run a laboratory stability on this type of mix it would probably be very low indeed.

However, for example Telegraph Road near Detroit, Michigan, must exhibit properties of sufficient stability to prevent the surface from being shoved and rutted by the heavy truck traffic.

Most of this high stability is obtained from the interlocking of crushed stone particles. The asphalt in the mix offers only a little stability and primarily it serves to hold the aggregate particles together against the scouring action of traffic and to seal the pavement from water penetration.

One of the early laboratory methods used in measuring stability was the Hubbard Field Machine. This was used for sheet asphalt design and later was enlarged to design bituminous concrete. Other tests are the compression test, Triaxial Test, Hveem Stabilometer, and the Marshall Stability test.

All of these methods stressed the ability of a specimen to withstand certain loads.

Basically what we are trying to do is to arrive at a proper aggregate gradation that will give us the most particle interlocking for the particular materials involved. Then we must coat these particles with a sufficient film thickness of asphalt to bind them together. The mixture must then be compacted to approach its maximum density. If it is not properly densified, traffic will continue the compaction and may rut the pavement in the process.

However, if the gradation of the aggregate is such that when compacted it has a very small amount of voids, then this aggregate can hold only a small amount of asphalt, and the film thickness of the binder will be insufficient to give us a durable pavement. If we add more asphalt to this mixture the excess will only come to the surface and cause bleeding. Another problem is that of absorption. There are some aggregates that tend to absorb the bitumen. Under such conditions additional asphalt is necessary to overcome this absorption and still give us a sufficient film thickness.

Voids in a finished mix are an important factor in mix design. For the average high class bituminous concrete, the air voids normally are held between 3 and 5 percent. This is based on the past behavior of dense graded bituminous surfaces that have shown good performance. For an open graded type of pavement, as found in several other states, this void content may be somewhat higher.

There are other factors entering into proper mix design, but much study must still be done to develop methods that would cover the great variety of material sources.

Now you may ask how do we design mixes in the Michigan State Highway Laboratory. To design a 4.09 bituminous aggregate mixture, a grading is run on a representative sample of gravel. From this grading, by an empirical calculation, we determine the surface area of all the particles in a given quantity of sample. Most of us can readily appreciate that the surface area of a number of small stones is much larger than that of a single stone having the same volume. Consequently it takes more asphalt to coat many smaller stones than it does one equivalently sized larger stone. We therefore base the design on the principal that the greater the surface area the more asphalt it will require to give an equal film thickness. So from a set of surface area curves we find the amount of bitumen required for the particular gravel in question.

For the higher class of bituminous concrete we base our mix design on past laboratory and field experience. Adjustments in mixture design are made depending on the source of materials used. The mixture designs are checked in the Laboratory using the Marshall method. Recently we have obtained a triaxial unit which we hope to use in this work. Rather than attempting to change our mix design every time the grading of the aggregate changes, we control the production of crushed stone to within a very close tolerance. For economical reasons this is kept within the practical limits as obtained from the crushing process.

The sand portion of the mix is also controlled within close gradation limits, which were arrived at through laboratory work done using the Hubbard Field Stability Method. Since high "belly" type of sand is quite common in this state, it was natural to want to use it, but it was found that this does not produce a good stability. By proper blending of fine and coarse sand, with or without "belly" sand, we were able to economically produce a sand having a gradation within the limits as found desirable by the Hubbard Field Stability Method.

This combination of stone, sand, filler, and asphalt produces a mixture that is more or less of a skip type grading. It exhibits excellent stability and when the aggregate is properly dried it has produced good wearing surfaces that have stood up under many years of service. However, as mentioned before with a very small amount of moisture, about 0.05 percent, the mixture may on occasion become critical and difficult to handle.

As part of the study of the moisture problem, last summer the Highway Department constructed seven experimental projects in which we used a coarser type sand, such as is being used in portland cement concrete. This has straightened out the grading curve somewhat and provided a bituminous mixture less critical to moisture. This coming year we plan on continuing this type of investigation and it looks like some minor changes in mixture design may be forthcoming.

Another important investigation which is being studied is the anti-skid properties of different bituminous surfaces. Throughout the years most of us have been indoctrinated with the idea that a somewhat open textured, stoney surface gives the best skid resistance for moving vehicles. In fact, as one drives down the highway on an open textured surface, the rumbling under the wheels gives us a false sense of feeling that we are riding on a good braking surface.

This is not necessarily true. Rather, after a year's usage the stone particles orient themselves exposing flat surfaces which become polished with traffic thus making the pavement slippery.

The Michigan State Highway Department Research Laboratory in cooperation with the General Motors Proving Grounds have developed a machine that measures skid resistance and obtains figures of the coefficient of friction of the pavement surfaces. Correlating these figures against actual auto skidding they have determined that for an automobile traveling 40 miles per hour the pavement in order to be safe must have a coefficient of friction of at least 0.4.

To follow up with this investigation, two years ago, we constructed seven different types of sand surfaces on US-23 south of Ann Arbor. Some of these showed good skid resistance after construction and still exhibit good anti-skid properties. This investigation confirmed the belief that the skid resistance of a surface comes primarily from the sand mortar and not the sharp edges of the crushed larger aggregate particles. In the future it is planned to continue this type of investigation and develop economical bituminous sand mixtures that would correct the old rough, broken, surfaces, and at the same time make them skid resistant to traffic particularly in wet weather.

Many of us have heard the statement made that our asphalt today is not as good as it used to be. Since the introduction of the Wyoming Crude asphalts several years ago, this thinking has become even more prevalent.

In order to study this, the laboratory has made several investigations to examine the physical properties of asphalts used for a number of years and compare these against the asphalts from new sources. The tests showed some definite differences between the various asphalt sources. In order to evaluate these test results with field performance, five years ago the Department constructed an experimental bituminous road on US-10 between Pontiac and Flint. Six sources of asphalts available to us at that time were used on this project. Five years have passed now and investigations have shown some differences between the sections containing the different asphalts. One section, constructed with asphalt from a Venezuelan Boscan Crude, shows a more open texture. One section, using Winkler

Crude, shows slightly more wear than the others. However, by our standards they all look good. One of the troubles with constructing a research project in the field is that the inspection on these jobs is usually of superior quality. As a result it may take a longer period of time to determine any detrimental characteristics of these materials.

An offshoot of this investigation showed that different sources of asphalt, even though at test temperature are of the same grade, require different temperatures for handling the hot mixture during laying. This is because the temperature susceptability of asphalts are different from the various sources.

Good engineering must be a combination of technical background plus good horse sense that can be obtained only through hard knocks. Based on the temperature susceptabilities of the test road asphalts we can arrive on the temperatures that should be used for handling the mixtures during paving. As experienced during the paving of the bituminous surface on the Mackinac Straits Bridge, it was necessary to deviate from these theoretical figures. The bridge had a deadline opening of November first and paving of the bituminous surface was performed during the cold month of October. You fellows know how cold it can be here in the Upper Peninsula during that time of the year. Well, hanging up 300 feet or more in the air above the cold waters of the Straits of Mackinac during the latter part of October required some extraordinary modifications not only in raising the mixture temperature but other conditions as well in order to properly compact the bituminous mixtures.

Talking about compactions, another investigation being studied is the effect of rubber-tired or pneumatic-tired rollers on the initial compaction of the bituminous surfaces. Last summer several projects were being investigated to compare the compactive effort of the rubber-tired rollers against the standard 10-ton steel tired rollers. It was determined that when properly operated the rubber-tired roller produced better compaction up to a certain number of passes. However, beyond about 12 to 16 passes of the pneumatic roller the density of the pavement starts to decrease showing an overdisturbance of the aggregate particles. It is planned this summer to continue this investigation in order to set up the basic minimum requirements of this type of compaction.

As a further tool towards field investigation the Highway Department a year ago constructed a mobile Bituminous Laboratory. It is well equipped, able to obtain cores from finished pavements, prepare Marshall specimens, determine voids, run stability tests, determine moisture in bituminous mixtures, run extractions to determine gradation of the aggregates and the bitumen content. This unit travels all over the state and performs the necessary testing as a supplement to the control of bituminous construction.

The Highway Testing Laboratory in Ann Arbor has a well equipped bituminous section, second to none in the world. It is located at the University of Michigan, East Engineering Building. It is staffed by Highway Engineers and Technicians. In the summer we utilize students from the University and young men from other sources to perform the routine work. The control of all engineering and inspection of bituminous mixtures both in the Laboratory and in the field is performed under the supervision of this unit.

During the winter time the bituminous section, as well as the other sections, are engaged in numerous research projects. Some are evaluations of data obtained during the past seasons construction. Other investigations are carried on to establish next mixture designs, study new materials, promulgate new specifications, and many other functions.

A NEW METHOD OF ASPHALT MIXING

by Ladis H. Csanyi

Can asphalt cements be mixed with cold and wet aggregates? General opinion says "no", recent research says "yes". Which of these is correct and wherein lies the difference? Both are correct. The difference lies in the manner in which the asphalt cement is applied to the aggregate during mixing.

When the asphalt cement is added in the form of a liquid, as in the usual conventional operations, the asphalt and the wet aggregates are not compatible. If, however, the asphalt cement is added as a foam the two materials become compatible. This change in behavior is simply a matter of the amount of energy the asphalt possesses at the time it contacts the aggregate. Hot liquid asphalt cements apparently do not possess enough energy to displace the moisture from the surface of the aggregate. Foaming of the same asphalt cement provides it with sufficient additional energy to displace the water and coat the aggregate with a thin film of asphalt. This theory is fundamentally logical and sound. The big question is how may it be applied practically, economically, and commercially.

The Bituminous Research Laboratory of Iowa State University undertook a research project sponsored by the Iowa Highway Research Board to develop means for the practical application of the foamed asphalt theory which the Laboratory propounded.

The study conducted by the Bituminous Research Laboratory was divided into several phases. The first phase involved the development of a means of practically applying foamed asphalt during mixing; the second, consisted of testing mixes produced in the laboratory under the Foamed Asphalt Process to determine their physical properties; and the third phase involved the conducting of large scale field tests to determine the commercial feasibility of the Process and the trafficability of the mixes produced.

The major problems in the first phases involved the determination of the best way of foaming the asphalt under strict control, and the proper placement of the foamed asphalt to secure uniform distribution of the desired quantity of asphalt at the required time during mixing.

After considerable study, research, development and test a nozzle was devised that would instantaneously and continuously generate foamed asphalt cement consistently and uniformly. The nozzle devised consists of a body, nozzle tip, foaming agent tube and other control appurtenances. The asphalt cement enters the nozzle by way of the body and passes on to the tip. The foaming agents enter through the foaming agent tube, centered in the body, which carries it to the tip. Although a variety of foaming agents may be used, saturated steam was selected because it will foam the asphalt instantaneously and has practically no effect upon the chemical composition of the asphalt. The steam and the asphalt meet just above the orifice of the nozzle tip where an asphalt foam is instantly created. The asphalt foam is continuously emitted through the nozzle orifice by the flow of the asphalt and steam through the nozzle.

The type of foam produced is controlled by the dimensional characteristics of the nozzle tip, its clearance from the foaming agent tube, and the quantity and pressure of both the asphalt and the steam introduced into the nozzle. A congealed or concentrated foam, one in which the bubbles are in contact with one another, was found most effective in producing paving mixes. In this case a concentrated foam nozzle tip is used which produces a shallow cone spread. Although asphalt pressures as low as 5 pounds psi with 15 pounds psi steam pressure may be used best results are obtained with asphalt pressure at 25 pounds psi and steam pressure at 40 pounds psi. Under these conditions asphalt cement of penetration grades between 5 and 200 plus may be efficiently foamed provided the asphalt entering the nozzle is at 300° F.

The distribution of the foamed asphalt in the mixer at the proper quantity and at the desired time was solved by the development of a spray system. This system consists of a spray bar fitted with the required number of nozzles so situated that a uniform distribution of the foamed asphalt in the mixer is obtained; an asphalt pump drawing asphalt from an asphalt measuring device; a steam boiler supplying steam; and the necessary valve, guages and regulators to control the flow and pressure of the asphalt and steam. The operation of the system is simple. The steam is turned on first, in order to blow the nozzle tips clear and warm up the nozzle. The asphalt is then turned on and measured for the quantity required by the mix. When the desired quantity has been added, the asphalt is shut off. As soon as the nozzles are clear, the steam is shut off. Thus the system may be adapted to either batch or continuous mix operations.

Since the Foamed Asphalt Process requires a kneading action of the mixer to distribute the foamed asphalt throughout the aggregate no changes in the usual twin shaft pug mills are required. Further, since the foamed asphalt system operates on 25 pounds psi asphalt pressure, which is well within plant asphalt pump range, no changes are required in this regard. Thus, any commercial asphalt plant may be adapted to the Foamed Asphalt Process by installation of the foamed asphalt spray bar and necessary interconnection with the normal plant asphalt supply lines. If a two way cock valve is used in this connection, the operation of the plant may be alternated almost instantly between normal operation and the Foamed Asphalt Process by merely turning this valve.

In order to test the operation of the foamed asphalt system and determine the character and properties of mixes produced by the Foamed Asphalt Process, a small Hetherington & Berner laboratory twin shaft pug mill mixer of 50 pound capacity was adapted to the Process. A wide variety of foamed asphalt mixes were produced in this mixer including, standard high type hot mixes, ungraded aggregate hot mixes, ungraded aggregate cold mixes, stockpile mixes, hot mastic mixes, cold asphalt cement slurry mixes and a variety of soil stabilization mixes. These series of tests disclosed that excellent mixes of the foregoing types, suitable for highway pavements and bases, can be produced by the Foamed Asphalt Process.

Stability and other physical property tests made on the various mixes produced in the laboratory mixer disclosed that mixes mating usual specification requirements for various purposes could be produced by this process. Detailed results of these tests have been published as Highway Research Board and American Road Builder's Association Bulletins (1,2).

In the course of the laboratory tests it was noted, and confirmed by tests, that the physical properties of the asphalt cement were altered by foaming as expected. An asphalt cement of 60-70 penetration when foamed would gain a penetration of 300 plus and become much more liquid. Through foaming, the surface tension of the asphalt was also altered giving it the energy to displace water from an aggregate. It also became quite rubbery and possessed high adhesiveness. When the foam bubbles were broken the asphalt cement regained its original properties. It was also found that foaming with steam did not alter the chemical composition of the asphalt.

The laboratory tests on mixes proved so successful and encouraging that a number of full scale field road tests were undertaken in which regular construction equipment was used. These tests included the preparation and laying of an ungraded aggregate mix; a soil stabilization test on a county road; and an asphalt cement slurry seal coat test on county and primary roads. The foregoing tests were conducted by the Iowa Highway Research Board. Other tests by cities, states and private sources included tests of hot asphalt mastic mixes, stockpile mixes, precoated aggregate mixes in Dubuque, Iowa; soil stabilization in Sioux City, Iowa; cold mix paving surfaces in Arizona; and sand stabilization in South Carolina.

A brief review of each of these tests follows:

Hot Ungraded Aggregate Mix, Ringgold County, Iowa

The aggregate used in this test was an agricultural limestone, a by product, and a run of crusher limestone, having the following gradations.

Sieve Size	Total Percent Passing Ag Lime	Run of Crusher
3/4	-	100
1/2	-	94
3/8	-	81
No.4	98	58
8	79	42
16	60	-
30	45	24
50	33	-
100	26	-
200	22	16

In this case a Cedar Rapids Continuous Mix Asphalt Plant was adapted to the Foamed Asphalt Process. The aggregates were dried and heated to 280° F. in the usual manner. The asphalt cement used was a 150 to 200 penetration grade heated to 280° F. About $6\frac{1}{2}$ to 7% of foamed asphalt was used in the Ag Lime mix and about $5\frac{1}{2}$ to 6% of foamed asphalt was used in the run of crusher mix. The plant operated at a production capacity of 110 tons per hour for the Ag Lime mix and 130 tons per hour on the other mix. This was slightly below full capacity of the plant. Excellent mixes were produced which met high type asphaltic concrete specification requirements. The mixes were laid by a Barber-Greene Finisher as parts of the surfacing and base of the test road project. They have served excellently during the past three years.

Asphalt Soil Stabilization

Several full scale road tests were laid to determine the efficacy of the Foamed Asphalt Process on in-place soil stabilization. These tests included the following:

Campus Roads. 1956

The material the roadway in this case consisted of about $1\frac{1}{2}$ inches of power-house cinder overlying a heavy clayey soil. A four inch depth of cut during stabilization had the following gradation of combined materials.

Sieve	Total % Passing
3/8	93
4	82
10	68
40	46
80	34
200	26

The stabilization was accomplished by a Seaman Andwall Pulver-Mixer adapted to the Foamed Asphalt Process. The stabilization was processed in the following manner: The road surface was scarified. This was followed by a blending pass of the mixer. After blending sufficient water was added to raise the moisture content to 8%. About 6% of 150-200 penetration asphalt cement was added by the mixer. The mixed material was rolled immediately behind the mixer. The mix produced had the following properties.

Marshall Stability 140° F. Wet	480 pounds
Unit Weight per cubic foot	142 pounds
Resistance to Freeze and Thaw	fair

These results indicate that excellent soil stabilization was attained by the Foamed Asphalt Process suitable for base purposes (1). This base sealed with a single layer seal coat has served excellently, carrying about 400 cars a day during the past four years.

<u>County Road Project. 1957</u>

The next test was the stabilization of a county road just north of Ames, Iowa, for a distance of one half mile. In this case the existing county road consisted of about 3/4 inch of gravel upon the native soil which varied between an A-2(4) and A-6(9) classification.

The stabilization of this road was conducted in a manner similar to that used on the Campus Roads using the same machine. The asphalt cement used in this case was of 100 to 120 penetration grade, and the moisture in the soil was adjusted to about 9%. A stabilized base four inches in compacted thickness was constructed on this road. Stability tests - Marshall Stability at 140° F. Wet - yielded 420 pounds for this mix. The stabilized base was sealed with a single layer seal coat soon after stabilization. After three years of operation, carrying about 300 cars per day, and weathering winter temperatures of 30° F. below zero, also very heavy rains and high temperatures of 105° F. this base is in excellent condition.

Sioux City Parking Lot. 1959

This work was undertaken by the Brower Construction Company of Sioux City, Iowa using a P & H Single Pass Stabilizer equipped with the Foamed Asphalt Process, and involved stabilization of a five acre parking lot. The soil in the parking lot area was of a loess, all particles of which passed the No. 200 screen and which contained about 15% clay.

In order to hold stabilization within 6% asphalt, preliminary tests showed that about 33% of sand would be required as a blend to meet this requirement. Consequently the stabilization operations were as follows:

Since a six inch compacted depth of stabilization was required a two inch layer of sand having the following gradation was spread on the prepared surface of the lot. Total percent passing No. 100-100%, No. 40-82%, No. 80-16%, No. 200-0%. After spreading of the sand sufficient water was added to raise the moisture content of the sand-loess blend to 11%. The P & H Single Pass Stabilizer then went into operation cutting the soil and sand to a depth of 6 inches, blending them and adding 6% of 100-120 penetration grade asphalt cement as a foam in the process of mixing all in one pass. After stabilization, the mix was rolled with a sheeps foot roller followed by pneumatic rolling for compaction and steel rolling for finishing. The physical properties of the stabilize mix were:

Hubbard Field Stability	77° F. dry	4150
	140° F. dry	2500
	140° F. wet	400
Moisture absorption compacted specimen		3%
Resistance to Freezing & Thawing		Satisfactory

The stabilized base was surfaced by a single layer seal coat. This pavement laid during the summer of 1959 resisted temperatures up to 100° F. and one of the severest winters ever encountered in the area. It is serving excellently.

South Carolina Beach Sand Stabilization. 1960

Several tests were conducted recently in Charleston, South Carolina by the Banks Construction Company to determine the efficacy of the Foamed Asphalt Process in stabilizing beach sands. Preliminary tests disclosed that a South Carolina beach sand having a gradation as follows: Percent passing No. 8 screen - 96%, No. 40 screen - 94%, No. 80 screen - 51%, and No. 200 screen - 4% could readily be stabilized with 5 to 6% of 120-150 penetration grade foamed asphalt cement in the presence of 10% moisture and yield a mix having a Hubbard Field Stability at 77° F. of 2800 pounds and at 140° F. wet of 930 pounds with a moisture absorption in a compacted specimen of 1.2%.

Based upon these results, field trials were made with a P & H Single Pass Stabilizer equipped with foamed asphalt. These trials showed that excellent base stabilization could be secured with the Foamed Asphalt Process. Based upon these results, authorization was granted to stabilize the bases of about three miles of streets and roads with this process. All stabilized bases will be surfaced with single layer seal coats.

Hot Liquid Asphalt Mastic Surfacing, Dubuque, Iowa. 1959

The application of a thin layer asphaltic surfacing upon old worn concrete pavements has seldom been successful in practice. Laboratory tests of a hot liquid asphalt mastic mix prepared by the Foamed Asphalt Process indicated that such a mix might be successful when used for such a purpose.

The City of Dubuque, troubled with rapid deterioration of old concrete pavements, decided to test the efficacy of this mix. Contracts were let to the Schueller Construction Company of Dubuque, who had his two ton Madson Batch Plant adapted to the Foamed Asphalt Process. The streets selected were White Street, a major street carrying about 13,000 cars a day with a large percentage of heavy trucks, and several hill streets having grades of 10, 11 and 12 percent and carrying about 10,000 cars a day.

The aggregate used in this mix was a local crushed limestone having the following gradation:

Sieve No.	Total % Passing
3/8	100
1/4	92
No. 8	67
No. 16	52
No. 30	44
No. 50	35
No. 100	23
No. 200	13

The mix was prepared in the following manner: The aggregate was heated to 425° F. in the usual manner and the proper quantity placed in the mixer. Here, during mixing, about 9½% of 120 to 150 penetration asphalt cement was added by the Foamed Asphalt Process. Total mixing time was one minute. The mix discharged from the mixer had a temperature of about 400° F. and a consistency of molasses. The mix was laid by a Barber-Greene Finisher at a temperature of about 375° F. to an average thickness of 3/4 inch, with actual thickness varying between 1/8 inch to 1-1/2 inches. The mix laid smoothly through the machine and upon the pavement which had no other preparation than brooming. As soon as the mix cooled to 175° F. it was compacted with pneumatic rollers and finished with steel tandem rollers. The pavement was opened to traffic immediately behind the finishing rollers. An excellent dense surfacing was secured that adhered tenaciously to the concrete and brick pavements upon which it had been placed. The cost of this surfacing averaging 3/4 inch in thickness, including all incidental costs was $0.618 per square yard on a job including about 25,000 square yards of surfacing. (4) This pavement has served excellently during the past year showing no cracking during the winter or shoving on the steep hills during the hot summer.

Some concern was expressed concerning the effect of the high temperature on the asphalt. Tests were conducted by the Iowa Highway Commission to determine this effect. The results of the test showed that the recovered asphalt introduced by the Foamed Asphalt Process in these mixes met all specifications of the Iowa Highway Commission for high type asphaltic concrete mixed at 280° F. The loss in penetration was 33% well within allowable limits; increase in softening point was only 9° F. from 109° F. to 118° F., which was amazing. In fact the results were better than those secured with asphaltic concrete mixed at 280° F. Consequently it appears that high temperature has little effect on foamed asphalt. The mix possessed a modified Hveem Stability of 55 with a specific gravity of 2.33, both well within specifications for high type asphaltic concrete.

Stockpile Mix, Dubuque, Iowa.

The Dubuque contractor also undertook the test of a stockpile mix produced by the Foamed Asphalt Process. In this case the usual specification mix is produced in the normal manner except that the asphalt cement is added as a foam. As the mix is discharged from the mixer, it is sprayed with cold water in order to chill and set the asphalt film coating the aggregate, thereby preventing agglomeration of aggregate particles. The mix is then placed in stockpiles about four feet deep and again sprayed with cold water. Such a mix will remain friable for many months. The contractor is selling this mix to Dubuque for patching and shipping the mix to cities in a radius of fifty miles for the same purpose.

Precoated Aggregates for Seal Coating, Dubuque.

The Dubuque contractor, noting the behavior of the Foamed Asphalt Stockpile Mix, decided to try the Process for precoating seal coat aggregates. In this case the usual seal coat aggregate is heated to about 200° F. and placed in the mixer where sufficient foamed asphalt is added to just coat all of the aggregate particles with a thin film of asphalt. This requires about 3/4 of one percent of asphalt for a 3/8 inch aggregate. As the precoated aggregate is discharged from the mixer it is thoroughly wetted with cold water. It is then placed in stockpiles ready for shipment. Precoating the aggregate has the following advantages: Less prime is required and better embedment of aggregates is secured; aggregate scatter and dusting is eliminated and the surfacing is black when laid.

Cold Mix Asphaltic Concrete Surfacing; Phoenix, Arizona

Laboratory tests indicated that cold mix asphaltic concrete mixes, suitable for pavement surfaces, could be produced by the Foamed Asphalt Process. In this instance, aggregates of standard gradation, or local ungraded aggregates containing sufficient fines and having a moisture content up to 10% could be used.

During February 1960 a test road was laid just north of Phoenix, Arizona sponsored by Maricopa County and the Arizona Highway Department. Two basic aggregates available locally in Arizona were tested, one was a local river gravel and the other was a crushed lava rock. These aggregates had the following gradations:

	Total % Passing	
Sieve No.	River Gravel	Cinders
3/4	95	100
3/8	78	80-82
1/4	72	67-71
4	69	61-64
10	59	46-49
40	24	26
200	8	10

The mix in this case was prepared in the following manner: The aggregates were wetted to the desired moisture content and placed into the hopper of a Hetherington & Berner Moto Paver equipped with the Foamed Asphalt Process. The Moto Paver adds the foamed asphalt and mixes the mix as it pounds forward at a speed of about 28 feet per minute. The mix produced at a rate of about 125 tons per hour is discharged onto the pavement where the machine spreads it and screeds it to the desired thickness as it moves forward. The mix may be rolled by pneumatic rollers immediately behind the Moto Paver and finished by steel rollers. The pavement may be opened to traffic immediately after finishing. No aeration is necessary. The mix combinations used and tests of their physical properties are as follows:

	Gravel Mix	Cinder Mix	
% Foamed Asphalt	4.2	5.0	7.5
% Moisture in Mix	3.5	9.5	9.4
Hveem Stability value	33	23	9
Hveem Cohension value	243	84	105
Density pounds/cu. ft.	140	120	119

The results of these tests were so successful that seventeen miles of road north of Prescott is now being laid, using cinders as the aggregate, in a mix produced by the Foamed Asphalt Process.

Asphalt Cement Slurry Seal Coats. 1958 & 1959

Laboratory tests also showed that an asphalt cement slurry seal coat mix could be produced by the Foamed Asphalt Process, using American practices and equipment. Several test projects were conducted at various locations to test the efficacy of the Process in this regard. The test projects included sections on U. S. Highway 6 east of Des Moines, Iowa, and Iowa Highway 210 and 211 in Story County, Iowa, and a three mile county road in Hancock County, Iowa. In each case the asphaltic concrete road was showing distress and required sealing.

In each case the aggregate used was an agricultural limestone having the following gradation:

Sieve Size	Total % Passing
4	100
10	70-90
40	35-50
80	20-30
200	12-20

The mixes were prepared in a small Cedar Rapids continuous mixing plant, equipped with the Foamed Asphalt Process, at a rate of about 25 tons per hour in the following manner: The aggregate in the cold feed hopper was wetted with sufficient water to raise the moisture content to 16% as it dropped from the hopper into the mixer. The initial stage of mixing at the front end of the mixer created an aggregate paste, as the mix passed along in the mixer, about 13% of 150-200 penetration grade asphalt cement was added as a foam and mixing continued to create an asphalt paste. The asphalt paste was discharged from the mixer directly into a rotary drum concrete mixer, that was truck mounted. Additional water was added to the asphalt paste in this mixer until an asphalt cement slurry of the desired consistency for laying was attained. During transport to the laying site the mixer drum was rotated at agitator speed in order to retain a homogeneous mix.

The laying of the asphalt cement slurry seal coat was accomplished in the following manner: A spreader consisting of a screed and broom drag was hitched to the rear of the mixer truck and pulled into position on the road surface. The slurry was discharged into the spreader as the truck moved forward, spreading a layer of slurry about 1/8 inch thick upon the road surface. The consistency of the slurry containing about 30% moisture was such that it flowed into all cracks sealing them and levelling the surface to a true grade. After spreading, the slurry required about 90 minutes to set on a warm dry day. On humid, cloudy days much longer time was required to set the slurry seal. As soon as the slurry set it was rolled with pneumatic rollers and opened to traffic. If rain is expected on a heavily travelled road, traffic must be kept off the seal coat until it has thoroughly set in order to avoid reslurrification by traffic and rain.

The asphalt cement slurry seals produced by the Foamed Asphalt Process possess excellent wearing qualities, do not bleed under traffic if properly designed, nor do they dust under traffic. The seal coats laid under the tests have served excellently since laid.

Crack Filler

An interesting and unsuspected application of the asphalt cement slurry was discovered during the test road operations. In the process of spreading the slurry it was noted the cracks were thoroughly filled. This led to a test of the slurry as a crack or joint filler. In this case, the slurry is placed in pour pots from which the slurry is poured into the cracks until they are just filled. Excess slurry is squeegeed off the surface, leaving a neatly filled crack. As the slurry sets, it shrinks slightly, giving a neat clean appearance. Traffic may be allowed to operate over cracks immediately after filling. This test was so successful that a contractor is now packaging the asphalt paste in drums and selling it as a crack filler. In this case, sufficient water is added to the paste in a small concrete mixer or plaster mixer to make a slurry of the desired consistency. Many cities and counties are now purchasing this material as an excellent crack filler.

Patents:

The Foamed Asphalt Process developed in the Bituminous Research Laboratory of Iowa State University was patented by the Iowa State University Research Foundation. The patents were assigned to this Foundation by Prof. L. H. Csanyi, the inventor.

Two patents covering the process have been issued by the United States Patent Office. One, No. 2,861,787, issued on November 25, 1958, covers the apparatus aspects of the process, the other No. 2,917,395, issued December 15, 1959, covers the theory and numerous applications of the process.

Other patent applications are pending in Canada, England, Australia and Germany.

Licenses of the patents are granted to equipment manufacturers by the Iowa State University Research Foundation

Conclusions

The studies and developments made at the Bituminous Research Laboratory of Iowa State University have harnessed the unusual properties of foamed asphalt and have made asphalt cements applicable in conjunction with wet aggregates. Asphalt cements may now be used in many new ways and in some cases previously believed impossible. The Foamed Asphalt Process has been tested and found effective in the following respects:

1. More even and uniform distribution of the asphalt throughout the mix.

2. Ungraded aggregates may now be used for the production of satisfactory paving mixes.

3. Cold, damp or wet aggregates may be used in the production of cold mix asphaltic concretes.

4. Stockpile mixes containing asphalt cement which will stockpile for many months may now be produced.

5. Asphalt cement slurry seal coat mixes which contain up to 30% moisture may now be produced by American practices and in American equipment.

6. A hot liquid asphalt mastic mix has been made available that will adhere to old concrete pavements in thin layer surfacings.

7. Clayey, sands or granular soils may not be stabilized in a moist or wet condition with asphalt cements.

8. There is no doubt many other applications, such as Precoated Aggregates and Crack Filler, may yet be found wherein foamed asphalt may be used to a distinct advantage.

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4. Foamed Asphalt, K. J. Cullen, American City, Dec. 1959

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6. Contractor Equips for Foamed Asphalt Stabilization, Roads & Streets, April 1960.

Note:

Numbers shown in parentheses refer to slides not included with this talk.