**PLASTIC MOISTURE BARRIERS
FOR
HIGHWAY SUBGRADE PROTECTION**

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**PURDUE UNIVERSITY
LAFAYETTE INDIANA**

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ELASTIC MOISTURE BARRIERS
FOR HIGHWAY SUBGRADE PROTECTION

TO: K. B. Needs, Director
Joint Highway Research Project

FROM: Harold L. Michael, Assistant Director

April 19, 1956

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Attached is a report entitled "Elastic Moisture Barriers for Highway Subgrade Protection" by J. R. Seil and E. J. Yoder of our staff. This report was presented at the 42nd Annual Purdue Road School on April 2, 1956.

This paper presents information obtained during a study of plastic moisture barriers under a contract with the Bakelite Company. The study is presented to the Advisory Board for information.

This paper will be presented for inclusion in the Proceedings of the 42nd Annual Purdue Road School.

Respectfully submitted,

Harold L. Michael

Harold L. Michael, Assistant Director
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Attachment

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INTRODUCTION

Most soils, even fine grained soils, can be compacted to have relatively high strengths if moisture and density are properly controlled. However, under present design concepts, when these soils are used as highway subgrades, only a fraction of this ultimate strength is used as the design strength. As a result, large thicknesses of stronger and more expensive materials are required to spread the load so as not to exceed this reduced strength. This is necessary because it is known that most subgrade soils will not retain their initial strength after years of service under highway pavements. This loss of strength is usually the result of an increase in water content and may be accompanied by frost heaving or swelling. If subgrade soils, subject to these detrimental effects of increasing water content, could be isolated from external sources of water, their design strengths could be greatly increased, effecting, in many cases, substantial savings in the total cost of the highway.

GENERAL

This paper is a summary of a research project being conducted at Purdue University, sponsored by the Bakelite Company, to investigate the feasibility of using plastic films as moisture barriers to protect pavement subgrades from changes in water content. The data presented are the results of the laboratory and theoretical investigations. The practical problems of construction have not been completely evaluated at this date.

Figure 1 illustrates two possible applications of plastic water barriers. In the first case, the membrane is simply a capillary cut-off which extends across a fill and prevents moisture from moving upward into

the subgrade. This membrane is represented on the Figure by the dashed line. This installation would be applicable in areas of moderate rainfall and high ground water table. It would eliminate much of the problem of frost action as well as protect the subgrade from capillary water. The construction of such a water barrier would be simple and inexpensive. This is a promising use of the plastic films that would be particularly effective where highways cross wet areas on low fills. The bulk of this paper, however, will be concerned with a moisture barrier giving the all-around protection required in areas of greater precipitation where protection would also be required on the top and sides of the subgrade to prevent movement of water from the shoulders, ditches, and through the pavement. In this second case, a complete envelope would be necessary. The soil would be completely sealed on all sides, and the envelope would extend like a giant bag longitudinally under the pavement. This is indicated on the Figure by the heavy line around the enveloped sub-base.

This second application has the greatest potential uses of the two. It is especially promising under flexible pavements because they require greater thicknesses of base and sub-base materials than do rigid pavements. In this application, the enveloped subgrade soil would replace much of the required granular material and serve as the sub-base. Both plastic water barrier installations would greatly reduce the need for sub-drains.

Figure 2 compares a normal highway cross section with one incorporating a plastic water barrier envelope.

If an enveloped soil was used as the sub-base, the pavement thickness could be designed on the basis of the soil's as-compacted strength and

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not on the saturated strength as is the common practice now. Also, the effects of frost heave or swelling would be negligible. In both cases, the total thickness (T) would be equal, but for the enveloped case, only the thickness (S) would be select material as compared to the total thickness of select material in the normal design.

A plastic envelope would only be justified under a rigid pavement if some factor such as frost action, rather than strength, controlled the depth of sub-base, because rigid pavements do not depend on their sub-soils for the majority of their strength and usually require thin bases. Thick bases are normally used under Portland Cement concrete pavements only to protect against frost action or swelling.

This paper will be concerned primarily with the problems of the design and the economics of a flexible pavement incorporating a completely enveloped subgrade material as a sub-base. This condition is selected because it has possibly the widest application.

The points discussed will be the properties of the plastic films, the strength of enveloped soils, and the relative economics of envelopes versus granular sub-bases.

THE PLASTIC FILMS

Two types of plastic films were studied in this project: a vinyl and a polyethylene plastic. These are the same films that in the last few years have become so popular as raincoats, table cloths, food packages, and many other everyday objects.

The plastics have low permeabilities, are tough, and are highly resistant to nearly all forms of deterioration. They are not seriously affected by acids, alkalies, mold, or oxidation. Practically the only thing occurring in nature that will affect them is ultra-violet radiation from the sun, and this is no problem when they are buried under highways.

The plastic would be used in the form of manufactured sheets. They would not be sprayed onto the soil. This point is emphasized because it is often misunderstood that the plastic would be sprayed onto the subgrade as a liquid. The film would not be sprayed onto the soil because it is more expensive to process the plastic in a liquid form and because thicker films would be required to insure complete coverage without holes. The film thicknesses under consideration are from 4 to 8 thousandths of an inch.

The polyethylene films can be obtained in widths up to 32 feet. This offers an advantage over the vinyl films which are only manufactured in widths up to about 10 feet. The polyethylene is also less permeable than the vinyl. However, the vinyl film has one great advantage in that it has the greater resistance to puncture of the two types. Both films can be readily spliced by heat and pressure (heat sealing) or by special plastic adhesives. The cost of these films is approximately 10¢ per square yard.

FILM PERMEABILITY

Obviously in this study one of the most important properties of the films is permeability. A study of the movement of water through the films has shown that the term "permeability" as usually used in Civil Engineering is not applicable to these plastics. The term "permeability" is generally used in connection with the viscous flow of a fluid through a porous medium, but the films do not have sufficient pores to permit viscous flow and water can only move through them as individual molecules. Therefore, the permeation of the film is a form of vapor diffusion (1)*. This diffusion depends on the vapor pressure gradient across the film rather than on a hydraulic gradient as is the case for viscous flow.

The diffusion rates for the membranes were determined at several temperatures and vapor pressure gradients and were found to be very low for the films studied. This will be discussed in greater detail in later paragraphs.

* Numbers in parentheses refer to references in the Bibliography.

SOIL WATER

Although the diffusion rates for the films are low, long periods of time would be involved in a subgrade moisture barrier installation; therefore, to evaluate the effectiveness of the plastics as water barriers, it is necessary to predict the vapor pressure gradients which might actually be established across the film. This is a very difficult problem because all of the factors involved are constantly changing with time. For simplicity, an effort is made to predict only the worst possible condition and from this to determine the maximum rate of water movement through the membrane.

Since water can permeate the film only as a vapor and as a result of a vapor pressure gradient, the problem is one concerned with soil vapor pressure relationships. If a closed container is partially filled with water, evaporation will take place from the water surface and will continue until the vapor pressure in the atmosphere reaches a value at which evaporation and condensation are equal. This equilibrium vapor pressure is equal to the vapor pressure of a free water surface and depends only on temperature. If a moist soil were substituted for the water in the container, evaporation would again take place until equilibrium between evaporation and condensation were established. Equilibrium would occur in the second case at a lower vapor pressure because the forces holding the water to the soil would reduce the vapor pressure of the soil water surface below the value for a free water surface. The magnitude of this reduction in vapor pressure depends on the water content of the soil.

Therefore, if the relative humidity of the soil is defined as the ratio of the soil water vapor pressure to the vapor pressure of a free water surface at the same temperature, it has been found that a given soil will have a distinctive relative humidity versus water content curve (2).

Figure 3 is a typical soil relative humidity versus water content curve. This curve is for a silty clay. The curve for any soil would have a similar shape but would be shifted to the left for sands and to the right for clays. The actual values on this curve are not very important because they will vary depending upon the density and structure of the soil. However, the position of the various soil-water relationships on this curve is very important. The Atterberg Limits and the optimum water content for Standard Proctor Compaction all fall very high on the curve. Even the shrinkage limit occurs at a relative humidity in excess of 90%. For any normal soil condition, the relative humidity inside the envelope would always be almost as high as the relative humidity outside and diffusion would, therefore, be low.

The maximum vapor pressure outside the envelope would occur at complete saturation of the soil and would correspond to a relative humidity of 100%. The relative humidity of the soil inside the envelope as compacted would be approximately 99%. The vapor pressure difference across the film would then be only about 1% of the vapor pressure of a free water surface. For this very low pressure, diffusion would be negligible.

If the water were to become redistributed inside the envelope after construction, the gradient could be increased. The greatest movement within the envelope would occur under freezing conditions with the top

frozen and the bottom unfrozen. In this case, water would migrate upward to the frozen area, and the water content of the soil adjacent to the lower membrane would be decreased causing a corresponding decrease in relative humidity. Experiments conducted at the Corps of Engineers Frost Effects Laboratories (3) show that the soil water content in this lower unfrozen area could possibly be decreased to a value slightly below the shrinkage limit. If this condition existed in the envelope, the vapor pressure gradient across the film would correspond to a relative humidity difference of about 25% (100% outside, 75% inside).

Figure 4 shows the water transmission through the film plotted against temperature for the condition of 25% relative humidity difference across the film. This Figure shows that, at temperatures which might be encountered in the soil (below about 55) during freezing of upper layers, diffusion for polyethylene is negligible and for vinyl is less than 0.2 lb./ft.²/yr. It is evident that the maximum gradient set forth above could not exist 100% of the time since it requires a freezing condition. During the yearly temperature cycle, the gradient would vary from this maximum to a minimum of zero. Therefore, the maximum increase in water content of the enveloped soil would not exceed about 1% in 10 years for the vinyl, and for the polyethylene about 1% in 100 years. Thus, the films are seen to be very effective water barriers.

The previous discussion points out the possibility that some redistribution of the water within the enveloped soil might occur, causing a concentration of water in the upper part of the envelope. This increase in water content would be undesirable, because it would bring about a loss

of stability in the upper portion where stresses from traffic loads would be the greatest. The freezing studies by the Corps of Engineers mentioned before indicate that such moisture concentration will be small if the enveloped soils are initially compacted at less than about 80% saturation. If the enveloped soils are not subject to freezing, any water content practical for compaction can be used as far as moisture migration is concerned.

STRENGTH OF ENVELOPED SUB-BASE

The next question which arises is whether or not the soils to be enveloped can be compacted at less than 80% saturation to give satisfactory strengths without resorting to extraordinary compaction methods. To answer this question some method of evaluating the supporting capacity of the enveloped soils and of comparing them with non-enveloped soils is required. The California Bearing Ratio (CBR) procedure was selected for this purpose (4). The CBR value for enveloped sub-bases was obtained by testing the soils immediately after molding without soaking in water. This value was compared with the standard CBR values obtained after a 4-day soaking period.

Most flexible pavement design procedures specify a minimum thickness of bituminous surface and base course of material with a minimum CBR of 80%. For this analysis this minimum thickness of surface plus base course was selected as 6 inches over the top membrane of the envelope. From the Corps of Engineers CBR highway design curve (Figure 5) for a 9,000 wheel loading the CBR value requiring 6 inches of cover is equal to 25%. Therefore, to utilize the envelope method of construction to its fullest advantage, it is necessary to compact the enveloped soil so that it will have an unsoaked CBR of at least 25%. If this can be done, the total thickness of surface and base course required will not exceed the specified 6 inch minimum.

Two soils, a silty clay and a plastic clay, were tested and compaction and CBR curves obtained. A study of these data showed that compaction

of these soils to 95% of modified density at modified optimum water content resulted in unsoaked CBR values in excess of the required value of 25% and a degree of saturation less than 80%. From these results it was concluded that many of the more plastic soils can be satisfactorily compacted by standard methods to adequately serve as highway sub-bases when enveloped.

ECONOMICS

Assuming that the enveloped subgrade soil can be compacted to a design CBR of 25% or greater, the total required thickness of surface and granular material is 6 inches. Without the envelope, the total thickness of aggregate required is some finite value which is controlled by the soaked CBR of the subgrade. The amount of granular material replaced by the enveloped subgrade soil would be this total thickness minus 6 inches. For example, assume a soaked CBR of subgrade soil equal to 5%. Then, from the design curve the total pavement thickness required would be 16 inches. This thickness minus 6 inches equals 10 inches and is the thickness of granular sub-base material replaced. The relative economics of the two methods of design can be obtained by comparing the cost of 10 inches of suitable granular material in place with the cost of constructing a 10 inch thick envelope.

The cost of the plastic required per mile of 2-lane pavement is approximately \$3,500 to \$4,000. However, it is very difficult to predict accurately the cost of incorporating a plastic envelope into highway construction because some of the construction procedures have not been worked out in detail. However, some assumptions were made and estimates computed. These estimates are believed to be at least of the correct order of magnitude.

Figure 6 is a graphic representation of the comparison of the cost of normal and enveloped construction. The numbers on the vertical scale represent the cost of the granular sub-base being replaced in dollars per

cubic yard. A range of values is used instead of making the estimate for one specific case because the prices vary greatly from location to location, and by this method it can be seen whether or not the possibility of using plastic envelopes is economical for the prices prevalent in any specific area. On the horizontal scale, is shown the thickness in inches of granular material that is replaced by the enveloped subgrade. The curves are plots of points which represent savings of approximately 0, 5, or 10 thousand dollars per mile of 2-lane pavement, as indicated on each curve. The shaded area represents conditions where the envelope method of construction would never be economically justified. To use this curve, it is necessary to know the cost of the granular sub-base and the thickness that could be replaced with protected subgrade material.

For convenience, the values of CBR of subgrade and Freezing Index (5) are given on the graph for their appropriate saving in granular material. For example, again referring to a CBR equal to 5%, it is remembered that the savings were 10 inches of base; therefore, in the construction of Figure 6, CBR of 5% was placed directly under the thickness of 10 inches. The other values of CBR were placed in a similar way. The same general scheme is followed with the Freezing Index (FI). To illustrate, assuming FI equals 500 degree days, a total pavement thickness of 20 inches is necessary to prevent freezing of the subgrade. This total thickness of 20 inches minus 6 inches for surface and base course leaves 14 inches of granular sub-base replaced; note that the freezing index of 500 is located directly under the thickness of 14 inches. With this information, it is no longer necessary to compute the thickness saved. The CBR or FI, whichever controls the design, can now be used directly.

To use this chart, simply read up from the soaked CBR of the soil (or freezing index of the location). The horizontal scale of the graph paper gives the thickness of base saved (actual thickness of enveloped soil required). Proceeding up to the cost of base material gives the savings in cost.

As a further example, assume that temperature records for a given site indicate a freezing index of 400 degree days and a soaked CBR soil of 3%. From Figure 6, on the basis of freezing index the thickness saved is 12 inches, while for a soaked CBR of 3% the saving is about 14 inches. For this case the latter is the critical value and the enveloped pavement design would be 14 inches of enveloped soil plus 6 inches of base and surface. If the base cost \$3.00 per cubic foot, the enveloped soil design would be about \$6,000 per mile cheaper than one using no envelope.

From this figure, it is possible to establish the general range of economic applicability of plastic envelope moisture barriers. It is seen that if frost action or volume change are not important factors the envelopes are only economical for use with soils which have soaked CBR values less than about 6% or 8% or when sub-base materials are very expensive. However, when frost action is important, this chart shows there would be an appreciable saving whenever the Freezing Index exceeds about 400. This is the approximate value for the northern part of Indiana. Also, there are large areas of highly expansive soils in some of the southern states which require pavements at least 18 inches thick to give sufficient confining pressures to prevent excessive volume change of the

subgrade soils. In this case, subtracting 6 inches for surface and base leaves a 12 inch saving by the use of plastic water barriers, and going into the figure for 12 inches of granular material replaced gives large savings even at relatively low sub-base prices.

In the preparation of Figure 6, no allowance was made for savings from the reduction of sub-drains required. The cost of sub-base construction for the two designs was the only item considered.

CONCLUSION

From the previous discussions, it is apparent that there are areas in the United States which have problems arising from changes in the water contents of highway subgrade soils and that these problems could in many cases be economically solved by the use of plastic moisture barriers. Admittedly there still remain some unsolved problems but it is felt that the results to date justify continued research on these problems; consequently, at the present time plans are being made to continue the study with the construction of a full-scale field test this summer.

The results of this field test will be made available at some future date. Final recommendations will be made at that time.

FIG. 1 PAVEMENT CROSS SECTION WITH
PLASTIC MOISTURE BARRIERS

Not to scale

FIG. 2 COMPARISON OF NORMAL AND ENVELOPED SECTIONS

FIG. 3 RELATIONSHIP BETWEEN SOIL
RELATIVE HUMIDITY AND WATER CONTENT

FIG. 4 WATER TRANSMISSION VS TEMPERATURE FOR VINYL AND POLYETHYLENE PLASTIC FILMS

FIG. 5 FLEXIBLE PAVEMENT DESIGN
CURVE FOR HIGHWAYS.
9000 LB. WHEEL LOAD

FIG. 6 APPROXIMATE SAVING FROM USE OF ENVELOPED SUBBASE

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