

**RECONSTRUCTION OF RIGID PAVEMENTS
USING
ASPHALT PAVEMENT ALTERNATIVES**

**THE MICHIGAN ASPHALT PAVING ASSOCIATION
(MAPA)**

Final Report

Submitted by

**Gilbert Baladi, Ph.D., P.E.
Professor of Civil Engineering
Director, Pavement Research Center of Excellence
Michigan State University**

November 27, 1998

Table of Contents

Topic	Page
Executive Summary	2
1.0 INTRODUCTION	3
2.0 PURPOSE	4
3.0 DEFINITIONS	5
3.1. Pavement Components	5
3.2. Pavement Structure	6
3.3. Pavement Serviceability	6
3.4. Pavement Performance	7
3.5. Pavement Behavior	7
3.6. Structural Capacity	7
3.7. Pavement Distress	9
3.8. Rigid Pavements	9
3.9. Flexible Pavements	9
3.10. Composite Pavements	10
4.0 THE MICHIGAN RIGID PAVEMENT NETWORK	10
4.1 Rigid Pavement Sections for Non-Frost Susceptible Subgrade Soil	10
4.2 Rigid Pavement Sections for Frost Susceptible Subgrade Soil	10
5.0 RIGID PAVEMENT RECONSTRUCTION OPTIONS	16
5.1 Pavement Design Issues	16
5.1.1 Environment	16
5.1.2 Load and Materials	18
5.1.3 Cost	19
5.1.4 Quality of Construction	19
6.0 DESIGN ALTERNATIVES FOR THE RECONSTRUCTION OF RIGID PAVEMENT TO FLEXIBLE PAVEMENT	20
6.1 Reconstruction of Rigid Pavements Situated on OGDC – Flexible Pavement Structural Design Alternatives	22
6.2 Reconstruction of Rigid Pavements Situated on OGDC with Geotextile Separator - Flexible Pavement Structural Design Alternatives	25

Table of Contents (continued)

Topic		Page
6.3	Reconstruction of Rigid Pavements Situated on Dense Graded Aggregate Base and Sand Subbase - Flexible Pavement Structural Design Alternatives	28
6.4	Reconstruction of Rigid Pavements Situated on Frost Susceptible Soil - Flexible Pavement Structural Design Alternatives	32
7.0	RECOMMENDATIONS	32
8.0	SUMMARY	34
	REFERENCES	35

**RECONSTRUCTION OF RIGID PAVEMENTS
USING
ASPHALT PAVEMENT ALTERNATIVES**

**THE MICHIGAN ASPHALT PAVING ASSOCIATION
ASSOCIATION
(MAPA)**

Final Report

Submitted by

**Gilbert Baladi, Ph.D., P.E.
Professor of Civil Engineering
Director, Pavement Research Center of Excellence
Michigan State University**

November 27, 1998

RECONSTRUCTION OF RIGID PAVEMENTS USING ASPHALT PAVEMENT ALTERNATIVES

Executive Summary

At a reasonable cost that the public is willing to support, the highway pavement systems could not be engineered to last forever. They deteriorate and disintegrate at an accelerated rate, which forces State Highway Agencies (SHAs) to continually maintain, rehabilitate, redesign and reconstruct the systems. This can be accomplished by using various design alternatives of two types of pavements, asphalt and concrete. Each alternative is typically evaluated based on costs and benefits prior to the final pavement type selection. This report presents asphalt pavements design alternatives, which may be used for the replacement of concrete pavements at the end of their design lives.

Several basic principles govern the design and construction of asphalt and concrete pavements. These include:

- Equal protection of the roadbed soil against frost heave, which can be achieved by providing appropriate section thickness.
- Good structural capacity to carry the design traffic without excessive deformation and/or failure.
- Reasonable safety margin.
- Rational cost that the public is willing to support.

A large percent of the concrete pavement network in the State of Michigan has reached its design life and recently is

being subjected to major rehabilitation or reconstruction. Based upon the frost Susceptibility of the roadbed soil and construction time, four concrete pavement sections can be found. Two sections that are shown in figures 2 and 3 were built on non-frost susceptible soils after the early 1980's, one section (shown in figure 4) was built on non-frost susceptible soil prior to the early 1980's and one section shown in figure 5 was built on frost susceptible soil. Two of these sections provides good protection (30-inch or more cover) of the roadbed soil against frost damage. The other two concrete sections provide less than 30-inch cover of the roadbed soil. Since, frost protection applies equally to both concrete and asphalt pavements, the latter two concrete pavement sections can be considered somewhat deficient.

For each of the existing four concrete pavement sections, three alternatives asphalt pavements were designed using the AASHTO and mechanistic-based design procedures. The results are presented in figures 7 through 13. It is shown that each of the asphalt pavement alternatives provides good protection of the roadbed soil against frost damage and adequate capacity to carry the design traffic loads and volumes of 5, 20 and 30 million ESAL.

RECONSTRUCTION OF RIGID PAVEMENTS USING ASPHALT DESIGN ALTERNATIVES

1.0 INTRODUCTION

The highway systems in the United States and most of the industrialized world represent the single largest investment ever made in the history of these nations. Modern highway systems are a necessity that a nation must utilize in order to thrive or advance. In the underdeveloped world, the lack of modern and efficient transportation systems to move people and goods represents a major obstacle in their development. Without efficient and modern transportation systems, farm products spoil in fields and industrial goods remain in the factories.

The engineering and construction of a road system must be based on one objective, make the highway functional. This can be accomplished, if and only if, the highway system is designed and constructed to provide:

- Safe and easy access to the users.
- Adequate capacity to handle traffic demand.
- Good structural capacity to carry the anticipated traffic load without excessive deformation and/or failure.
- Good protection of the roadbed soil against frost damage.

Unfortunately, as is the case with any natural or manufactured products, highway systems cannot be made to last forever. They deteriorate and disintegrate at an accelerated rate. Hence, they must be properly and continually maintained, rehabilitated, redesigned and reconstructed. A constant flow of money (estimated around \$80 to 100 billion in the U.S.) is required on an annual basis to keep existing highway pavements operating in safe and acceptable conditions. This sum of money, however small as a percentage of the nation's gross national product, is not available to the highway agencies. Lack of funds, coupled with a high public demand to repair the highway systems, makes the highway engineer's job a difficult one. The problem is further compounded by several other factors including:

- The variability of the material properties that make up the highway pavements.
- The number of available alternatives for repair and their associated costs.
- The number of miles and the different classes of the highway pavements that are in need of repair.
- The increasing traffic volume and load (1 - 9)

In lieu of these factors, several important questions must be properly addressed. These are:

- What design and/or pavement fix alternative to use?
- How many miles to fix?

- When and where (time and space) pavement repair should be undertaken?
- How can one stretch the available dollars to cover as many miles as possible and yet maximize the benefits for a given cost?

The answers to these questions cannot be obtained unless all available alternatives are analyzed, engineered, and compared to provide effective solutions. One of the feasible alternatives that can be applied when a rigid pavement is deteriorated beyond a predetermined threshold value is to redesign and reconstruct the pavement as a flexible pavement. This report presents several design alternatives of flexible pavements that would replace existing rigid pavements.

2.0 PURPOSE

Highway pavements can be constructed as flexible (asphalt), rigid (concrete) or composite. In the State of Michigan, the rigid pavement network consists of five sections depending on the type of subgrade soil (frost versus non-frost susceptible soils) and the type of separator course (dense aggregate base or geotextile). Because of their state of distress, rehabilitation of some of the pavement sections is not a cost-effective option. Hence, reconstruction is the preferred alternative.

An existing rigid pavement can be reconstructed as flexible, rigid or composite pavement. In Michigan, pavements are typically constructed as flexible or rigid. A pavement may become composite by default through rehabilitation work.

The design and construction of a pavement structure must address various engineering problems including the pavement structural capacity and the protection of the subgrade soil against frost damage.

The purpose of this report is to present flexible pavement design alternatives that would replace existing rigid pavement sections. Each design alternative is based on empirical (the AASHTO design) and Mechanistic-based procedures. Hence, all design alternatives meet the ride quality standards (the AASHTO method) and fatigue life and rut standards (mechanistic-based design).

During the analysis and design of each alternative, several factors were considered including:

- The pavement sections must provide protection of the subgrade soil against frost action.
- The pavement sections must possess adequate structural capacity to serve the traffic over the estimated design life.
- Existing bridge clearances must be maintained.

- Increasing elevation of the pavement surface requires increasing the width of the embankment. Hence, the cost of extending culverts, cross drains, and other elements must be included in the overall cost of the alternative.

This report uses several terms that may or may not be clearly understood by some readers. Hence, these terms are defined in the next section.

3.0 DEFINITIONS

Several definitions concerning technical terms like pavement, pavement components, pavement types, and others, exist throughout the literature. In this report, the MDOT or the AASHTO (12) definitions are used when applicable. These definitions are presented below.

3.1. Pavement Components

The number of pavement components varies with the type and class of the pavement. Furthermore, in many situations, the natural roadbed soil may receive treatment (compaction, stabilization, or both) before, during, or after construction. Pavement components include roadbed soil, subgrade, subbase, base and surface layer.

Roadbed – The AASHTO Design Guide defines roadbed soil as “the graded portion of a highway between top and side slopes, prepared as a foundation for the pavement structure and shoulder.”

Roadbed Material – The AASHTO Design Guide defines the roadbed material as “the material below the subgrade in cuts and embankments and in embankment foundations, extending to such depth as affects the support of the pavement structure.”

Subgrade – The AASHTO Design Guide defines the subgrade as “the top surface of a roadbed upon which the pavement structure and shoulder are constructed.”

Selected Material – The AASHTO Design guide defines selected material as “a suitable native material obtained from a specific source such as a particular roadway cut or borrow area, of a suitable material having specified characteristics to be used for a specific purpose.”

Subbase – The AASHTO Design Guide defines the subbase as “the layer or layers of specified or selected material of designed thickness placed on a subgrade to support a base course (or in the case of rigid pavements, the portland cement concrete slab).”

Base – The AASHTO Design Guide defines base “the layer or layers of specified or selected material of designed thickness placed on a subbase or a subgrade to support a surface course.”

Surface course – The AASHTO Design Guide defines a surface course as “one or more layers of a pavement structure designed to accommodate the traffic load, the top layer of which resists skidding, traffic abrasion, and the disintegrating effects of climate. The top layer of flexible pavements is sometimes called wearing course.”

Frost heave – The Michigan Department of Transportation defines frost-textured material as “Material containing more than 50 percent silt particles by weight, with a plasticity index less than 10. Silt is defined as material having a particle size of 0.075 to 0.002 mm.” The AASHTO soil classification that meets such definition is A-4.

The term “frost susceptible soil” is a relative term. According to the US Corps of Engineers, the term includes all inorganic soils that contain more than 3 percent by weight particles finer than 0.02 mm. The Corps of Engineers have divided soils into four categories relative to their frost susceptibility. Group 1, which is the least frost susceptible, includes all gravelly soils with 3 to 20 percent passing the 0.02-mm sieve. Group 4, the most frost susceptible soils, includes all silts, silty sands, lean clays and varved clays. Since frost damage depends greatly on the amount of water available to freezing, one can generalize that a frost susceptible soil is any type of soil that has high water holding capacity and relatively low permeability.

3.2 Pavement Structure

A pavement structure is a combination of subbase, base, and surface courses placed on a subgrade to support the traffic load and distribute it to the roadbed. Hence, the term "pavement structure" does not include the subgrade soil.

3.3 Pavement Serviceability

Pavement serviceability is the ability, at time of observation, of a pavement to serve traffic (autos and trucks) which use the facility. This definition indicates that the pavement serviceability is a subjective pavement-rating scheme that depends on the opinion of the individual user of the pavement. The numerical value assigned to the pavement serviceability is called the pavement serviceability rating (PSR).

The PSR is a subjective concept first developed by Carey and Irick at the AASHO road test (7). The PSR is based upon a rating scale that varies from one country to another. For example, the scale in USA ranges from 0.0 to 5.0 (5.0 indicates a perfect pavement); the scale in Canada ranges from 0.0 to 10.0 (10 is the best). The subjective value of PSR of a pavement section is the numerical average rating determined by a panel of individuals who ride the pavement in question and independently rate it.

At the AASHO road test, PSR was correlated to objective measurements made on the pavement surface, which included a measure of roughness index, extent of cracking and patching, and for flexible pavement, the average rut depth in the wheel tracks (1, 5). This

important development allowed the engineer to compute a present serviceability index (PSI) that objectively predicts the subjective PSR. Equations 1 and 2 were developed at the AASHO road test for flexible and rigid pavements, respectively.

$$\text{PSI} = 5.03 - 1.91 \log (1 + \text{SV}) - 1.38 (\text{RD})^2 - 0.01 (\text{C} + \text{P})^{1/2} \quad (1)$$

$$\text{PSI} = 5.41 - 1.78 \log (1 + \text{SV}) - 0.09 (\text{C} + \text{P})^{1/2} \quad (2)$$

Where: log = logarithm (base 10);
 SV = slope variance;
 RD = average rut depth;
 C = length of class 2 and 3 cracking per 1000 ft²; and
 P = area of patching per 1000 ft².

It should be noted that many engineers use only the SV term obtained from the measurement of the longitudinal roughness to calculate PSI. The other terms (C, P, and RD) have negligible effects on the accuracy of the equations.

3.4 Pavement Performance

Pavement performance is the assessment of how well the pavement serves the user over time. The engineer often associates pavement condition with an arbitrary, but quantifiable, value relating to pavement roughness, pavement distress, or pavement strength. Performance is the measured change of condition and/or serviceability over increments of time. Hence, pavement performance may be measured by the integration of equation 1 or 2 with respect to time (i.e., it is measured by the area between the threshold value and the pavement condition curve as shown in figure 1). Relative to figure 1, each curve represents one pavement section. It can be seen that the service life of both pavements is the same (about 16.5 years). Yet, the performances of the pavements are quite different. The challenge to the pavement engineers and to the paving industry is to maximize the pavement performance while keeping the cost at a constant level. Nevertheless, it should be noted that a growing number of engineers feel that the proper measure of pavement performance should also include pavement distress, structural capacity (pavement strength), and safety (1).

3.5 Pavement Behavior

Pavement behavior is defined as the direct response of a pavement section to the wheel load (1, 5). Pavement behavior can be directly measured using nondestructive deflection tests (NDT). During the tests, the pavement deflection can be measured under traveling or simulated wheel loads. Pavement deflection data can be used to estimate the structural capacity of the pavement, assess the variability of the pavement structure, and backcalculate the pavement layer moduli.

3.6 Structural Capacity

The structural capacity of a pavement is defined as the ability of the pavement section to carry the design load without failure or excessive deformation. The structural capacity of

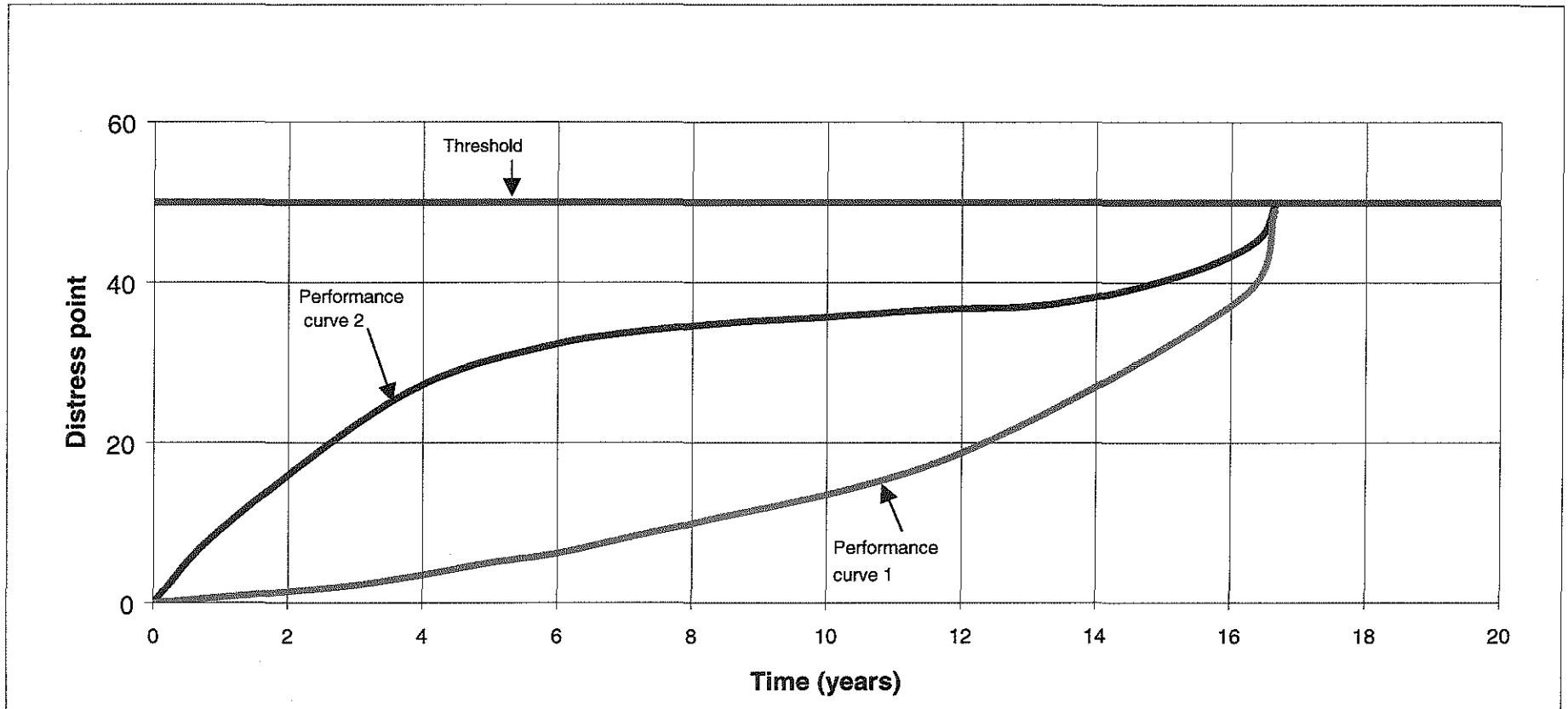


Figure 1. Pavement condition in terms of distress points versus time.

a pavement section is a function of the strength of the individual layers and the global strength of the pavement section. Two types of tests can be used to assess the structural capacity of the pavement, destructive and nondestructive.

1. Destructive or direct measurement by sampling such as coring and laboratory testing.
2. Nondestructive or indirect measurement using one or more of the nondestructive testing (NDT) devices such as the Benkelman beam, falling weight deflectometer, and plate load test. The deflection data can be used for backcalculation the layer moduli. It should be noted, however, that measurement of the deflection basin (not deflection at a single point) is required in order to obtain relatively accurate information concerning the different pavement layers (9, 10). As noted above, NDT can also be used to assess the variability of the pavement structure.

3.7 Pavement Distress

Pavement distress is defined by any condition that adversely affects pavement functions. Pavement distress is measured using pavement condition survey (the survey can be visual or automated such as in video taping). During the survey, each type of observable distress (e.g., cracks, rut depth) is noted and assigned a value based upon its severity, extent, and frequency. Later, a distress index (DI) or a pavement condition index (PCI) is calculated as an indicator of the pavement distress.

3.8 Rigid Pavements

The AASHTO Design Guide defines rigid pavements as "pavement structures which distribute loads to the subgrade, having as one course portland cement concrete (PCC) slabs of relatively high bending resistance." The term "rigid pavements" includes:

1. Jointed plain concrete pavement (JPCP).
2. Jointed reinforced concrete pavement (JRCP).
3. Continuously reinforced concrete pavement (CRCP).
4. Prestressed concrete pavement (PCP).

In general, rigid pavements have base and/or subbase courses although some rest immediately on improved subgrade soils. The function of the base course is to enhance water drainage or to be used as a construction platform or both. The strength of rigid pavements is derived mainly from the concrete layer, which is considered to carry the load in bending.

3.9 Flexible Pavements

The AASHTO Design Guide defines flexible pavements as "pavement structures which maintain intimate contact with and distribute loads to the subgrade and depends on aggregate interlock, particle friction, and cohesion for stability." Flexible pavements are built in layers. The strength of each layer typically increases toward the surface course, which is made of asphalt concrete or of an asphalt treated granular materials. Therefore, the strength of the pavement structure is affected by the strength of each layer, including the roadbed. Flexible pavements are considered to support the applied load by spreading action

(distributing the load from the strong upper layer, the asphalt course, to the lower and weaker layers, the subgrade soil).

3.10 Composite Pavements

The AASHTO Design Guide defines composite pavements as “pavement structures composed of an asphalt concrete wearing surface and Portland cement concrete slab; an asphalt concrete overlay on a PCC slab is also referred to as a composite pavement.”

4.0 THE MICHIGAN RIGID PAVEMENT NETWORK

The design of rigid pavements in the State of Michigan has changed over time based on experience and observations of pavement performance. Prior to the early 1980's, most rigid pavements were built using two standard cross-sections. One section was used in areas where frost susceptible subgrade soils are found and the other was designated for non-frost susceptible subgrade soil. In the early 1980's, the standard cross-section for the non-frost susceptible subgrade soil was changed and an Open graded drainage course (OGDC) was added. The pavement section for the frost susceptible subgrade soil remained the same. Hence the existing rigid pavement network in the State of Michigan consists of 5 different cross-sections: three sections for the non-frost susceptible subgrade soil and two sections for the frost susceptible subgrade soil.

It is very important to note that the terms “frost susceptible and non-frost susceptible soils” are relative terms. All soils (clay, silt, sand and aggregate” will be subjected to frost and heave damage if water is allowed to accumulate in those soils. Hence, the importance of proper drainage cannot be overemphasized.

4.1 Rigid Pavement Sections for Non-Frost Susceptible Subgrade Soil

For non-frost susceptible subgrade soils, three rigid pavement sections can be found in the State of Michigan. These are:

1. Pavement sections, which were built after the early 1980's. Two alternatives can be found as shown in figures 2 and 3.
 - a) The first alternative (see figure 2) consists of 12-inch of sand subbase, 4-inch of dense graded base separator, 4-inch of Open graded drainage course (OGDC), and concrete whose thickness varies and depends on the design ESAL.
 - b) The second alternative (see figure 3) is similar to the first one except that a geotextile separator replaces the 4-inch dense graded base separator.

2. Pavement sections, which were built earlier than the early 1980s. As shown in figure 4, the section consists of 10-inch of sand subbase, 4-inch of aggregate base, and a concrete surface course whose thickness varies depending on the design ESAL.

4.2 Rigid Pavement Sections for Frost Susceptible Subgrade Soil

Rigid pavement sections located on frost susceptible subgrade soils did not change over time. Figure 5 shows the standard rigid pavement cross-section used on frost susceptible subgrade soils. The practice of the Michigan Department of Transportation calls for:

1. Cutting the subgrade soil by 24-inch and replacing it by an engineered class 2 sand backfill with underdrain.
2. Placing 12-inch of compacted sand on top of the 12-inch class 2 - sand backfill.
3. Placing 4-inch dense graded base separator or geotextile.
4. Placing 4-inch Open graded drainage course (OGDC).
5. Placing the appropriate concrete thickness depending on the design ESAL.

Some of the older concrete pavement sections have reached the end of their potential service lives and they are targeted for reconstruction. The reconstruction options include:

The reconstruction of existing rigid pavement sections into flexible or rigid sections involve the analysis and design of the new sections. Such design and analysis could be accomplished under several scenarios including:

1. The existing aggregate base and/or the sand subbase are damaged and need to be reconstructed. Hence, the analysis and design are not restricted by the thicknesses of the existing materials.
3. The existing sub-drains are damaged and need to be replaced. This requires that the outside borders of the existing embankment (sand subbase and aggregate base) be excavated. The rest of the embankment can be used to support the new pavements.
4. The existing pavement cross-section does not provide adequate cover against frost protection. Hence the total thickness of the pavement must be increased. This may not be possible when bridge clearance is restricted. For this, removing the entire sand subbase and aggregate base and undercutting the subgrade soil becomes a viable option. In addition, increasing the total pavement thickness may require the widening of the embankment and extension of culverts and cross drains. It should be noted that this scenario applies equally to new rigid and flexible pavements.
5. The existing sand subbase and aggregate base are in good condition. In this case, the structural design can be accomplished by utilizing the existing materials.

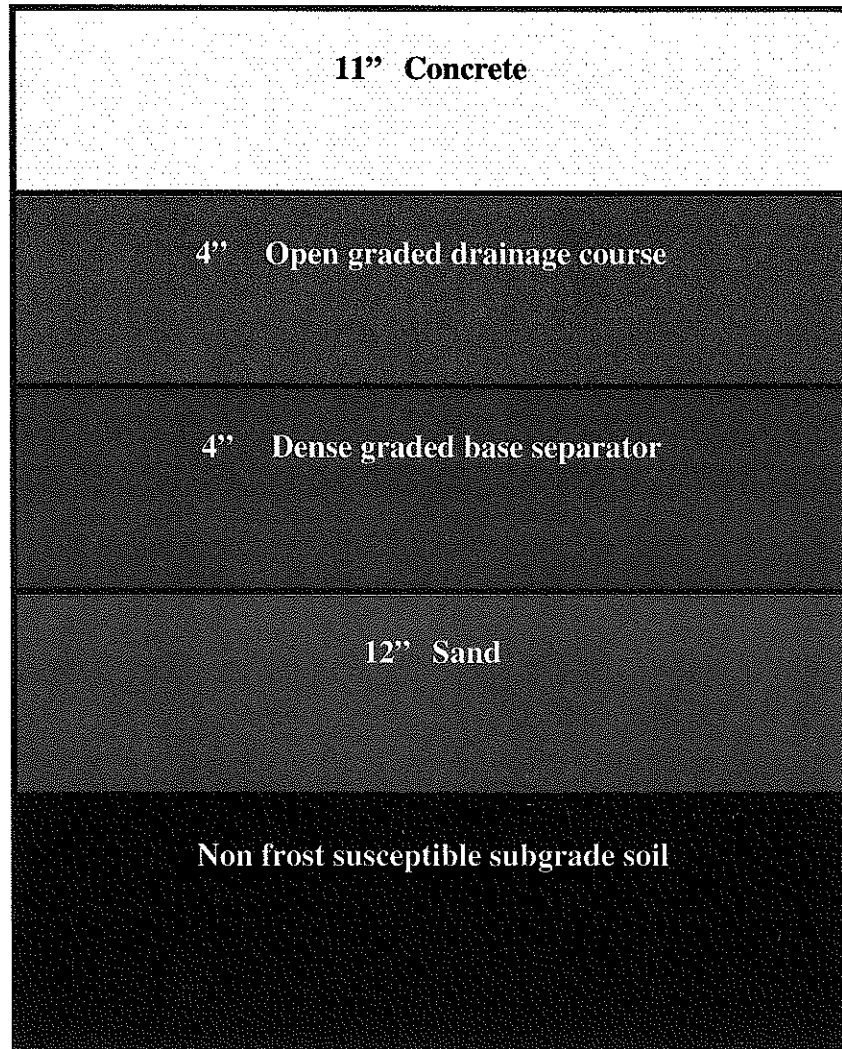


Figure 2. Standard rigid pavement cross-section with an OGDC option used by MDOT since the early 1980's.

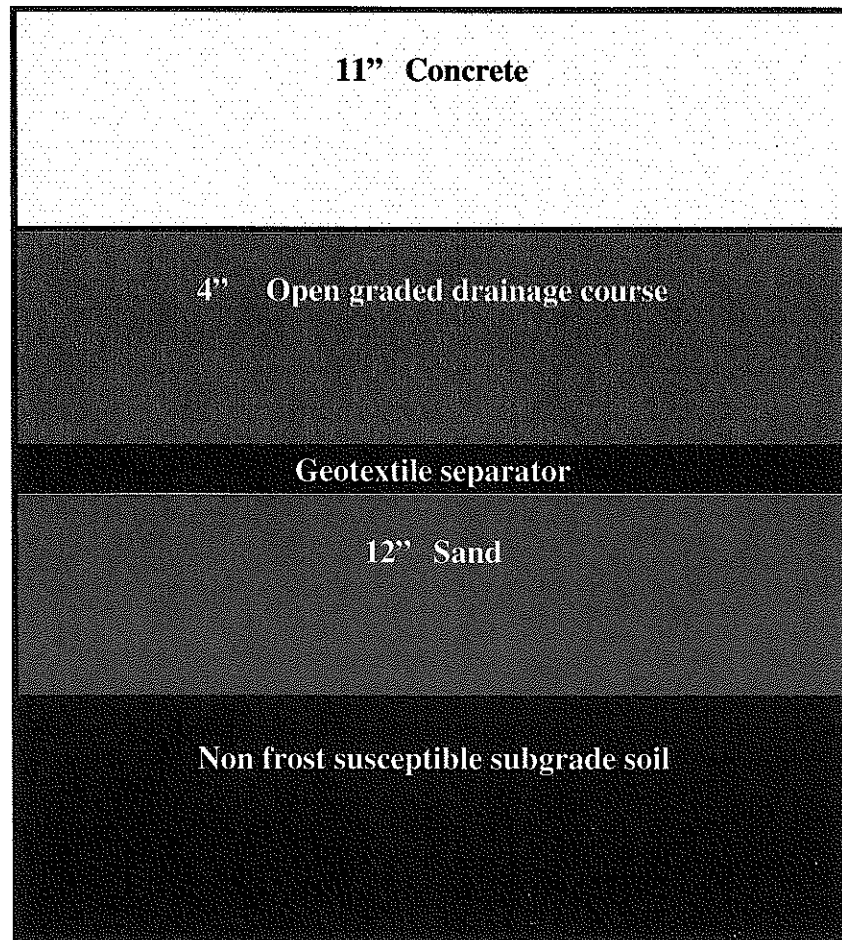


Figure 3. Standard rigid pavement cross-section with a geotextile separator option used by MDOT since the early 1980's.

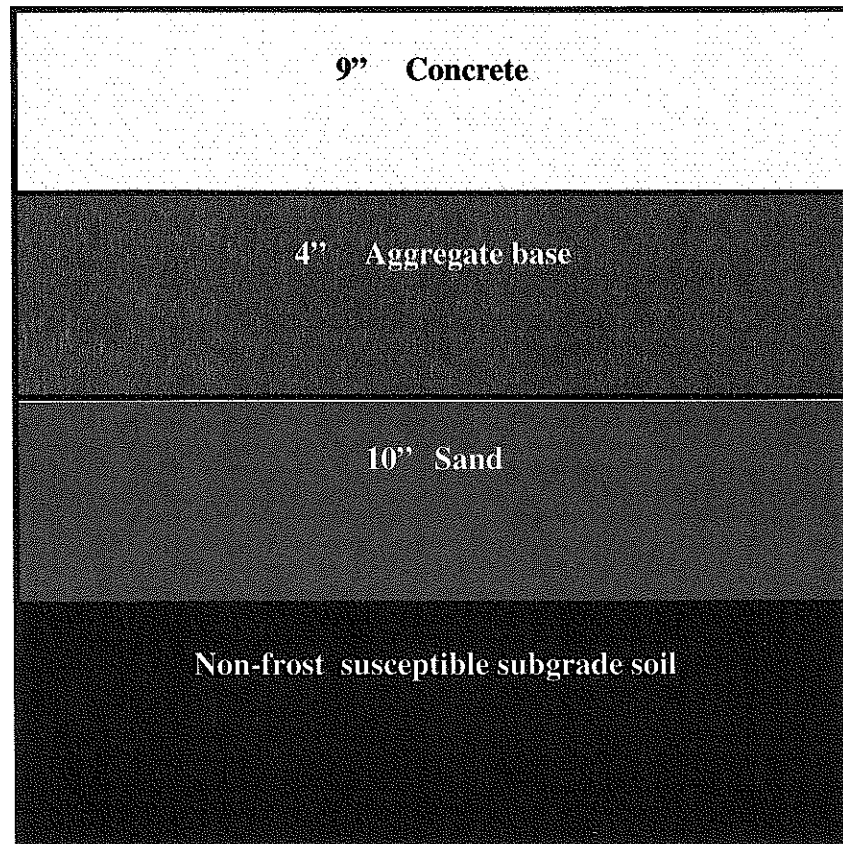


Figure 4. Standard rigid pavement section for non-frost susceptible subgrade soil (Michigan practice prior to the early 1980's).

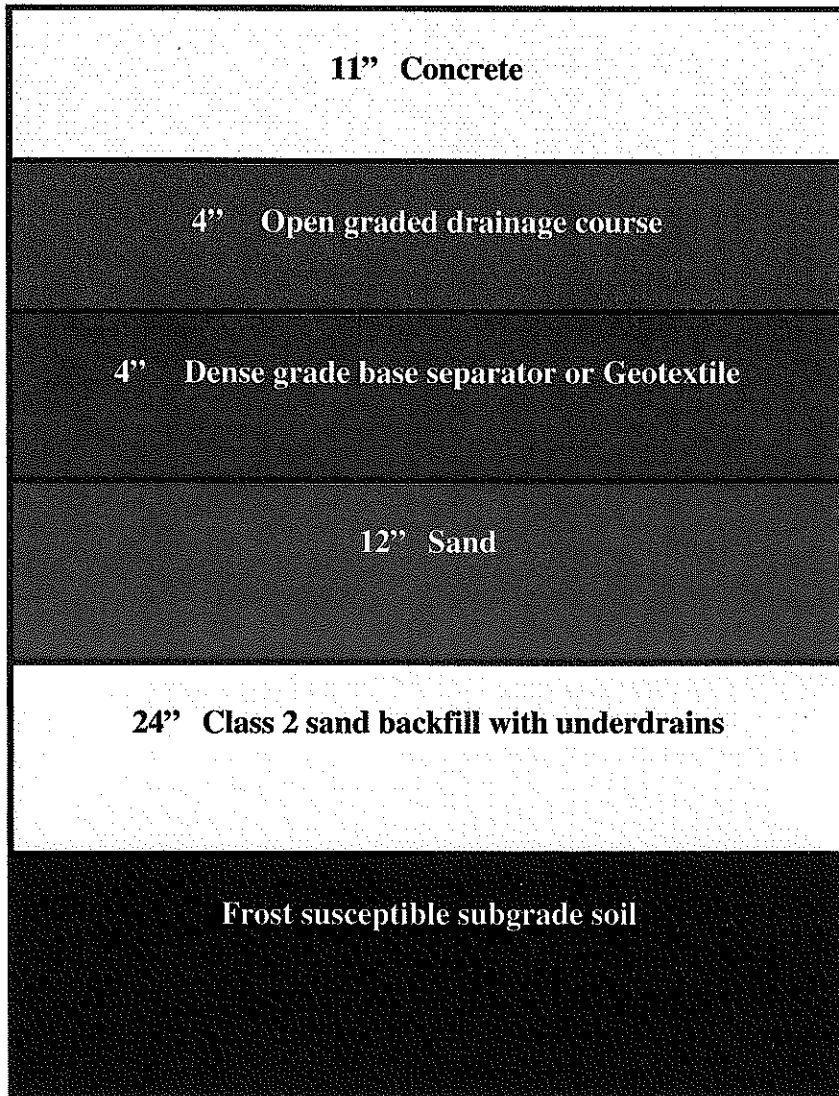


Figure 5. Standard cross section for rigid pavements located on frost susceptible soil.

In the next sections, the design of flexible pavement alternatives for the replacement of rigid pavements are presented and discussed. The design and discussion are centered on two issues:

1. The structural design of the flexible pavements. The design was conducted using two procedures: empirical and mechanistic. Each alternative pavement section was designed using the AASHTO procedure. The resulting section was then analyzed using two mechanistic-based computer programs: MICHPAVE and the Shell method.
2. The frost protection of the subgrade soil. In this regard, it should be noted that the total thickness of the pavement structure that is required to protect the subgrade soil from frost damage is the same for both flexible and rigid pavements.

5.0 RIGID PAVEMENT RECONSTRUCTION OPTIONS

As stated earlier, pavements deteriorate with time and increasing traffic weight and volume. Preventive maintenance options may decelerate the rate of deterioration. When the pavement reaches certain distress condition, the pavement may be rehabilitated using one of the rehabilitation options stated in the MDOT Pavement Preservation Guide. At some time, engineering assessment of the pavement condition and the cost and benefits of pavement rehabilitation may dictate a reconstruction option.

Rigid pavements can be reconstructed to rigid (RR) or to flexible (RF) pavements as shown in figure 6. The upper case letters in the pavement preservation code indicate pavement type. The first letter indicates the existing pavement (R = rigid, F = flexible, and C = composite) while the second letter (R, F or C) indicates the pavement type after rehabilitation or reconstruction.

In this report, engineering assessment of the reconstruction of rigid pavement (R) to flexible pavement (F), and flexible pavement design alternatives and issues are presented and discussed.

5.1 Pavement Design Issues

During the design and reconstruction of pavement structures, several issues must be addressed. These include environment, load, materials, costs, and quality of construction.

5.1.1 Environment

Environmental factors such as rainfall, snowfall, freezing and thawing, and the elevation of ground water table play a major role in pavement performance. The most important of these factors is the temperature. Temperature affects flexible

Existing Pavement Type	Future Pavement Type, Preservation Actions					
	Rigid					
	Preventive Maintenance	Rehabilitation/ Overlay	Reconstruction	Preventive Maintenance/ Maintenance	Preventive Maintenance/ Rehabilitation	Preventive Maintenance/ Reconstruction
Rigid	1RR-01 to 1RR-07	2RR-01 2RR-02	3RR-01 3RR-02	4RR-01 to 4RR-05		
Flexible		2FR-01 2FR-02	3FR-01 3FR-02			
Composite		2CR-01 to 2CR-03	3CR-01 3CR-02			
	Flexible					
Rigid		2RF-01 2RF-02	3RF-01 3RF-02 3RF-03			
Flexible	1FF-01 to 1FF-17	2FF-01 to 2FF-07	3FF-01 to 3FF-05	4FF-01 to 4FF-06	5FF-01 to 5FF-06	6FF-01 6FF-02
Composite	1CF-01	2CF-01 2CF-02	3CF-01 to 3CF-03			6CF-01 6CF-02
	Composite					
Rigid		2RC-01			5RC-01 to 5RC-06	
Flexible						
Composite	1CC-01 to 1CC-13	2CC-01 2CC-02		4CC-01 to 4CC-05	5CC-01 to 5CC-12	

Figure 6. Pavement preservation options – MDOT practice (1).

pavements in three ways, freezing and thawing, expansion and contraction, and softening and hardening of the asphalt mix. Moisture in pavements along with sub-freezing temperatures causes heave in winter and subsidence in the spring. These vertical and uneven movements decrease the service life of the pavement.

Using good pavement design and construction practices can minimize the effects of freezing and thawing on pavement performance. Such practice must include the prevention of water from freezing by removing it or providing adequate cover thickness.

The problem can be solved by:

1. Providing the proper drainage elements such as subdrain to **remove the water before it freezes.**
2. Providing adequate cover thickness to **prevent the subgrade soil from freezing.** Since, on the average, subgrade soils have relatively low permeability, it must be protected from freezing.

Lowering the freezing temperature by additive such as sodium chloride to **prevent the subgrade soil from freezing.**

5.1.2 Load and Materials

Pavement structures must provide good ride quality, must protect the subgrade soil from freezing, and must possess good structural capacity to prevent excessive deformation and shear failure. The ride quality can be easily achieved by smoothing the surface of the wearing course (construction quality). The protection of the subgrade soil from freezing, excessive deformation and shear failure can be achieved by providing adequate structural capacity and total thickness. The structural capacity of any pavement layer is a function of the material type, the layer thicknesses and construction quality. Hence, during the design process, the required thickness of each pavement layer must be carefully determined as to ensure the proper protection of the subgrade soil at reasonable cost.

To summarize, several issues must be addressed during the pavement design process. These are:

1. **Providing adequate layer thicknesses to assure protection of the roadbed soil from frost action.**

2. Providing good structural capacity to resist excessive deformation and shear failure.

5.1.3 Cost

Pavements can be designed in various ways, constructed using different materials (e.g., asphalt, concrete, river gravel, crushed stones, etc.) and built using various quality control measures. Each of the above alternatives affects the pavement cost and performance. A good pavement design, pavement type selection, and construction practices dictate that for the same cost (available budget), the alternative that yields the highest pavement performance to life cycle cost ratio be selected. The adequacy of such selection depends to a large extent on the accuracy of the cost data and the assumed pavement maintenance and rehabilitation schedules.

One very important point should be noted is that, regardless of the quality and integrity of the pavement design process, pavement construction could employ detrimental methods that adversely affect pavement performance. Hence, construction technicians must be aware of the impacts of their action upon pavement performance. For example, segregation of the hot asphalt mix may cause premature pavement failure or several pavement defects such as raveling, rutting, cracking and stripping. Hence, in general, segregation lowers the pavement performance substantially. Careful and well-balanced construction practice would likely eliminate segregation.

5.1.4 Quality of Construction

As stated above, construction practices can have detrimental effects on pavement performance. This can be illustrated by several examples.

1. Segregation of the asphalt mix during the paving operation causes various problems including raveling. Hence, segregation of the mix causes substantial reduction in the pavement life and performance.
2. Untimely sawing of pavement joints may cause premature transverse and longitudinal cracking.
3. The over compaction of a cool asphalt mat causes micro cracking.
4. Insufficient compaction of the asphalt mix produces higher air voids, which lead to durability problems.
5. Over vibration and consolidation of fresh concrete brings more water to the top of the concrete. This may lead to scaling and spalling of the concrete pavement.

5. Over vibration and consolidation of fresh concrete brings more water to the top of the concrete. This may lead to scaling and spalling of the concrete pavement.

Hence, the effect of construction quality on pavement performance cannot be over emphasized.

6.0 DESIGN ALTERNATIVES FOR THE RECONSTRUCTION OF RIGID PAVEMENT TO FLEXIBLE PAVEMENT

When a rigid pavement reaches certain condition and its rehabilitation becomes an expensive and ineffective option, reconstruction becomes the preferred alternative. Rigid pavements may be reconstructed as either rigid or flexible pavements. In this report the option of reconstructing rigid pavement to flexible pavement is discussed.

In general, the reconstruction of rigid pavement into a flexible one can be accomplished using two methods:

1. Rubblizing and compacting the concrete surface. In this method, the concrete surface is broken into small pieces and the temperature steel is ruptured or debonded. Depending on the structural capacity of the rubblized concrete and the existing sand subbase, an AC surface may be placed directly on the rubblized concrete or an aggregate base could be placed and compacted prior to placing the AC surface. This option is limited to those locations where the surface elevation of the finished pavement can be higher than that of the rigid pavement. Typically, in certain areas such as bridge approaches, the pavement is undercut to maintain bridge clearance. Care should be taken to assure that the aggregate base and/or subbase under the rigid pavement is not damaged during the rubblization of the concrete.
2. Removing the existing rigid pavement surface, enhancing the existing aggregate base, correcting potential drainage problems, and placing an AC surface. Again, care should be taken as not to damage the aggregate base and/or sand subbase during the concrete removal operation.

Two problems are typically associated with the reconstruction of an existing rigid pavement into a flexible one. These are:

1. The layers (sand subbase and aggregate base) of the existing rigid pavement do not, in general, possess the structural capacity that is required for flexible pavements.
2. In certain scenarios, the total thickness of the pavement section does not provide adequate frost protection cover over the subgrade soil.

1. Open Graded Drainage Course (OGDC) – These pavements are designed and constructed after the early 1980s. The pavement is supported on a non-frost susceptible soil. A typical pavement cross section is shown in figure 2.
2. Open Graded Drainage Course (OGDC) with Geotextile Separator - These pavements are designed and constructed after the early 1980s. They are supported on a non-frost susceptible soil. A typical cross-section is shown in figure 3.
3. Dense Graded Base Course - These pavements were designed and constructed prior to about 1984. The pavement is supported on a non-frost susceptible soil. A typical pavement cross section is shown in figure 4.
4. Undercut and Sand Replacement – These pavements are designed and constructed on a frost susceptible subgrade soil. A typical cross-section is shown in figure 5.

For each of the four pavement sections, various flexible pavement structural design alternatives were conducted. Each alternative was designed using mechanistic-based and the 1993 AASHTO procedures. All designs were based on the following parameters:

1. Equivalent Single Axle Load (ESAL) - 5, 20 and 30 millions.
2. Design reliability – 95 percent.
3. Asphalt concrete modulus of 400,000 psi.
4. Dense graded base layer modulus of 25,000 psi.
5. Sand subbase modulus of 12,000 psi.
6. Non-frost susceptible subgrade soil modulus of 4,000 psi.
7. Frost susceptible subgrade soil modulus of 3,000 psi.

One important point should be noted here is that, in the design of the various alternatives, the following assumptions were made:

The dense graded aggregate base and the sand subbase are in good condition and they can be used to support the new pavement. If this is not the case, the material should be replaced. The new materials must have compatible modulus values to those assumed in the design process. It is further assumed that the open graded drainage course is not capable of supporting construction traffic, hence, it is replaced by a dense graded aggregate base course.

The results of the design are presented in the next four sections of this report.

6.1 Reconstruction of Rigid Pavements Situated on OGDC - Flexible Pavement Structural Design Alternatives

Figures 7 and 8 show flexible pavement design alternatives for the reconstruction/replacement of the rigid pavement section shown in the left-hand column of each figure (an OGDC section). Each design alternative consists of three flexible pavement sections that were designed for three traffic levels, 5, 20 and 30 million ESAL. All designs were accomplished using mechanistic-based and the AASHTO procedures. The six pavement sections are supported on the same non-frost susceptible subgrade soil and they possess the required structural capacity to carry the indicated ESAL. The three pavement sections in figure 7 were designed by utilizing the existing 12-inch sand subbase and 4-inch dense-graded aggregate base layers. A new 6- or 4-inch dense graded aggregate base replaces the existing 4-inch open graded drainage course. This makes the total pavement thicknesses of 30.5, 31, and 32-inch for the design alternatives of 5, 20 and 30 million ESAL, respectively. The Structural capacity of each of the three pavement-sections is adequate to carry the indicated traffic during its service life without excessive deformation and/or shear failure. The total thickness of two pavement sections is equal to or less than the total thickness of the original rigid pavement. The 30-million ESAL section is one inch thicker than the existing rigid pavement thickness. This could be problematic in bridge areas where clearance is restricted. In such areas, the aggregate base could be stabilized to a modulus value of 50,000 psi or better. This would precipitate a decrease in the AC thickness from 12 to 10-inch.

The adequacy of the pavement sections of figure 7 relative to environmental damage (frost action) is very good. In the southern half of the lower-Peninsula of Michigan, the subgrade soil should be protected from frost damage by a minimum of 30-inch thick cover. That is the total thickness of the pavement section should be 30 inch. Hence, the three pavement sections of figure 7 provide excellent protection of the subgrade soil against freezing and good structural capacity. Other design alternatives are presented in figure 8. It can be seen that, the sections consist of:

1. The existing 12-inch sand subbase and 4-inch dense graded aggregate base separator.
2. An eight-inch dense graded aggregate base course. Four-inch of this base course replaces the existing 4-inch thick OGDC. The other 4-inch is to enhance the structural capacity of the pavement.
3. Asphalt concrete surface.

Examination of the three pavement sections of figure 8 indicates that the total thicknesses of the sections are 31.5, 34 and 35-inch for 5, 20, and 30 million ESAL, respectively. These total thicknesses represent an addition of 0.5, 3, and 4-inch over and above the total thickness of the existing rigid pavement that being replaced. Such additions in the total thickness may not cause problems relative to the existing cross-drains, culverts, and

Existing Rigid Pavement	Reconstructed pavements			Remarks
	5,000,000 ESAL	20,000,000 ESAL	30,000,000 ESAL	
11" Concrete	8.5" Asphalt concrete	11" Asphalt concrete	12" Asphalt concrete	
4" Open graded drainage course	6" Dense graded aggregate base course	4" Dense graded aggregate base course	4" Dense graded aggregate base course	
4" Dense graded base separator	4" Dense graded base separator	4" Dense graded base separator	4" Dense graded base separator	
12" Sand	12" Sand	12" Sand	12" Sand	
31"	30.5"	31"	32"	Total thickness
Non frost Susceptible Subgrade soil	Non frost susceptible subgrade soil	Non frost Susceptible subgrade soil	Non frost Susceptible subgrade soil	

Figure 7. A flexible pavement design alternative for the reconstruction of rigid pavement with an OGDC option used by MDOT since the early 1980's.

Existing Rigid Pavement	Reconstructed pavements			Remarks
	5,000,000 ESAL	20,000,000 ESAL	30,000,000 ESAL	
11" Concrete	7.5" Asphalt concrete	10" Asphalt concrete	11" Asphalt concrete	
4" Open graded drainage course	8" Dense graded aggregate base course	8" Dense graded aggregate base course	8" Dense graded aggregate base course	
4" Dense graded base separator	4" Dense graded base separator	4" Dense graded base separator	4" Dense graded base separator	
12" Sand	12" Sand	12" Sand	12" Sand	
31"	31.5"	34"	35"	Total thickness
Non frost Susceptible Subgrade soil	Non frost Susceptible Subgrade soil	Non frost Susceptible subgrade soil	Non frost Susceptible subgrade soil	

Figure 8. Another flexible pavement design alternative for the reconstruction of rigid pavement with an OGDC option used by MDOT since the early 1980's.

subdrainage. That is those substructures may not need to be widened if specifications relative to the embankment slopes can be satisfied. However, they may present a problem in areas where bridge clearance is restricted. In such scenario, two alternatives can be undertaken as follows:

1. Using 6-inch stabilized aggregate base rather than the 6-inch dense aggregate base. The stabilized material should have a minimum modulus of 50,000 psi. For the three pavement sections of figure 8, this would decrease the required AC thickness to 5.5, 7.0, and 8.0-inch for the 5,000,000, 20,000,000 and 30,000,000 ESAL sections, respectively. Hence the total respective pavement thickness for the three sections becomes 27.5, 29.0 and 30-inch.
2. Undercutting the subgrade soil by about 5-inches. This alternative however, is much more expensive than the first one because it involves the removal and re-compaction of the sand subbase and aggregate base.

It should be noted that the three sections of figure 8 represent an enhanced protection of the subgrade soil against frost action. Such protection, if desired or required apply to both flexible and rigid pavements. That is, it applies to a new rigid pavement designed to replace the existing one.

6.2 Reconstruction of Rigid Pavements Situated on OGDC with Geotextile Separator - Flexible Pavement Structural Design Alternatives

Figures 9 and 10 provide the results of two design alternatives of flexible pavement sections for the replacement of an existing rigid pavement situated on 4-inch OGDC with geotextile separator (see the left-hand column in the figure).

First, it should be noted that the total depth from the rigid pavement surface to the non-frost susceptible subgrade soil is only 27 inch. Hence, the existing rigid pavement section is deficient in that it does not provide adequate protection cover (30-inch minimum) against frost damage of the subgrade soil. This total thickness should be enhanced to a minimum of 30-inch regardless of the type of pavement (rigid or flexible) to be constructed.

The flexible pavement sections shown in figure 9 provide adequate structural capacity and protection against frost damage of the subgrade soil. It can be seen that the three sections consist of:

Existing Rigid pavement	Reconstructed pavements			Remarks
	5,000,000 ESAL	20,000,000 ESAL	30,000,000 ESAL	
11" Concrete	7.5" Asphalt concrete	10" Asphalt concrete	11" Asphalt concrete	
4" Open graded drainage course	12" Dense graded aggregate base course	12" Dense graded aggregate base course	12" Dense graded aggregate base course	
Geotextile separator	Geotextile separator	Geotextile separator	Geotextile separator	
12" Sand	12" Sand	12" Sand	12" Sand	
27"	31.5"	34"	35"	Total thickness
Non frost susceptible subgrade soil	Non frost susceptible subgrade soil	Non frost susceptible subgrade soil	Non frost susceptible subgrade soil	

Figure 9. A flexible pavement design alternative for the reconstruction of rigid pavement cross-section with a geotextile separator option used by MDOT since the early 1980's.

Existing Rigid pavement	Reconstructed pavements			Remarks
	5,000,000 ESAL	20,000,000 ESAL	30,000,000 ESAL	
11" Concrete	8.5" Asphalt concrete	11" Asphalt concrete	12" Asphalt concrete	
4" Open graded drainage course	10" dense graded aggregate base course	8" dense graded aggregate base course	8" dense graded aggregate base course	
Geotextile separator	Geotextile separator	Geotextile separator	Geotextile separator	
12" Sand	12" Sand	12" Sand	12" Sand	
27"	30.5"	31"	32"	Total thickness
Non frost susceptible subgrade soil	Non frost susceptible subgrade soil	Non frost susceptible subgrade soil	Non frost susceptible subgrade soil	

Figure 10. A second flexible pavement design alternative for the reconstruction of rigid pavement cross-section with a geotextile separator option used by MDOT since the early 1980's.

1. 12-inch sand subbase.
2. 12-inch dense graded aggregate base course. The existing 4-inch OGDC is replaced by 4-inch of dense graded aggregate base course.
3. 7.5, 10 and 11-inch thick asphalt layer for 5, 20 and 30 million ESAL, respectively.

The total thicknesses of the three flexible pavement sections are 31.5, 34 and 35-inch for 5, 20, and 30 million ESAL, respectively. These total thicknesses represent an addition of 4.5, 7, and 11-inch over and above the total thickness of the rigid pavement that being replaced. Such additions in the total thickness may be problematic and they may require embankment widening. This may also precipitate the extension of the existing cross-drains, culverts, and subdrainage. The additions in the total pavement thickness may also present a problem in areas where clearance (such as bridge clearance) is restricted. In such scenario, the two pavement design alternatives presented at the end of section 6.1 (see page 24) could be used.

Other design alternatives, which provide lower total pavement thickness, are shown in figure 10. It can be seen that the total thicknesses of the three sections are 30.5, 31 and 32-inch for 5, 20 and 30 million ESAL, respectively. All three sections have adequate structural capacity to carry the traffic load and volume and to provide adequate protection against frost damage of the subgrade soil. Although the three-pavement sections provide the minimum total thickness of 30-inch, those sections shown in figure 9 are preferable. They do provide higher factor of safety against frost damage.

It should be noted that if the existing pavement is to be reconstructed as rigid pavement, the total thickness must be increased to the 30-inch minimum that is required for frost protection. Hence, both pavement types will have similar problems as far as bridge clearance and widening.

Finally, other design alternatives such as the use of stabilized sand subbase and aggregate base layers, Cram sections (an asphalt layer sandwiched in between the subgrade and the aggregate base), and others were analyzed. The analysis yielded thinner pavement sections. However, frost protection of the subgrade soil was problematic. Therefore, the sections are not presented in this report.

6.3 Reconstruction of Rigid Pavements Situated on Dense Graded Aggregate Base and Sand Subbase - Flexible Pavement Structural Design Alternatives

Figures 11 and 12 provide the results of two alternative designs of flexible pavement sections for the replacement of an existing rigid pavement situated on 4-inch of aggregate base and 10-inch of sand on a non-frost susceptible subgrade soil.

Regarding the existing rigid pavement section (see the left-hand column in figures 11 and 12), it can be seen that the total depth from the rigid pavement surface to the non-frost susceptible subgrade soil is only 25 inch. Hence, the rigid pavement section is deficient in

Existing Rigid pavement	Reconstructed pavement			Remarks
	5,000,000 ESAL	20,000,000 ESAL	30,000,000 ESAL	
11" Concrete	8" Asphalt concrete	10" Asphalt concrete	11" Asphalt concrete	
	8" Dense graded aggregate base course	8" Dense graded aggregate base course	8" Dense graded aggregate base course	
4" Dense graded aggregate base course	4" Dense graded aggregate base course	4" Dense graded aggregate base course	4" Dense graded aggregate base course	
10" Sand	10" Sand	10" Sand	10" Sand	
25"	30"	32"	33"	Total thickness
Non-frost susceptible subgrade soil	Non-frost susceptible subgrade soil	Non-frost susceptible subgrade soil	Non-frost susceptible subgrade soil	

Figure 11. A third flexible pavement design alternative for the reconstruction of rigid pavement section built on a non-frost susceptible subgrade soil (Michigan practice prior to the early 1980's).

Existing Rigid pavement	Reconstructed pavement			Remarks
	5,000,000 ESAL	20,000,000 ESAL	30,000,000 ESAL	
11" Concrete	8" Asphalt concrete	10" Asphalt concrete	12" Asphalt concrete	
	8" Dense graded aggregate base course	6" dense graded & asphalt stabilized aggregate base course	4" Dense graded & asphalt stabilized aggregate base course	
4" Dense graded aggregate base course	4" Dense graded aggregate base course	4" Dense graded aggregate base course	4" Dense graded aggregate base course	
10" Sand	10" Sand	10" Sand	10" Sand	
25"	30	30"	30"	Total thickness
Non-frost susceptible subgrade soil	Non-frost susceptible subgrade soil	Non-frost susceptible subgrade soil	Non-frost susceptible subgrade soil	

Figure 12. A second flexible pavement design alternative for the reconstruction of rigid pavement section built on a non-frost susceptible subgrade soil (Michigan practice prior to the early 1980's).

that it does not provide the adequate protection cover (30-inch minimum) against frost damage of the subgrade soil. Second, since the early 1980s, the Michigan Department of Transportation has changed its practice, and the rigid pavement section in the figures was abandoned. Currently, the majority of the rigid pavement sections that are being reconstructed involve these deficient sections.

The above scenario implies that the total thickness of the existing pavement must be increased regardless of whether or not the new pavement is flexible or rigid. The increase in pavement thickness would assure adequate protection against frost damage.

Two flexible pavement design alternatives are also shown in figures 11 and 12 for 5, 20 and 30 million ESAL. It can be seen that the three flexible pavement sections shown in figure 11 provide adequate structural capacity and protection against frost damage of the subgrade soil. The sections consist of:

1. 10-inch sand subbase (an existing layer).
2. 12-inch of aggregate base (4-inch is already in place).
3. Asphalt layer whose thickness depends upon the design ESAL.

The total thicknesses of the three flexible pavement sections are 30, 32 and 33-inch for 5, 20, and 30 million ESAL, respectively. These total thicknesses represent an addition of 5, 7 and 8-inch over and above the total thickness of the rigid pavement that being replaced. Such additions in the total thickness may be problematic and they may require pavement widening. This may also precipitate the extension of the existing cross-drains, culverts, and subdrainage. The additions in the total pavement thickness may also present a problem in areas where clearance (such as bridge clearance) is restricted. Once again, for such scenario, the two pavement design alternatives presented at the end of section 6.1 (see page 24) could be used.

Once again, the structural capacity of the three pavement sections could be satisfied with slightly lower layer thicknesses as shown in figure 12. As it can be seen from the figure, the total thickness of each section is 30 inch. The decrease in the thickness was made possible by using dense graded and asphalt stabilized aggregate base. The stabilized material must have a minimum modulus value of 50,000 psi.

A possible solution to the problem of widening the pavement section is heightening the slopes of the embankment. In this regard, the required new slopes should be checked against the existing ones. If the material properties, existing safety standards, and the maximum slope allowable for mowing operation can be satisfied, the slopes may be heightened and, perhaps, no pavement widening is required.

6.4 Reconstruction of Rigid Pavements Situated on Frost Susceptible Soil - Flexible Pavement Structural Design Alternatives

Figure 13 shows an existing rigid pavement section situated on a frost susceptible soil. It can be seen that the section consists of:

1. 24-inch of class-2 sand backfill with underdrain. 12-inch of sand subbase.
2. 4-inch of dense graded aggregate base or geotextile separator.
3. 4-inch of OGDC.
4. 9 to 11-inch concrete surface.

The total thickness of the pavement section is either 49 or 53-inch depending on whether or not a geotextile separator is used. Such thickness provides an excellent protection against frost damage of the subgrade soil throughout the State of Michigan. It should be noted that, in certain areas and/or for some projects, such pavement section could be intermittent and is not uniform for any considerable length. That is the existing pavement has variable sections within a project. For this scenario, it is highly likely that the design would be altered as to reconstruct the entire project using a uniform section.

Three flexible pavement sections that were designed for 5, 20 and 30 million design ESAL are also shown in figure 13. The three sections consist of:

1. The existing 24-inch class-2 sand backfill with underdrains.
2. The existing 12-inch sand subbase.
3. The existing 4-inch dense graded base aggregate or geotextile separator.
4. A 4-inch dense graded aggregate base course, which replaces the existing 4-inch ODGC.
5. Asphalt concrete layer of 7.5, 10 and 11-inch thick for 5, 20 and 30 million design ESAL, respectively.

The total thicknesses of the three flexible pavement sections are 51.5, 54 and 55-inch for 5, 20, and 30 million ESAL, respectively. These thicknesses are equivalent to or less than the thickness of the existing rigid pavement. Therefore, they do not represent any foreseeable problems regarding pavement widening or bridge clearance. It should be noted that under certain scenario, the underdrains may be damaged and must be changed. In this case, the entire pavement section along the project or at limited locations (where the underdrains are located) may be excavated and reconstructed from the subgrade soil and up. This would be the best possible solution regardless of whether the pavement is to be reconstructed as rigid or as asphalt section.

7.0 RECOMMENDATIONS

Existing rigid pavements may be reconstructed as rigid or as flexible pavements. Although this report includes several flexible pavement design alternatives for the

Existing Rigid pavement	Reconstructed pavement			Remarks
	5,000,000 ESAL	20,000,000 ESAL	30,000,000 ESAL	
11" Concrete	7.5" Asphalt concrete	10" Asphalt concrete	11" Asphalt concrete	
4" Open graded drainage course	4" Dense graded aggregate base course	4" Dense graded aggregate base course	4" Dense graded aggregate base course	
4" Dense grade base separator or Geotextile	4" Dense grade base separator or Geotextile	4" Dense grade base separator or Geotextile	4" Dense grade base separator or Geotextile	
12" Sand	12" Sand	12" Sand	12" Sand	
24" Class 2 sand backfill with underdrains	24" Class 2 sand backfill with underdrains	24" Class 2 sand backfill with underdrains	24" Class 2 sand backfill with underdrains	
51 or 55"	47.5 or 51.5"	50 or 54"	51 or 55"	Total thickness
Frost susceptible subgrade soil	Frost susceptible subgrade soil	Frost susceptible subgrade soil	Frost susceptible subgrade soil	

Figure 13. Flexible pavement design alternatives for the reconstruction of rigid pavements located on a frost susceptible soil.

replacement of existing rigid pavements, the following alternatives are highly recommended because they provide the highest degree of frost protection:

1. For the reconstruction of rigid pavements situated on OGDC and base course separator with non-frost susceptible subgrade soil, use the flexible pavement sections presented in figure 8.
2. For the reconstruction of rigid pavements situated on OGDC and geotextile separator with non-frost susceptible subgrade soil, use the flexible pavement sections presented in figure 9.
3. For the reconstruction of rigid pavements situated on dense graded aggregate base and sand subbase with non-frost susceptible subgrade soil, use the flexible pavement sections presented in figure 11.
4. For the reconstruction of rigid pavements situated on frost susceptible subgrade soil, use the flexible pavement sections presented in figure 13.

8.0 SUMMARY

Pavements represent the single largest investment ever made by the taxpayers in the USA and most of the industrialized world. Pavements can be constructed as flexible (asphalt), rigid (concrete) or composite. In general, in the State of Michigan, the rigid pavement network consists of five sections depending on the type of subgrade soil (frost versus non-frost susceptible soils) and the type of separator course (dense aggregate base or geotextile). Because of their state of distress, rehabilitation of some of the pavement sections is not a cost-effective option. Hence, reconstruction is the preferred alternative.

An existing rigid pavement can be reconstructed as flexible, rigid or composite pavement. In Michigan, pavements are typically constructed as flexible or rigid. A pavement may become composite by default through rehabilitation work. Hence, pavements are constructed or reconstructed as either rigid or flexible.

The design and construction of a pavement structure must address two engineering problems: the pavement structural capacity and the protection of the subgrade soil against frost damage. Various flexible pavement design alternatives for the reconstruction of rigid pavement are presented and discussed. Each alternative was designed by using the AASHTO and mechanistic-based design procedures. Hence, the pavements were designed to meet the ride quality standards (the AASHTO method) and fatigue life and rut standards (mechanistic-based design).

Respectfully submitted



Gilbert Y. Baladi, Ph.D., P.E.
Professor of Civil Engineering

REFERENCES

1. Center for Transportation Research, Bureau of Engineering Research, the University of Texas at Austin. "A Program of Study in Pavement Management." Vol. I, II, and III. National Highway Institute, Washington, D.C., 1984.
2. Oglesby C. H., and G.R. Hicks. "Highway Engineering." 4th. edition. New York: John Wiley and Sons, 1982.
3. Wright P. H., and R.J. Paquette. Highway Engineering. 5th. edition. John Wiley and Sons, New York, 1987.
4. Hazard J. L. "Transportation: Management, Economics Policy." Cambridge, Massachusetts, Cornell Maritime Press Inc., 1977.
5. Yoder E. J. "Principles of Pavement Design." New York: John Wiley and Sons, 1959.
6. ERES Consultants Inc. "Techniques for Pavement Rehabilitation." Champaign, Illinois, National Highway Institute, Washington, D.C., 1987.
7. Carey, W. N., and P. E., Irick. "The Pavement Serviceability-Performance Concept." Bulletin 250. Highway Research Board, Washington, D.C., 1960.
8. Hutchinson, B.G. and R. C. G., Haas. "A Systems Analysis of the Highway Pavement Design Process." Highway Research Record No. 239. Transportation Research Board, Washington, D.C., 1969.
8. Baladi, G.Y. "In-Service Performance of Flexible Pavements." Volume II, Proceedings, International Air Transportation Conference, American Society for Civil Engineering, New Orleans, 1979.
9. Baladi, G. Y. "Nondestructive Pavement Evaluation: the Deflection Beam." Transportation Research Record Number 666. Transportation Research Board, National Academy of Sciences, Washington, D.C., 1980.
10. Yoder E. J., and M.W. Witczak. Principles of Pavement Design. 2nd edition, New York, John Wiley and Sons, 1987.
11. "AASHTO Guide for Design of Pavement Structures." American Association of State and Highway Officials, Washington, D.C., 1993.