Bituminous Pavement Design and Construction for Low-Volume Roads in Cold Climates

Alan Forsberg, *Blue Earth County, Minnesota, Highway Department*

Blue Earth County in Minnesota has developed a process for bituminous pavement design and construction for low-volume roads in cold climates. Principal features of the process include cost-effectiveness, quality pavements, and the flexibility to adapt the design to the particular road segment. The process allows separate payment for asphalt cement and aggregate. However, the contractor must pay for any asphalt cement over a given percentage. This requires the contractor to balance the quality and gradation of aggregate against the cost of providing asphalt over the given maximum amount. Construction inspection remains the county's responsibility. This typically saves $0.50 per ton added to contracts for the quality management approach where design and testing responsibilities lie with the contractor. Key features necessary to ensure quality pavements include approval of a trial mix by Minnesota Department of Transportation, provision of a nuclear density gauge and roll test patterns to determine the maximum density compaction process, regular gradation and asphalt cement content tests to ensure that a proper blend of quality materials is used, regular voids content tests during construction, and trimming of the aggregate base by use of automatic controls on a motor grader to ensure good ride quality and a uniform aggregate base and pavement section. The process described has evolved over the last 5 years. There is no quantitative measure of results. Qualitatively, results appear to be good. In addition, the concepts appear to be consistent with the Super Pave Level I concepts of the Strategic Highway Research Program now being implemented.

The emphasis in this paper is on bituminous pavements for low-volume roads in cold climates typical of rural county highway departments in the northern United States. An integrated design and construction method for bituminous pavements is discussed that controls the air voids content appropriate for the particular road by varying the gradation of aggregates and asphalt content.

Construction of quality bituminous pavements requires a systems approach. In concept, this is simple. The product—consisting of appropriate aggregates mixed with a relatively small amount of asphalt, placed on a prepared base, and compacted—provides a serviceable pavement. However, due to the large number of variables and demanding environment, execution can be very complex and filled with risks.

Because the system relationships of a quality pavement are critical to success, a brief discussion of the planning, design, construction, and maintenance of these pavements will provide a proper context.

It was also noted during research for this paper that the basic concepts of designing and constructing bituminous pavements have been under consideration for several decades. It is hoped that the Strategic Highway

Research Program (SHRP) will synthesize the work done to date and advance the process toward science.

Background

The paper describes an empirically based method that has worked for Blue Earth County, Minnesota. Blue Earth County has 720 mi of highway divided about equally among local, minor collector, and major collector by functional classification. Average daily traffic ranges from under 100 to several thousand vehicles. About 400 mi is paved; the rest is aggregate surfaced. The population is slowly declining in the rural areas of the county; traffic volumes in these areas are relatively stable. Population and traffic volumes around Mankato, a growing regional center, are both steadily increasing.

The method described here may be inappropriate for larger, high-traffic-volume agencies. Also, small agencies typically cannot economically control some critical variables, such as asphalt cement grade and quality, available aggregates, and state and federal aid regulations. The typical county engineer needs the wisdom to accept those variables that cannot be changed and to optimize those that can. The local road agency engineer must be pragmatic in view of his or her immediate accountability to the governing body and the public.

Systems Approach to Bituminous Pavement

Quality bituminous pavements can be achieved only by pursuing a systems approach, including planning, design, construction, and operation and maintenance. Planning includes the selection of the roads to pave considering their present and future role in the road system. Design includes the selection of the type of pavement and required structural strength. Construction includes the contracting, inspection, and administrative process. Finally, effective operation and maintenance are essential to maximize the return on the investment in the pavement.

Large agencies frequently have the resources to research and develop each of the stages in detail. However, they also risk losing the relationship between these stages. Smaller agencies are often forced to operate as a system since one engineer administers and directs the entire program. However, Blue Earth County lacks the expertise to understand each stage in detail and must rely on the larger state department of transportation (DOT) agencies for technical assistance.

Planning

The decision to pave versus maintain an aggregate surface is generally a function of maintenance cost, safety, environmental considerations such as dust and erosion, and future economic development potential. Local politics also plays a role, but often with checks and balances provided by limited resources and multimember boards. Increasing demands for road improvements and limited funds require that engineers effectively plan where and how pavement investments are made.

Design

Several design methods are available for bituminous pavements, including the Asphalt Institute method, *AASHTO Guide for Design of Pavement Structures* (*1*), and state DOT methods. Often, low-volume road agencies have no choice of methods if state or federal funds are used. However, even in such cases, the low-volume road agency can project traffic estimates, select the type of pavement, estimate soil parameters, and have a major influence on the outcome.

Critical Design Considerations

Critical design considerations include selection of pavement design life, aggregate or bituminous base, and pavement drainage.

Pavement Design Life

Several critical design considerations are unique to low-volume roads. Low-volume roads often fail due to age (oxidation and stripping of asphalt cement). At other times, infrequent but heavy loads cause failure. Emphasis solely on equivalent axle loads will result in a short pavement life. An example that comes to mind is paving around an elementary school where the school playground, automobile parking lot, and bus lanes are paved at the same time. Several years later, all require rehabilitation due to cracking and raveling despite a large number of equivalent axle loads projected to remain in the playground and parking lot. It is evident that deterioration from weather and age can be as significant as that from traffic loads.

Design should focus on 15 to 20 years into the future. Design is then a compromise between the current, most economic design and the likely future need. Generally, this indicates that more asphalt is justified to withstand aging effects. The additional asphalt cement will provide increased durability and a reservoir to compensate for oxidation and stripping. The county has also noted that on higher-volume roads, alligator cracking seldom occurs in rutted and bleeding sections high in asphalt content.

Full-Depth Bituminous Designs

Full-depth bituminous designs have not worked well in Blue Earth County. Deterioration with age, apparent softening of the subgrade from capillary water in the fine clay soils, and difficulty of repair have discouraged their use.

Improved Pavement Drainage

Improved pavement drainage appears essential in the frost belt with fine-grained clay soils. Agricultural-type slotted, corrugated drain tile and open-graded aggregate drainage layers have been found to be economical and very effective. A modified aggregate base design where the aggregate base is not carried out to the shoulders (especially for wide shoulders) can result in significant cost savings of one-third or more of the aggregate for a thick aggregate base design with wide shoulders. When combined with an open-graded base and tile system, the design appears to work well. Figure 1 shows a modified aggregate base design. Two projects were constructed with the design 3 and 4 years ago. Both appear to be performing well. They have shown significant flows from the tile systems, especially during the critical spring thaw. There is some concern that water will be trapped in a "bathtub design" and not drain to the ditch inslope. However, as shown below, a dense-graded aggregate base with greater than 10 percent fines passing the No. 200 screen is essentially impermeable, especially when the fines are a clay or silt-type material (*1*).

	Coefficient of Permeability (ft/day) by Percent Passing No. 200 Sieve			
Type of Fines	*0*	*5*	*10*	*15*
Silica or limestone	10	0.07	0.08	0.03
Silt	10	0.08	0.001	0.0002
Clay	10	0.01	0.0005	0.00009

The full aggregate base section under the shoulder, therefore, is not justified for drainage reasons.

Bituminous Pavement Design Variables

During the bituminous pavement design process, the chief variables are the asphalt cement, aggregate, and design method used. Each has major implications for the performance of low-volume bituminous pavements in cold climates.

Asphalt Cement

Asphalt cement is essentially a cheap, largely unprocessed material costing about $100 to $150 per ton or about 5 cents per pound. It has a number of characteristics affecting pavement performance, including (*a*) consistency measured by penetration or viscosity and its variation with temperature and time, (*b*) ductility as new and aged material, and (*c*) pureness and "cracking" damage in the refining process. These characteristics vary due to different sources, and the same source with time.

In Minnesota, as is generally true, the local agency controls only the hardness of asphalt material by specifying penetration. The other variables are ignored, and changes in the resulting performance of pavement are accepted as a risk. It is hoped that the work of SHRP will improve the understanding of this material and refine its use.

Aggregate Properties

A number of aggregate properties are critical to a quality pavement, including gradation of material by size, hardness or toughness, shape, solubility, and affinity for asphalt. Unfortunately, economics dictates use of locally available, inexpensive materials. At $5 to $10 per ton, or about 5 cents per pound, extensive transportation or processing is not feasible.

Available aggregate resources can best be used by optimizing the design of subgrade, base, and pavement layer types and thicknesses. Optimum gradations can be developed by requiring two or more stockpiles graded by size. Crushing can be specified to improve the shape of the aggregate. Coarser materials and increased crushing content can be used when higher strengths are needed. It is also essential to limit the use of soft, deleterious materials to prevent surface spalling and reduced long-term stability.

Mix Design Methods

Generally, the state DOT determines the mix design method for the local agency. It is important to keep in mind the substantial differences between the laboratory and field environments. Small quantities of material are used in the laboratory, that is, a few pounds of materials. In the field, quantities are typically in the hundreds or thousands of tons. Ensuring a uniform, representative sample is difficult at best. In addition, determination of laboratory and field voids depends on compaction. The relationship of compaction energy and method in the laboratory to that in the field is also problematic. Nonetheless, the laboratory trial mix is essential for a satisfactory design to begin production. The laboratory tests provide advance information that either is never available from the field or only becomes available after a significant quantity of material is produced.

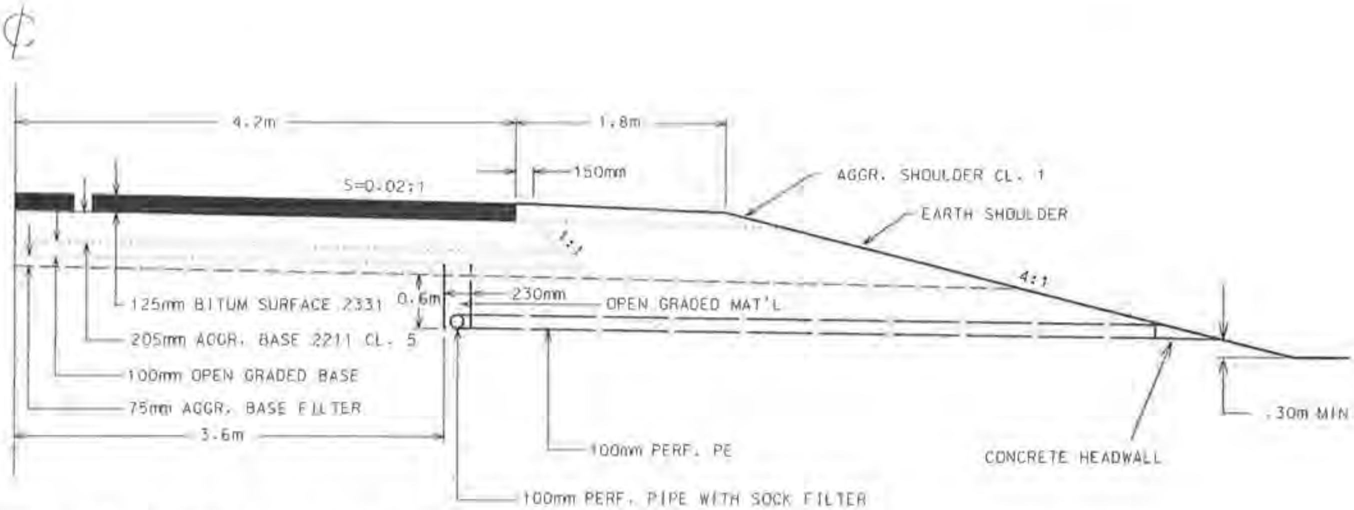

FIGURE 1 **Modified aggregate base section.**

Design Generalizations for Low-Volume Roads

Air Voids in the Mix

Several studies have shown that appropriate air void content in the mix is essential to a successful pavement (*2–4*). A number of state DOTs, including Minnesota and Colorado, have developed specifications based on this concept. Studies and experience show that high air voids promote deterioration of the pavement from oxidation and stripping. However, low voids promote rutting, bleeding, and flushing. It appears that the lowest voids that will avoid rutting and bleeding will result in the most long-lasting pavement. It then follows that low-volume roads, especially with lighter loads, should tend toward the low end of the acceptable air voids range to increase durability.

Aggregate Quality and Gradation

Hard, durable aggregate that will resist the effects of loads and weather is needed to transfer loads and reduce surface spalling. In the Blue County area, the Los Angeles rattler test is used to specify hardness. However, locally available crushed limestone is frequently used to meet the gradation specification. This material can be soft and susceptible to weathering. Aggregate quality specifications should apply to each aggregate source rock as well as to the entire mixture, or a poor-quality material may result in future pavement failure.

Crushed materials substantially increase stability and reduce rutting. However, as aggregate sources deplete, the larger particles needed for crushing may be unavailable. Use of higher-quality imported material in surface layers is one alternative.

Control of the gradation of materials can be achieved by requiring two or more stockpiles of materials. Proper stockpiling procedures are necessary to avoid segregation. This flexibility to adjust gradation is essential to account for differences in the laboratory and field environments and to implement the integrated design and construction method discussed later in this paper. Perhaps the best measure of the coarseness of the material and gradation is a comparison of the gradation to the maximum density curve as shown in Figure 2.

Low-volume road mixes should tend toward coarser mixes since these mixes can hold more asphalt for a given air void content and should therefore be more durable. In addition, the stability of these mixes is less sensitive to changes in asphalt and air void content as shown in Figure 3.

Asphalt Cement

Selection of the appropriate consistency (as measured by penetration or viscosity) is generally the only control the low-volume road agency has over the asphalt. Other essential characteristics—such as ductility, solubility, and aging—must be accepted as risk at this time. It is important that adequate asphalt be included for present as well as future needs. Generally, low-volume roads should tend toward high asphalt content to ensure durability. Most low-volume road agencies have extensive histories of working with local aggregate sources and mix designs for these sources. Trial mixes or contractor proposals for low asphalt content relative to the history of successful mixes should automatically be suspect. Generally, it is believed that softer asphalt should be chosen for low-volume roads with the hope that it will result in improved ductility and reduced cracking. The

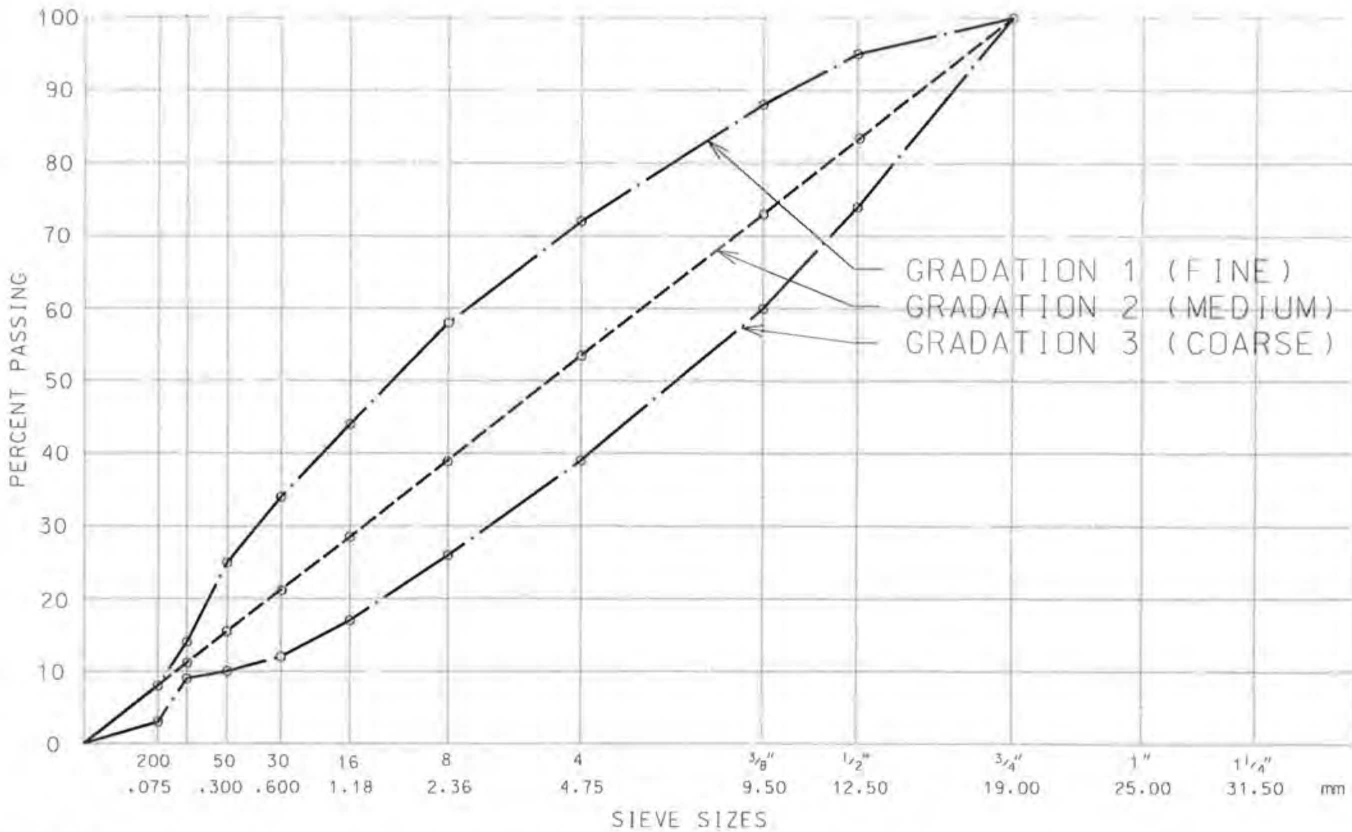

FIGURE 2 Fine, medium, and coarse gradations shown on maximum density plot (5).

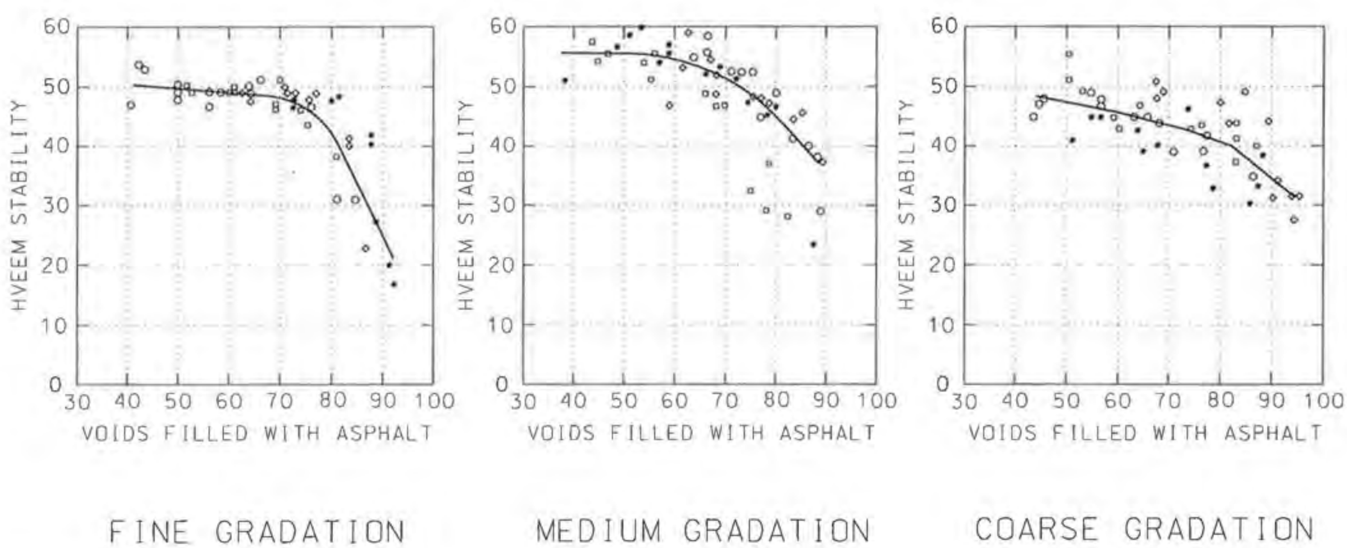

FIGURE 3 Stability versus voids filled with asphalt (5). Data shown are from 100 percent crushed material.

exceptional performance of some of the old road mix designs lends credence to this theory.

Construction

As discussed earlier, the laboratory design process is an essential but limited model of the field environment. The real need is to control the air voids, aggregate, and asphalt in the actual product. Conscientious, high-quality contractors and inspectors are needed.

The "tough enforcer" model of the agency that has a constant adversarial relationship with the contractor is giving way to the "partnering" relationship, where early coordination and good communication resolve problems before they occur. It would seem that both models are needed. Early coordination, good communication, and a close working relationship are needed for a quality product. However, constant vigilance and the will to enforce contracts are also needed when the agency and contractor do not always have the same objectives. The will to shut down contractors when necessary and to require that substandard materials be replaced remains essential to consistently procuring a quality product.

Integrated Design and Construction Model

The integrated design and construction model for low-volume bituminous pavements described here attempts to take the design from the bituminous laboratory and complete it in the field. This model includes the following components.

Final Pavement Grade

Good ride quality and consistent structural strength require a uniform pavement section. Yet cores from constructed pavements show a significant difference in thickness. Apparently, the "ski" on the paver has been doing a good job of providing an adequate pavement alignment by varying the thickness of the bituminous layer. This results in a nonuniform pavement with some overly strong and some weak areas. The problem seems to have grown with the retirement of many of the older motor grader operators with their skill for trimming the aggregate base before paving. Fortunately, technology now allows economical automatic control of the vertical alignment by laser or string-line controls.

Stringently Enforced Trial Mix

Production of bituminous material starts by stringently enforcing the trial mix design. The agency should require that all trial mix data and curves be provided. Aggregate gradation and air void samples are taken and asphalt content is measured as soon as production begins.

Adjustment of Asphalt Content

Frequently, the air void content will drift from the design level established for the mix (lower voids range for low traffic volumes). The asphalt content should be adjusted if such an adjustment will provide a void content appropriate for the road (higher asphalt range for low-volume road). If the asphalt content is not adjusted, the gradation should be adjusted.

Adjustment of Aggregate Gradation

The aggregate gradation should be adjusted by examining the relationship between the aggregate gradation and the maximum density curve.

No significant changes in either the asphalt content or gradation should be made without reviewing the stability curves from the trial mix to ensure that stability is not reduced below specifications. Figure 3 shows that stability can decline rapidly after a substantial portion of the voids are filled with asphalt, especially for mixes with fine gradations.

The contract must allow the agency to adjust the asphalt content and aggregate gradation upon request. This requires multiple aggregate stockpiles. It also requires separate pay items for asphalt and aggregate.

Maximum Density Curve Study by Colorado DOT

A Colorado DOT study (5) examined 101 mix designs for relationships between air voids and several alternative maximum density plots. It also examined 24 aggregate samples for voids and density relationships for additional variables: (*a*) gradation, (*b*) quantity finer than the No. 200 screen, (*c*) size distribution finer than the No. 200 screen, and (*d*) angularity of fine aggregate. Figure 4 shows alternative maximum density curves considered.

The study found the best relationship between voids and the distance of the gradation from the maximum density line with (*a*) a maximum density curve drawn from the origin to the actual percentage passing the nominal maximum aggregate size and (*b*) the portion of the maximum density line finer than the No. 8 screen. The study also found that the angularity of the particles has an effect on voids.

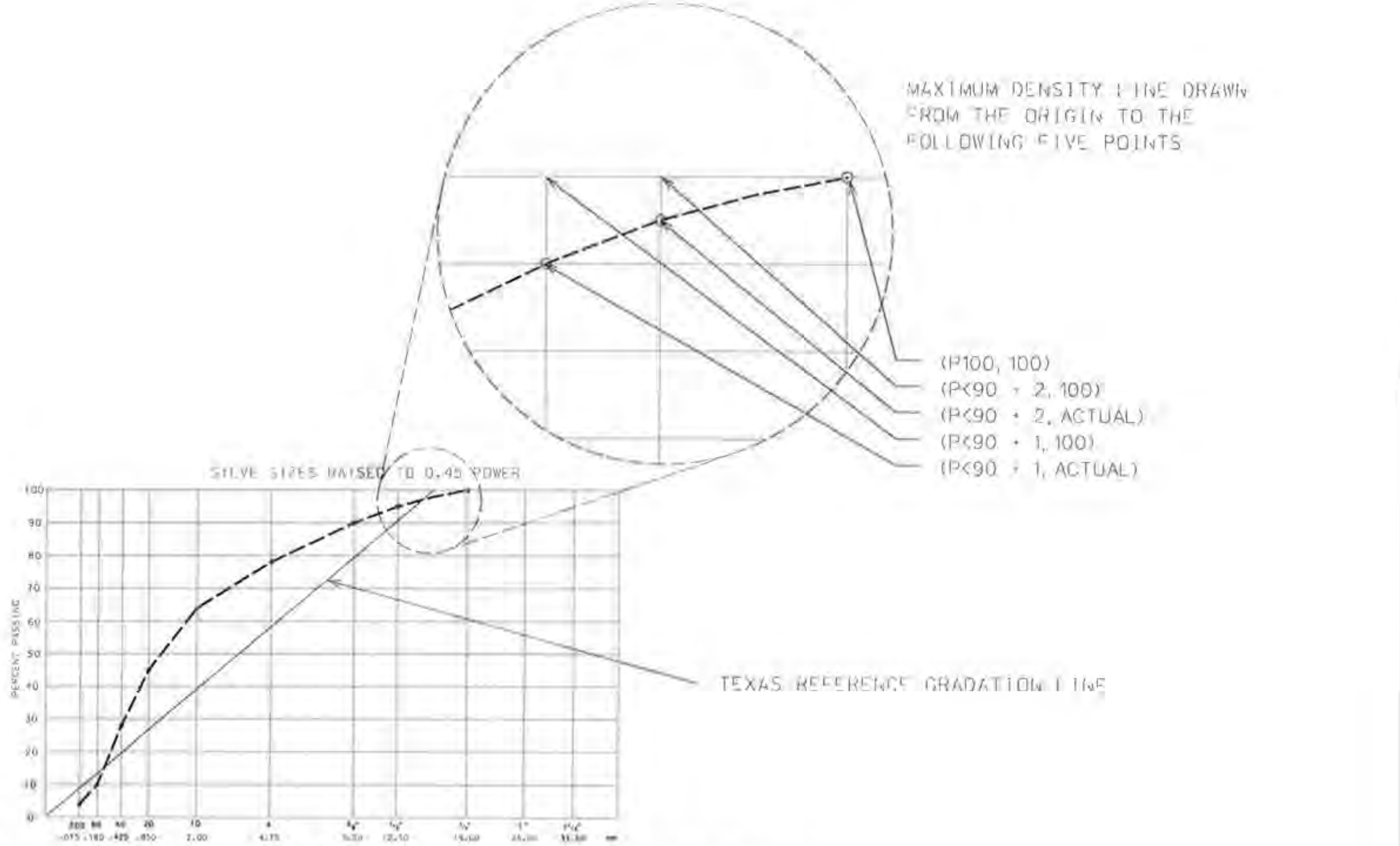

FIGURE 4 Variations of maximum density curves evaluated by Colorado DOT (5).

The study found that the maximum density line was a useful rule of thumb to determine how to adjust gradation to optimize the mixture's air voids. If higher air voids are desired, the gradation is adjusted away from the maximum density line. Conversely, if lower air voids are desired, the gradation is adjusted toward the maximum density line. If adjustment is above the line, the mix is finer, asphalt film thinner, and durability may be lower. If adjustment is below, the opposite may be true.

As an example of the application of asphalt and gradation adjustment to optimize voids, Blue Earth County had a bituminous paving contract with Loveall Construction in the summer of 1993. Gradation and asphalt content tests showed that the contractor was operating within the specifications. However, tests showed that the air void content at 5 percent was above the optimum by 3 to 4 percent for the low-volume road being paved. An asphalt content of 6.5 percent was considered appropriate based on past experience with this aggregate source. The production gradation was extremely close to the trial mix gradation.

The county elected to adjust the mix gradation since the asphalt content was appropriate. After studying the maximum density curve with trial mix and production gradations (see Figure 5), the county engineers instructed the contractor to decrease the sand in increments of 2 percent. This would move the production gradation toward the maximum density line and reduce the voids. A void content test was conducted after each increment until a voids content of 3.5 percent was reached. Production then continued with air voids at 3.5 percent, asphalt content at 6.5 percent, and a gradation that had been modified but was still within the trial mix band. These variables were considered ideal for this low-volume road with its projected use.

Compaction of Mix

Proper compaction of the mix is critical to the long-term performance of the pavement. It is also critical to the achievement of the voids established for the mix in

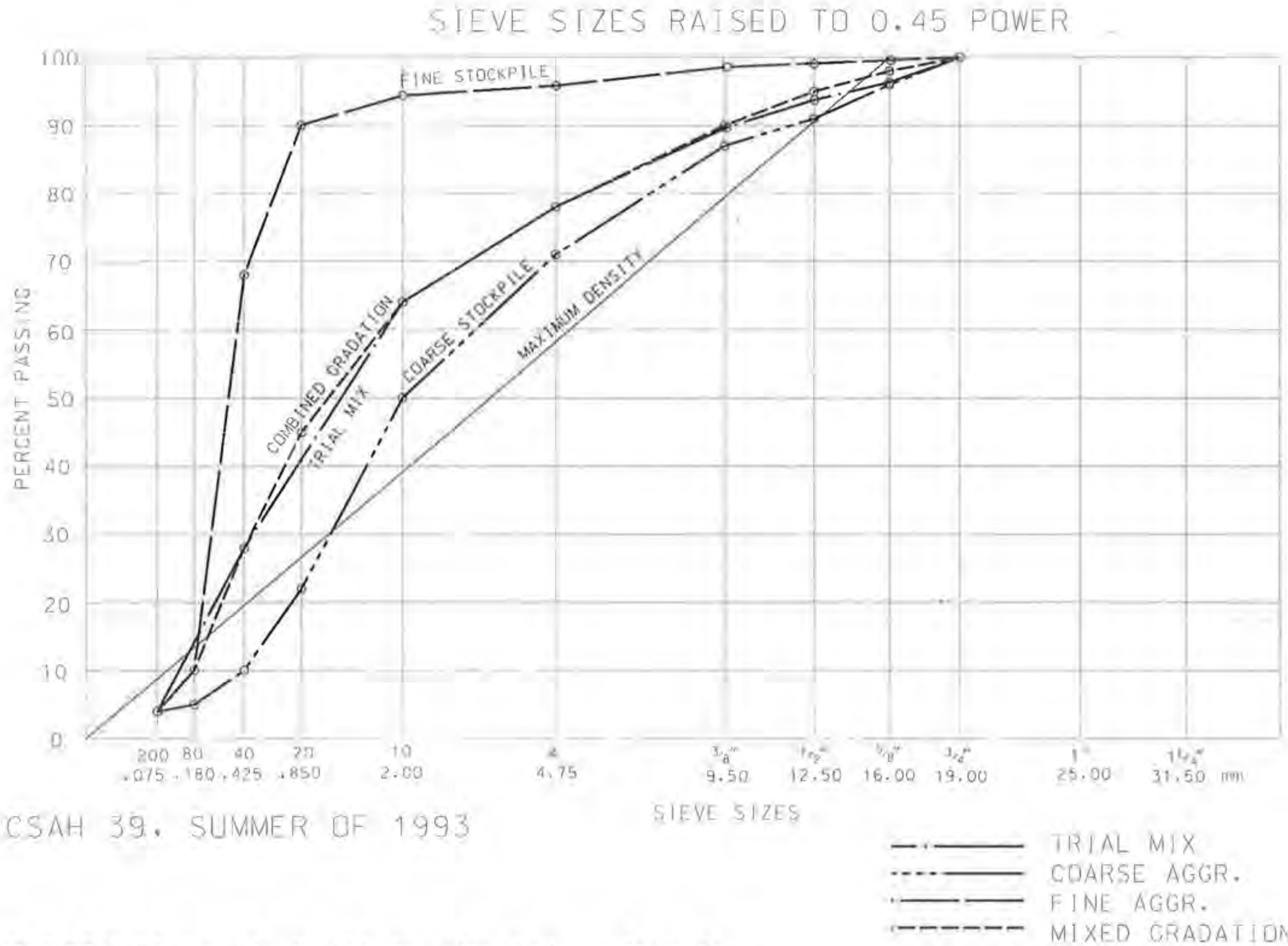

FIGURE 5 Maximum density, trial mix, and production gradation plot.

the laboratory. The contractor is required to construct a control strip to determine the best rolling pattern to reach maximum density. Densities are determined by a portable nuclear gauge furnished by the contractor. The absolute density is interesting but is not as important as the relative maximum density achieved. This reduces the importance of gauge calibration.

The county has been requiring breakdown by a steel roller, intermediate rolling by a rubber-tired roller, and final rolling by a steel roller. Assuming that rolling begins as soon after the paver as possible, this method is somewhat self-enforcing since adequate final rolling is necessary in order to erase the rubber tire marks.

Maintenance

Adequate and appropriate maintenance is an essential element of the quality bituminous pavement system. Pavement management systems should be of tremendous assistance as they are implemented. These systems should supplement experience and expertise of staff and assist in selecting the proper maintenance tool, whether it be crack sealing, seal coating, overlaying, or complete rehabilitation.

Summary

The planning, design, construction, and maintenance of quality bituminous pavements for low-volume roads are still an art but are slowly advancing toward a science. It is hoped that continued research and the efforts of SHRP will help us to better understand and control the many variables and that some of the ideas discussed here, including the integrated design-and-construction concept, will be useful.

REFERENCES

1. *AASHTO Guide for Design of Pavement Structures*. American Association of State Highway and Transportation Officials, Washington, D.C., 1993, pp. 1–19.
2. Heinz, R. E. *Asphalt Concrete Mix Design and Field Control*. FHWA Technical Advisory T 5040.27, 1988, 27 pp.
3. Huber, G. A., and T. S. Shuler. Providing Sufficient Void Space for Asphalt Cement: Relationship of Mineral Aggregate Voids and Aggregate Gradation. In *Effects of Aggregates and Mineral Fillers on Asphalt Mixture Performance*. ASTM STP 1147. ASTM, Philadelphia, Pa., 1992.
4. *Performance Based Specification to Be Used in Mixture Design and Analysis Systems*. Draft Working Paper, SHRP A001. Strategic Highway Research Program, 1991, 51 pp.
5. Aschenbrener, T., and C. MacKean. Factors That Affect the Voids in the Mineral Aggregate of Hot Mix Asphalt. In *Transportation Research Record 1469*, TRB, National Research Council, Washington, D.C., 1994.