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A State-of-the-Art Study and Survey of Flexible Pavement Construction Jointing Techniques

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Final Report

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16. Abstract

This report summarizes the state-of-the-art construction joints in airport hot-mix asphalt flexible pavement surfaces. It also discusses and develops criteria for improved Federal Aviation Administration (FAA) standards and procedures. Work leading to its completion consisted of three parts: a literature and experience review, field sampling and analysis of construction density of airport pavements, and a survey of organizations involved in airport and highway pavement construction. The literature review covered highway and airport joint construction techniques, experiences, and reports of public and private organizations. Information was examined for useful joint and mat construction data and for potential improvements in construction techniques and specifications. Construction techniques for making joints were summarized. Field sampling and analysis consisted of examining the effects of manual and mechanical joint-forming techniques on constructed density at three FAA airport projects. Densities in the interior portions of paved areas were also analyzed. Data indicated that interior and joint portions of pavements were different when characterized by density. The survey portion included (1) developing a hot-mix construction and performance questionnaire for organizations; (2) distributing it to state highway agencies, FAA airports, U.S. Government offices and a few non-U.S. locations; and (3) analyzing the completed responses. The intended audience was pavement owners, designers, specifiers, and contractors. Responses from 130 organizations were presented on a question-by-question basis. Some of the overall report findings indicated that airport runway longitudinal construction joint lengths easily exceed nine times the length of runways, creating a huge maintenance problem if they are not durable enough to resist traffic and environmental conditions. No single large-scale, long-term study comparing hot-mix jointing techniques was found in the literature. Recommendations for new or revised joint density criteria were suggested for FAA P-401 specifications.

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PREFACE

This technical report is the result of a research effort to summarize the state of the art of constructing joints in hot-mix airport flexible pavements. The Federal Aviation Administration of the U.S. Department of Transportation provided funding for examining construction jointing techniques and associated problems. Research was performed by the Pavement Systems Division of the Geotechnical Laboratory, U.S. Army Engineer Waterways Experiment Station (WES) located in Vicksburg, MS.

Officials involved in the overall effort at WES were Dr. Robert W. Whalin, Director, and Col. Leonard G. Hassell, Commander. In the Geotechnical Laboratory, the work was accomplished under the direction of Dr. William F. Marcuson III and Dr. Paul F. Hadala with Dr. George M. Hammitt II managing the Pavement Systems Division's team. Mr. Timothy W. Vollor, Chief of the Materials Research and Construction Technology Branch, was directly involved in the accomplishment of the work. The principal investigator was Mr. George L. Regan who wrote the report. Special thanks go to branch co-team members for their support in developing test data for the construction density phase of this project. Ms. Kay Woo and Ms. Benita Allen worked out the details of computerizing a database of responses to the construction jointing questionnaire phase of the study.

Dr. Xiagong Lee, of the Federal Aviation Administration U.S. Department of Transportation, was the project technical monitor.

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EXECUTIVE SUMMARY

This report summarizes the state of the art of constructing joints in airport hot-mix asphalt flexible pavement surfaces. It also discusses and develops criteria for improved Federal Aviation Administration (FAA) standards and procedures. Work leading to its completion consisted of three parts: a literature and experience review, field sampling and analysis of construction density of airport pavements, and a survey of organizations involved in airport and highway pavement construction.

The literature review covered highway and airport hot-mix asphalt joint construction techniques, experiences, and reports of public and private organizations. Information was examined for useful joint and mat construction data and for potential improvements in construction techniques and specifications. Construction techniques to build good joints in hot-mix asphalt surfaces were summarized. Among them are:

1. Using echelon pavers (at least two pavers placing mix on adjacent paving lanes) to minimize edge cooling, allowing for hot joint construction. Breakdown rolling will occur while the mixture is still hot, assisting in constructing dense joints. This technique should be used with high-capacity asphalt plants for good results.

2. Construction planning/design should minimize the frequency of longitudinal joints along the central portions of runways and taxiways. The idea is to minimize potential areas of low density that typically show lower resistance to traffic and environmental forces.

3. Mechanical joint forming devices, marketed by at least two companies, may provide more consistent construction joint density than manual manipulation by paving crews. This point was investigated for one of the devices used at three different construction projects. From a statistical analysis of in-place core density produced by manual and mechanical jointing techniques, there was not a significant difference between techniques at the 5 percent level. More study of these types of devices was recommended.

Field sampling and analysis consisted of examining the effects of manual and mechanical joint-forming techniques on constructed density at three FAA airport projects. Densities in the interior portions of paved areas were also analyzed. Data from the projects indicated that interior and joint portions of pavements were different when characterized by density. Some of the findings can be summarized as:

1. Estimated density variances, in squared pcf units, were 2.8, 4.5, and 8.1 for mat interiors with corresponding joint variances of 18.7, 39.8, and 26.2. This indicated that joint density variances ranged between three and nine times that of the interior of paving lanes.

2. Joint construction technique was found to contribute from 62 to 95 percent of the total estimated density variance.

3. In most cases, the average density of four-inch-diameter cores varied in a transverse direction along a 1-foot-wide (6 inches to either side of the joint) strip along abutting

paving lanes. Without reference to the order of lane placement, typical density results were lowest in the center or joint and higher at the edges of the adjacent lanes.

The survey part of the study included (1) developing a hot-mix asphalt construction and performance questionnaire for organizations; (2) distributing it to state highway agencies, FAA airports, U.S. Government offices, and a few non-U.S. locations; and (3) analyzing the completed responses. The intended audience was pavement owners, designers, specifiers, and contractors. Responses from 130 different organizations were presented on a question-by-question basis.

General findings indicated that airport runway longitudinal construction joint lengths easily exceed nine times the length of runways, creating a huge maintenance problem if they are not durable enough to resist traffic and environmental conditions. No single large-scale, long-term study comparing hot-mix jointing techniques was found in the literature. Recommendations for new or revised joint density criteria were suggested for FAA P-401 specifications.

INTRODUCTION

This section is the introducion of this particular study of construction joint-forming techniques. It identifies a driving force behind the search for improved construction methods for hot-mix joints. It also emphasizes joint and interior areas of construction and discusses parameters that may affect compacted density in mats and joints.

Each asphalt surfaced airport has tens of thousands of square feet of runway, taxiway, and apron paving. Longitudinal construction joints account for the major accumulated length of joints on a typical airport runway. Accumulated longitudinal joint length can quickly reach almost ten times the runway length. Like seams in a fabric, asphalt concrete joints have been weak links and locations where damage begins in otherwise good pavement surfaces. Figure 1 shows raveling damage at an airport joint. Since we cannot construct asphalt pavements without joints, we must develop methods and techniques that extend joint durability. Good methods will extend the time between construction and major maintenance due to joint nondurability.

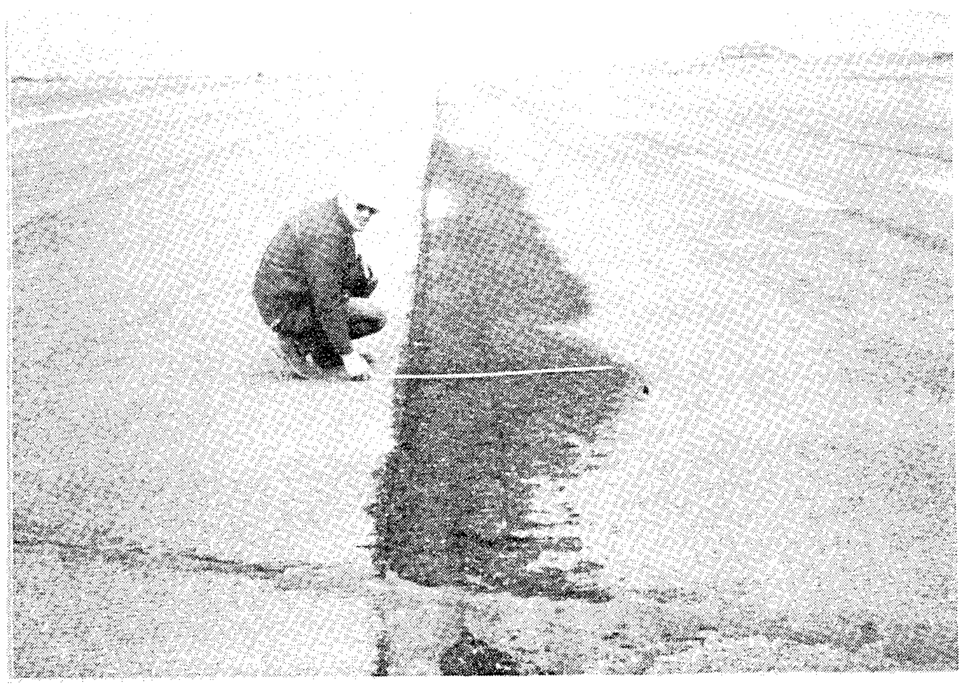

FIGURE 1. RAVELING AT LONGITUDINAL CONSTRUCTION JOINTS

BACKGROUND.

Recent new aircraft designs incorporating small tires and the increased traffic volumes have placed more stress on the asphalt pavement systems. This occurred on military asphalt concrete pavements during and after World War II. It required adjustments to mix design and construction quality verification methods. Laboratory mix design and field construction compactive efforts were increased to build stronger and more durable surfaces.

The U.S. Army Engineer Waterways Experiment Station (WES) led the way to finding solutions to those problems and continues to work toward solutions to newer pavement problems. WES and the Corps of Engineers have recognized the links between airport pavement design and construction. White traced the historical development of military airport hot-mix design and construction control criteria and related them to increased levels of laboratory compaction from the original Marshall effort, to the 50 blow effort, to the 75 blows per side heavy-duty effort [1]. Pavement surfaces that were designed and constructed to the 75 blow standard generally performed well under most traffic conditions. Sometimes rutting occurred when the predominant aircraft contact pressures were above 200 psi. Brown studied over 20 U.S. Air Force taxiways where 240 psi traffic was routine [2]. He found that although the upper surface mixes were designed and constructed according to established heavy-duty Marshall criteria, they often rutted during normal traffic at those stresses.

The basis for Marshall mix design criteria was empirical with few points in this high pressure range of the experience curve. During the 1980's, Regan extended laboratory airport mix design from low- (< 100 psi) and high-pressure (to 200 psi), experience-based technology to engineering fundamentals [3]. This was to support Air Force aircraft traffic with contact pressures of 350+ psi. The method used a higher laboratory compactive effort, simulating anticipated maximum vertical stresses, to develop design mix parameters. A gyratory testing machine was used to determine asphalt content and anticipated after-traffic density. The updated mix design method was successfully field verified in a subsequent Air Force study where full-scale pavements were constructed and traffic tested with actual loads and aircraft wheels. The rut-resistant mix supported 350+ psi stresses for much greater traffic volumes than Marshall-designed mixes.

These developments help ensure construction of hot-mix surfaces that will support anticipated high-stress aircraft loadings. Although these improvements in design and analysis allow more engineering alternatives, long-term maintenance problems can occur at construction joints.

CONSTRUCTION SPECIFICATIONS.

Asphalt concrete construction specifications for airports have developed with increased hot-mix compactive efforts. They, along with workmanship, are the links between design and the final pavement structure. Experience has shown that relatively high densities in both mat and joint areas are necessary for long term flexible pavement durability. Some construction specifications, such as the FAA's P-401, are based on the fact that joints usually receive a lower amount of compaction than mats. This is a viable approach to the problem of constructing durable and uniform hot-mix pavement layers.

To minimize damaging effects of traffic, minimum levels of constructed density are currently specified. In the old method or recipe specifications, contractors were told "how to" compact the hot mix. Later, constructed density was specified using intuitive minimums. Typical of these were specifications that required constructed density of at least a nominal percentage of laboratory compacted density; i.e., "at least 95 percent of design density." Experience and experimentation allowed the development of statistical based specifications. An example of this was the Western Association of State Highway Officials (WASHO) test road specifications where intuitive minimum constructed density was specified for mat interiors.

Increased emphasis on joint construction details during the past thirty years has attempted to ensure more uniform density distribution within constructed hot-mix pavement layers. A 1991 paper, by Rollings and Rollings, showed that the type of hot-mix construction specification and constructed density at several military airport overlay projects were related [4]. For joint densities, a comparison was made between two philosophies of construction. For minimum-value specifications with no incentive for density attainment, required minimum compacted density was specified at 96.5 percent of Marshall laboratory density. Field densities from several airfield construction projects using this type of specification showed that about 99.7 percent of sampled joints were less than the requirement. Conversely, projects that used reduced-pay specifications for joint density with the same target percentage of Marshall laboratory density showed 66.2 percent of joints were below the desired value. This indicated a significant improvement in constructed joint relative density. The implication was that higher joint density and its associated longer-term durability can be achieved when financial incentives for high levels of joint density were included in project specifications.

WHAT MAKES A JOINT DIFFERENT?

Joints are locations where hot-mix paving begins, ends, or borders adjacent to paved areas. They are made when a paver places lanes of material during the normal sequence of the paving operations. Longitudinal joints are parallel to the paving direction and transverse joints are perpendicular. Figure 2 shows typical paving lanes and construction joints.

During construction rolling, the free or unconfined edge of a paved lane typically squeezes outward toward the side of least resistance. Aggregate particles can slough down the unsupported face and form segregated, rough edges (figure 3). If left in this condition before placing an adjacent lane, a zone of lower density material is built into the pavement at joint locations. When this occurs in a surface layer, traffic and weathering can interact and dislodge or ravel particles from the low-density areas. This usually progresses to an accelerated state of wear or disintegration that appears as gaps between adjacent paving lanes. In highway construction, this may not appear significant because longitudinal joints usually occur between vehicle pathways. On airport pavements, joint location and traffic related deterioration can be directly affected by aircraft pathways due to variable undercarriage dimensions.

There are several parameters that can indicate differences between a hot-mix edge or joint and a mat interior area. One of the most obvious differences is that joints are built where two edges or discontinuities join and mat interiors are continuous. Figure 4 shows these areas on a schematic pavement surface.

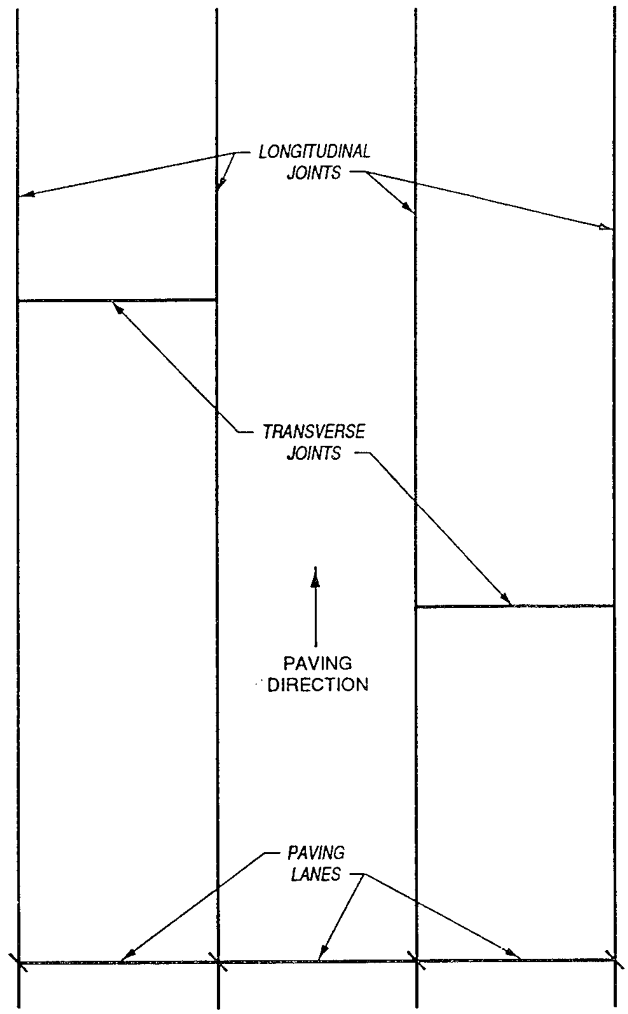

FIGURE 2. LONGITUDINAL AND TRANSVERSE CONSTRUCTION JOINTS AND PAVING LANES

Cooling and compaction behavior differences between interior and edge portions of paved lanes may be major factors that influence the construction process and final density. The presence of joints requires breakdown compaction rollers to deviate from uniform rolling patterns; this is shown in figure 5. Other factors such as levels of internal heat and paver associated manipulations may also influence constructed joint and mat density. Table 1 lists some of the similarities and differences between interior and edge areas of a paved surface.

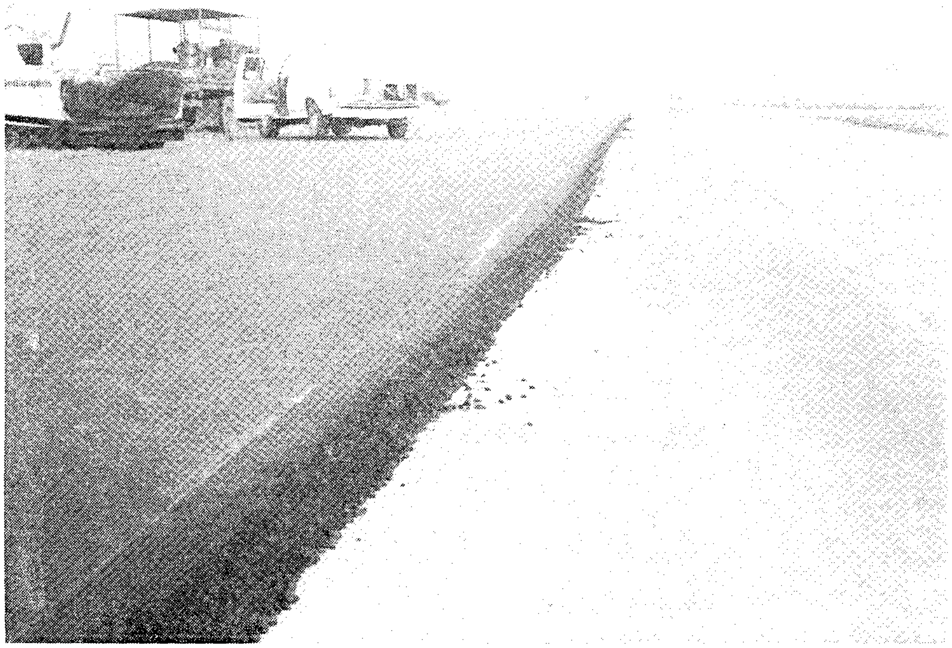

FIGURE 3. UNCONFINED EDGE OF A PAVING LANE (NOTE MIX ALONG EDGE)

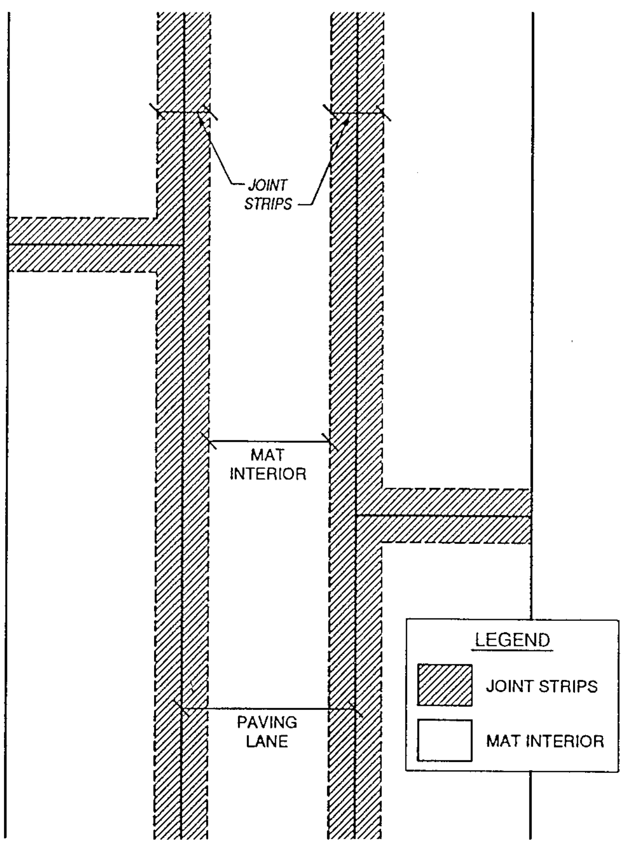

FIGURE 4. JOINT STRIPS AND MAT INTERIOR AREAS

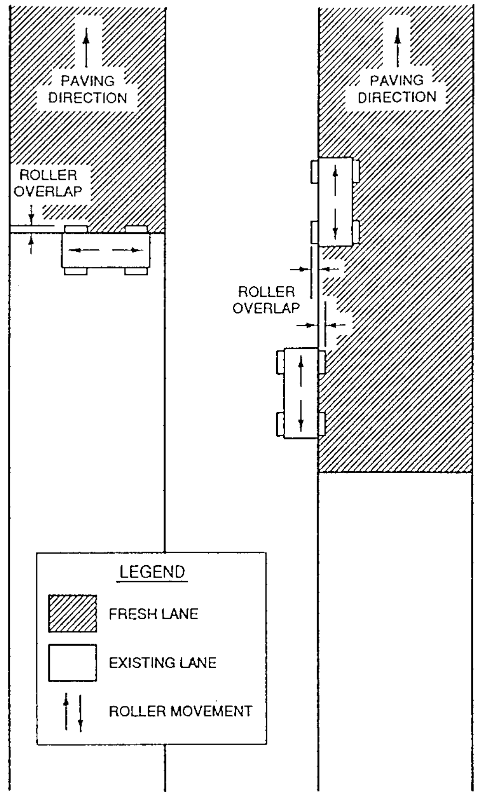

FIGURE 5. INITIAL ROLLING AT TRANSVERSE AND LONGITUDINAL JOINTS

TABLE 1. PARAMETER DIFFERENCES AT MAT AND JOINT AREAS OF CONSTRUCTED FLEXIBLE PAVEMENTS

Parameter	Pavement Area	
	Mat (Interior)	Joint (Edge-Edge)
Project mixture	Same	Same
Construction continuity	Continuous	Discontinuous
Lateral restraint	High	High for confined edge; very low for unconfined edge
Paver associated:		
Alignment	Not critical	More critical
Mix distribution	Critical	Critical
Initial compaction	Same	Same
Internal heat of mix	Higher	Lower
Cooling rate of mix	Lower	Higher
Mix manipulation, by hand, behind paver	Minimum	Higher
Roller compaction	Constant	Possibly more variable
Final density	Higher	Lower
Tensile strength	High	Probably lower

OBJECTIVE AND SCOPE.

This study was sponsored by the U.S. Department of Transportation's Federal Aviation Administration as part of a larger effort by the U.S.A.E. Waterways Experiment Station to develop improved durability criteria for airport pavements. This study was designated Task 4 on the densification of bituminous hot-mix surface course construction. Its objective was to review the current state of the art of constructing improved joints in airport pavements and to determine construction methods that assure that paved mat edges at construction joints are compacted to densities required by FAA in Item P-401 specifications. Work was to include field density testing at joints and mat interiors on projects where different potentially effective jointing techniques were used. The objective was also to develop or prepare criteria that may be used by the FAA to establish improved construction standards and procedures for hot-mix joints.

According to general objectives, this task was subdivided and accomplished in three phases. The first phase was a literature review. It included engineering experiences and judgments that have evolved through years of airfield, laboratory, and construction work. Phase two was field work and included data development from asphalt mix construction at airports and interviews with personnel that have developed construction equipment and evaluated density results from experimental construction jointing methods. The final phase of the study was to develop a questionnaire on hot-mix joint construction, distribute it, and summarize responses.

LITERATURE REVIEW

This section summarizes literature that documented hot-mix joint construction techniques and engineering experiences. The literature consisted of items that were both general and specific in terms of numerical data and techniques. During this review, papers and technical reports with specific data or recommendations are reviewed separately. Author and year headings are used. A brief literature summary is included at the end.

This literature search found a variety of construction manuals, a recently published textbook, and engineering technical papers that discuss joint densification in bituminous hot-mix construction [4-20, 23, 24]. Manuals generally discuss joints from a basic procedural perspective. They provide basic definitions, explanations of the purposes and types of equipment, and procedures used by construction personnel at the job site. An Asphalt Institute paving manual [5] presented good information on asphalt paving techniques. Other manuals give general information on joints but do not provide data for comparison of construction methods [6, 7]. The Corps of Engineers and U.S. Air Force technical manual on bituminous pavement standard practice has provided guidance in preparing plans and specifications for military bituminous paving work since its 1987 revision [8].

A handbook that specifically addressed detailed hot-mix asphalt paving was published by both the FAA and the Corps of Engineers in 1991 [9]. It was an effort that included input from many organizations including the Transportation Research Board, American Association of State Highway and Transportation Officials, Federal Highway Administration, Federal Aviation Administration, and the U.S. Army Corps of Engineers. It is a handbook for quality assurance personnel. Section 5 contains a good summary of longitudinal and transverse jointing information with photographs of construction and rolling operations.

A textbook on hot-mix asphalt was published in 1991 by the National Asphalt Pavement Association, NAPA [10]. Information on materials, design, and construction were included. Its chapter on construction and equipment was detailed and covered mix manufacture, placement, and rolling compaction.

SUMMARY OF JOINTING STUDIES: PAVING DATA AND SPECIFICATIONS.

Several papers that specifically summarized joint density data were found in the literature [11, 12, 16-19]. In 1964, a paper by Foster, Hudson, and Nelson [11] summarized a study of construction techniques that were applied to highway pavements in the states of Maryland and North Carolina. During the 1970's, Burns reported an experimental field construction study of vibratory compaction and included summary mat and joint construction data [12]. During and after the late 1980's, other papers were written on specific work involving airport and highway pavement joints and joint-forming techniques [13-19].

Organization experiences with asphalt airport construction were summarized by Brown, Hermann, and Rollings. Brown wrote Corps of Engineers' experience [14]. From private industry, Hermann presented experiences and suggestions on construction specification improvement [15]. Rollings and Rollings summarized pavement problems and failures [4]. In the remainder of this section, papers are summarized individually by author and year of publication.

FOSTER, HUDSON, AND NELSON (1964). Foster, Hudson, and Nelson presented results of experimentation during construction of highways [11]. They showed that severe density gradients existed across longitudinal construction joints in asphalt concrete highway construction. A 50 blows per side Marshall laboratory compactive effort was used to design those mixes. Rolling technique and numbers of passes, cutting and removing cold lane edges, applying a tack material, and applying additional heat to cold edges were tried prior to removing density specimens from the road. Laboratory testing for density and tensile strength was performed. This study proved that asphalt concrete density near unconfined sides of joints was lower than interior mat density and lower than the confined edges. Findings included the following:

1. Hot joints constructed with echelon pavers produced the highest density and best appearing joints; see figure 6 for echelon paving. Hot joints were made when existing paving lanes did not cool very much below initial placement temperature before an adjacent lane was paved.

FIGURE 6. ECHELON PAVING TECHNIQUE FOR PRODUCING HOT CONSTRUCTION JOINTS

2. Semi-hot joints constructed with an overlap rolling technique (rolling with most of the steel wheel roller's weight on the cooler side of the joint) produced the lowest density difference across the joint. Semi-hot joints were defined as joints made when existing paved lanes cooled to temperatures of 120 to 140°F before an adjacent lane was paved.

3. No definite conclusion could be made on the best technique for constructing cold joints.

Changes in construction and rolling techniques between sampling locations made it difficult to isolate the specific effects of some jointing techniques. To clarify some of the effects, this writer extracted some of the data and formulated table 2 for the Maryland highway sites. The data show that average densities in the mat and densities in hot joints were about the same. On the other hand, density variability for mat interior areas was about twice that of the hot joints. Average tensile strengths of the mat samples were about twice those of the hot joints. This implied better aggregate interlock existed out from the joints. The study showed that constructing asphalt pavements with all hot joints improved density uniformity of the construction, but tensile strength of joints remained lower than mat interiors.

TABLE 2. EXCERPTED DATA FROM MARYLAND HIGHWAY CONSTRUCTION (AFTER FOSTER ET AL., 1964)

Area	Component	Density		Tensile Strength	
		Number of Samples	Average pcf (std. dev.)	Number of Samples	Average psi (std. dev.)
Mat	Near hot joints	3	142.6 (4.55)	1	9.7 (-)
	Near semi-hot joints	4	141.2 (2.27)	-	-
	Near cold joints	6	143.8 (2.80)	6	36.4 (6.22)
	OVERALL	13	142.7 (3.10)	7	32.7 (6.22)
Hot Joint	Near unconfined edge	2	143.5 (1.41)	1	11.0 (-)
	Middle of joint	3	142.7 (2.00)	-	-
	Near confined edge	2	143.6 (0.78)	1	17.1 (-)
	OVERALL	7	143.2 (1.63)	-	-
Joint/Mat	Density Ratio = (143.2/142.7) = 100.4% Std Deviation Ratio = (1.63/3.10) = 52.6%				

- All mat cores were cut 6 feet from unconfined edges.
- Hot Joint—existing paved lane temperature was nearly the same as the freshly paved lane.
- Semi-Hot Joint—existing paved lane temperature had cooled to range 120-140^{o}F before placing new lane.
- Cold Joint—existing paved lane had cooled below 120^{o}F, overnight or longer, before placing new lane.

BURNS (1976). In 1976, Burns reported an experimental study of hot-mix construction compaction [12]. This Air Force sponsored study was conducted at WES to examine the feasibility of using vibratory roller compaction instead of conventional static rollers on military airport and other heavy-duty pavement construction. A test area was paved with surface courses of asphalt concrete and rubberized tar concrete. Each mix was designed to meet 75 blows per side Marshall criteria. Two different vibratory rollers and a combination of conventional static steel wheel and pneumatic tire rolling were used to compact each mix in the field. The type and number of passes of each roller were parameters that were used to compare final in-place densities. Paving lanes were constructed 10 feet wide by 120 feet long with sufficient mix to provide a compacted thickness of about 1 1/2 in. Due to the lengths of paving lanes, cold joints did not occur frequently. Normal jointing techniques (no edge cutting and removal) were used.

Tables 3 and 4, respectively, show data that was excerpted from asphalt and tar-rubber construction data. All joint data and select mat data were included in the tables. Relative compactive effort is indicated by roller passes in mat and joint portions of the paved area. Statistical density data were calculated by this writer and is shown as mean values for lanes and joints and standard errors of the mean. Standard errors for each paving lane's data are shown because the original data was reported as the average of groups of multiple core densities. Overall, table 3 shows that average asphalt concrete joint densities were about 4.4 pcf lower than mat interiors. Constructed joints averaged about 97 percent as dense as mat interior portions of lanes. Joint compactive effort was one factor that likely contributed to lower density. As indicated by Burns, the rolling pattern produced joints that were compacted with 50 percent of the effort applied to the interior.

TABLE 3. WES EXPERIMENTAL MAT AND JOINT CONSTRUCTION: ASPHALT CONCRETE MIX (AFTER BURNS 1976)

Mix	Paving Lane	Compactive Effort		Density (pcf)		Data Groups (Cores)
		Roller	No. Passes	Mean	Std. Error of Mean	
Asphalt concrete 1.5 in. thick	2	VTSW-V	14	148.80	0.775	3(2)
	2-3(J)		5	142.00	---	1(2)
	3		10	146.90	0.721	3(2)
	3-4(J)		5	140.00	---	1(2)
	4		8	144.80	0.458	3(2)
	4-5(J)		5	141.40	---	1(2)
	5		10	145.05	1.775	4(2)
	8		12	147.83	0.416	3(2)
	8-9(J)		5	143.00	---	1(2)
	9		10	146.80	0.721	3(2)
	9-10(J)		5	143.00	---	1(2)
	10	VTSW-S	12	146.20	0	2(2)
	11	VTSW-V	10	147.97	1.002	3(2)
	11-12(J)		4	146.50	---	1(2)
	12		8	146.63	0.773	3(2)
	14		10	146.80	0.700	3(2)
	14-15(J)		4	141.00	---	1(2)
	15		6	149.17	1.193	3(2)
	17	STSW-PTR-STSW	2-6-2	144.77	1.701	3(2)
	17-18(J)			140.90	---	1(2)
	18			145.20	0.458	3(2)
Overall Mat Density Average				146.66		
Overall Joint Density Average				142.23		
(Joint/Mat) Density Ratio				96.98%		

VTSW = Vibratory tandem steel wheel roller. Suffixes: -V is vibrating mode and -S is static weight compacting mode.

STSW = Static tandem steel wheel roller.

PTR = Pneumatic-tired roller.

Table 4 gives similar information for the rubberized tar mix construction. The difference between joint average density and mat average density was about 10 pcf, a much larger difference compared to the asphalt mix. Joint average density was about 93 percent of mat average density. The difference between asphalt and rubberized tar joint densities may have been due to differences in mix production temperatures and differences in cooling rates of the binders. Asphalt concrete was produced at about 300°F and rubberized tar mix was produced at about 220°F. From a joint construction point of view, this study showed that dense joints could be constructed with a heavy-duty asphalt mix and vibratory compaction. It also showed that high-density joint construction with a heavy-duty, rubberized tar mix was more difficult.

TABLE 4. WES EXPERIMENTAL MAT AND JOINT CONSTRUCTION: RUBBERIZED TAR CONCRETE MIX (AFTER BURNS 1976)

Mix	Paving Lane	Compactive Effort		Density (pcf)		Data Groups (Cores)
		Roller	No. Passes	Mean	Std. Error of Mean	
Rubberized tar concrete	20	VTSW-V	8	149.37	0.603	3(2)
Rubberized tar concrete	20	VTSW-V	8	149.37	0.603	3(2)
	20-21(J)		3	141.20	---	1(2)
	21		6	149.43	0.862	3(2)
	23		10	148.70	0.954	3(2)
	23-24(J)		5	140.00	---	1(2)
	24		10	150.43	1.159	3(2)
	25		8	150.83	2.055	3(2)
	25-26(J)		4	139.00	---	1(2)
	26		8	151.33	1.201	3(2)
	27		8	151.90	0.265	3(2)
	27-28(J)		4	140.50	---	1(2)
	28		6	151.30	1.300	3(2)
Overall Mat Average Density				150.41		
Overall Joint Average Density				140.18		
(Joint/Mat) Density Ratio				93.20%		

VTSW-V = Vibratory tandem steel wheel roller in vibrating mode.

DATA GROUPS (CORES) = Number of density groups used to compute the average; the number of density cores within each group is shown in parentheses. For example, 4(3) means four average group densities were used to compute an average, and each group density was an average of three cores.

LIVNEH (1988). A technical paper written by Livneh and published in 1988 presented results of a field study of jointing techniques during construction of an airfield [13]. Apparently, Livneh's work was based on a scientifically designed experiment that looked at several separate construction operations and their impact on constructed density and tensile strength. Four-inch-diameter cores were removed from the final construction for testing. Method A was a normal semi-hot jointing operation. Four other jointing techniques were used on cold joints that were made the next day or later. Method B was an untreated, normal cold joint. Methods C, D, and E were cold joints with additional operations that included combinations of added heat, cut unconfined edges, and applied tack material before adjacent lanes were paved. All joint construction methods were compared to average density results from specimens taken from the interior part of paving lanes. Experimental factors were changed in a methodical order for an analysis of changes in density and tensile strength.

Table 5 was assembled from information provided in Livneh's paper. Most of the data plots were tensile strength versus percentage density. Density data in the table were extracted from the plots. The table layout shows the experimental factors and how they affected the average relative density of each joint construction method. Constructed densities are shown relative to Marshall laboratory density. This data showed that mat interior density was significantly higher than the best jointing technique, the same day (semi-hot) untreated joints. Data also show that the variability of the same day joints was almost twice that of the mat interior portion of paving lanes.

TABLE 5. SUMMARY FROM AIRFIELD JOINT CONSTRUCTION EXPERIMENT (AFTER LIVNEH 1988)

Construction Method	Experimental Factors					Percent Marshall Density	
	Mat or Joint Area	Heat		Edge		Mean (Std. Dev.)	Number Tests
		Internal	External	Cut	Tack		
A	Joint	Medium	No	No	No	96.8 (2.9)	31
B	Joint	No	No	No	No	95.3 (1.2)	3
C	Joint	No	No	Yes	Yes	95.6 (2.0)	9
D	Joint	No	Yes	Yes	No	95.2 (1.4)	17
E	Joint	No	Yes	Yes	Yes	95.8 (0.3)	8
Mat	Mat	High	No	No	No	100.2 (1.7)	54
Total							122

where: A was a semi-hot (same day) joint,
B was a cold (next day) joint,
C, D, and E were cold joints, and
Mat was the interior nonjointed area.

Based on his findings, Livneh suggested the following:

1. Not enough effort has been put into compacting construction joints on airfield projects.

2. The definition and construction techniques applied to semi-hot joints, as defined by Foster et al., should be changed. Livneh noted that when a hot mat is placed adjacent to one that has been in place for 1 to 2 hours it probably should be classified as a cold joint and treated as one.

3. Cold joint construction techniques in order of preference were:

    a. Cutback (cut and remove) the edges, tack the surface, apply additional heat to the new edge, then pave and compact.

    b. Cutback the edges, apply heat, then pave and compact.

BROWN (1984). Several items were discussed by Brown, including paver-spreader operations, roller types and operations, and constructing longitudinal joints. Typical construction and maintenance problems that are associated with joints and their construction include raveling, cracking, lack of smoothness, and bird bath depressions. Based on Corps of Engineers experience with heavy-duty pavement construction, Brown made these recommendations for obtaining smooth dense longitudinal joints [14]:

- Ensure that the outside free edge of each paving lane is properly compacted; this is difficult. Rubber-tired rollers should be kept at least 5 to 6 inches away from free edges to prevent rounding and distortions that cause uneven joints. Figure 7 illustrates this point.

- Consider thickness effects on density. Layers that compact to 1 1/2 inches cool faster and do not deform as much laterally as those that are 3 inches or greater in thickness.

- Place adjoining paving lanes while the first placed lanes remain hot.

- When the unconfined edges of lanes are poorly compacted, cut and remove about 2 inches of material along the edge before paving the adjacent lane. Cutting wheels can be used.

- The paver should overlap a previously placed mat 2 to 3 inches during paving. Excess mix on the surface of the existing mat should be raked immediately toward the fresh lane before compaction begins.

- Joint heaters, for reheating cold edges of paved mats, had not proven very effective in improving joint density. The distribution of added heat had been sporadic.

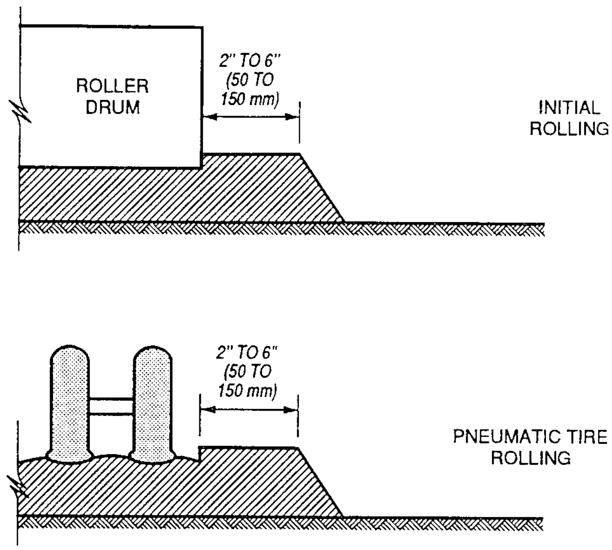

FIGURE 7. ROLLING COMPACTION NEAR UNCONFINED EDGES OF LONGITUDINAL JOINTS

HERMANN (1991). Hermann's airport pavement experiences showed an emphasis relative to the need to consider design and specification revisions for hot-mix asphalt concrete and portland cement concrete [15]. He emphasized that experienced paving crews in airfield or other severe load pavement construction are rare. He noted that highway longitudinal joints are normally located between traveled lanes and are not subject to severe and direct wheel load applications that are common with airport traffic. Airfield longitudinal joints, especially in the central portions of runways and taxiways, are subject to direct application of severe loads that has caused severe cracking in surface layers.

His suggestions to minimize joint problems at airfields included:

1. Specify construction joint locations to minimize direct load application to longitudinal joints.

2. Revised construction specifications should:

   a. Require more field density tests in construction joints.

   b. Advise the contractor of joint density testing requirements (in addition to interior mat density testing requirements) and specify a required course of action for correcting poor joints.

c. Consider the use of multiple pavers in echelon for the central portions of paved areas where aircraft wheel loads are concentrated. This would minimize occurrences of cold joints and increase the chances of constructing denser joints. The basis of this suggestion was an assumption that a contractor's production plant will have adequate capacity for such an operation.

ROLLINGS AND ROLLINGS (1991). Rollings and Rollings [4] discussed several failures in pavements, including asphalt concrete. They included previously unpublished data on asphalt pavement airfield construction that was summarized by Lynch at WES. The data were based on constructed asphalt concrete density relative to 75 blows per side Marshal! density. The type of specification that defined construction quality was classified as either minimum value or reduced pay. Half of the summary data was from minimum value specified projects and half was from reduced value specified projects where contractor pay was adjusted for a more nonuniform density in the finished pavement. Table 6 summarizes Lynch's review of bituminous concrete surface and intermediate course data.

One of the main points of the paper was that contractors can achieve better hot-mix asphalt density results if there is a financial incentive. Reduced-pay schedules in contract specifications for joint and mat density can provide that incentive.

TABLE 6. RELATIVE ASPHALT CONCRETE CONSTRUCTED DENSITY BY USE OF DIFFERENT SPECIFICATION METHODS (FROM ROLLINGS AND ROLLINGS 1991)

Basis for Requirement	Percent of Laboratory Density			
	Mat Density		Joint Density	
	Mean	Coefficient of Variation	Mean	Coefficient of Variation
Desired value	98-100	---	≥ 96.5	---
Minimum-value specification	97.5	0.5	93.1	1.3
Reduced-pay specification	98.0	0.3	96.3	0.5
Coefficient of variation (%) = (standard deviation/mean) x 100				

BAKER AND OTHERS (1990). A study of longitudinal joint construction in highway hot mixes was presented by Baker et al. in 1990 [16]. Five years of New Jersey DOT paving experience with a wedge plate paver attachment was summarized. The authors indicated that New Jersey achieved more uniform construction densities within a foot of longitudinal joints when wedge plate built slopes (1:3 vertical to horizontal) were used on unconfined edges of paving mats. Their comparisons were relative to conventional butt joints with vertical edges. Wedge plates were attached to hot-mix pavers along unconfined edges to form tapered edge ramps for safe vehicle operations on partially paved highways.

HUGHES (1989). Hughes, in NCHRP Synthesis 152, discussed specifications and recommended highway practice for constructing cold longitudinal joints [17]. Chapter four was based on a review of literature, results of a Transportation Research Board questionnaire on state highway construction specifications, and FAA P-401 specification related developments. State highway department specifications were found highly variable in their payment schedules for similar degrees of hot-mix compaction. No state had separate schedules for joint construction. The FAA had incorporated joint-specific compaction schedules in their airfield construction specifications but not without controversy on the pay schedule for various degrees of compaction.

This synthesis recommended these two methods of constructing highway longitudinal joints.

1. When paving is isolated from traffic:

    a. Keep the paver close to existing paved lanes. Overlaps of hot mix on the existing lane should be maintained at 1 to 2 in.

    b. Lute or push the overlapped mix to a vertical position adjacent to the joint.

    c. Level the humped mass with the breakdown or initial roller while the mix is hot.

    d. Apply up to two additional passes to an area 12 to 18 in. wide adjacent to joints.

    e. Use proper rolling procedures for static or vibratory rollers.

2. When paving adjacent to traffic lanes:

    a. Use a wedge jointing technique on the unconfined edges.

    b. Maintain a paver overlap of 1 in. on existing lanes and do not use a lute at the joint.

    c. Use proper rolling procedures for static or vibratory rollers.

BERNARD AND GRAINER (1991). In 1991, Bernard and Grainer of the New York Department of Transportation reported an experimental use of a device that attached to a paver's screed to improve highway joint construction [18]. The proprietary attachment had been developed by Alternate Ways To Rebuild Roads Inc. (AW-2R) of Clifton Park, NY. It was used and evaluated on a New York state highway construction project during the 1990 construction season. Work was done on a section of Route 145 near East Durham. An inverted v-shaped mound of material was built into the paving lanes near longitudinal joints. As the paver moved, the hot mix was distributed and forced through a slot in the screed to form the mound along the paving lane junctions. The mix was compacted by static steel wheel rollers using two different rolling patterns. For comparison, other joints were constructed by manual use of a lute or rake. Among conclusions of the report were:

- When constructing longitudinal joints, poor density occurs when the construction sequence omits overlapping the paver at the confined edge or omits raking mix from the top of the existing lane. Improper manual raking of the hot mix along the joint also results in poor density.

- It is important to leave extra asphalt concrete mix along the joint so it can be compacted into the hot side of the joint.

- During paver positioning and paving along a joint, it is important to overlap the existing lane. This provides extra material that may compensate for side to side drift of the paver.

- The AW-2R screed attachment was found capable of forming extra material along the longitudinal joints similar to the manual raking method.

- Side to side alignment of the paver becomes more critical with the screed attachment because overlapping is eliminated. This can cause too much or too little mix to be deposited along the joint and create more problems.

- Core densities along the hand prepared and the mechanically formed joints showed that densities were different. The mechanically formed joint average density was 142 pcf and the manually formed joint average density was 136 pcf. This difference was also affected by different rolling patterns used on each type of joint. Static compaction rolling was performed on each type of joint, but rolling was started from the hot side at mechanically jointed areas. Rolling started from the cold side at manually jointed areas.

Due to changing two experimental factors at the same time, jointing technique and rolling pattern, an observed change in joint density could not be singularly attributed to either factor.

BURATI AND ELZOGHBI (1987). Burati and Elzoghbi reported a study of joint densities in hot-mix airport pavements [19]. The study was directly related to FAA's later incorporation of statistically based acceptance plans for joint density into its P-401 bituminous mix specification. Primary interest of this review was core-based density sampling from mat and joint areas of the cited paving projects. Data were given from 1984 construction and testing at FAA Eastern Region airports at Morristown Municipal Airport, New Jersey, and Rochester-Monroe County Airport, New York. Rochester was constructed without pay adjustment provisions in its specifications for joint construction and Morristown's specifications included pay adjustment provisions that were based on joint density.

The authors showed that joint densities were statistically significantly lower than mat core densities at both projects. Joint density variability was significantly higher than mats at Rochester but not at Morristown. Results implied that inclusion of variable pay provisions in the construction specifications helped produce less variable joint density at Morristown.

Table 7 summarizes key data from construction at both airports. This table is based on information in the original reference. It shows density and statistical data for each airport's surface hot-mix construction. Both projects were constructed with density differences between mat and joint areas of 6 to 7 lb per cu ft (pcf). While average mat density of each project and average joint density of each project were not very different, the Rochester project showed less mat density variability but more joint variability than Morristown.

Relative variability is indicated in table 7 as a ratio of joint standard deviation to mat standard deviation within a construction project. Rochester joint construction densities were almost twice as variable as those at Morristown when compared to their respective mat standard deviations. Ratios were 2.05 at Rochester and 1.18 at Morristown.

TABLE 7. SUMMARY AIRPORT CORE DENSITY DATA
(AFTER BURATI AND ELZOGHBI 1987)

Quantity	Airport Paving Project	
	Rochester	Morristown
Mat Average Density, pcf (% lab)	150.7 (98.2)	151.5 (97.0)
COV, %	1.39	2.18
Number of cores	72	40
Joint Average Density, pcf (% lab)	143.3 (93.4)	145.6 (93.2)
COV, %	3.00	2.68
Number of cores	72	40
Laboratory Marshall Average Density, pcf	153.4	156.2
Variable Pay Provisions in Specifications Based on:		
Joint Density	No	Yes
Mat Density	Yes	Yes
Average Density Ratio (Joint/Mat), %	95.09	96.11
Standard Deviation Ratio (Joint/Mat), %	204.8	118.2
Joint-Mat Density Correlation Coefficient	0.414 (NS)	0.666 (S)
COV = Coefficient of variation = (standard deviation/average) x 100% NS = Not statistically significant S = Statistically significant		

This paper also compared average densities from each daily production lot at mat and joint areas. A project correlation between mat and joint density, on a lot basis, was computed for each airport. The difference between the two paving projects can be seen in the correlation coefficient. The 0.666 value for Morristown's 10 lots was significantly better than the 0.414 value for the 18 lots at Rochester. This data indicated that the constructed surface at Morristown was closer to uniform density conditions than Rochester's surface. The study of statistics shows that as two random variables, such as joint and mat density, approach the same average value and their standard deviations or variances also approach common values, their correlation coefficient approaches a value of 1.

The Burati-Elzoghbi study influenced the FAA's use of joint density in acceptance of bituminous airport pavements. The current P-401 specification dated July 7, 1992, [20] includes basic acceptance criteria developed by Burati and Elzoghbi. Percent within limits (PWL) criteria are used to relate mat construction quality to contractor pay. It is a statistically based measure of construction conformance to specification requirements.

COMPILATION OF JOINTING TECHNIQUES.

Engineering construction experiences, technical literature, and construction manuals and handbooks were reviewed to list general techniques for constructing longitudinal and transverse joints.

LONGITUDINAL JOINTING METHODS. Most techniques were for longitudinal joint construction; however, they should be applicable to transverse joints under the proper conditions. Following are general methods that have been used.

No Treatment. The paver spreads hot mix in a layer with vertical edges at each side of the machine. The work crew does not manually push on the unconfined edge with a lute. As the lane is rolled, particles of mix along the warm unrestrained edge slough off and roll down the face to form a natural angle of repose. The density distribution along the edges, after compaction, are approximately random. This joint construction method should be the method of comparison or baseline for all other methods. Figure 3 is a view of an untreated longitudinal unconfined edge joint. Figure 8 shows the technique.

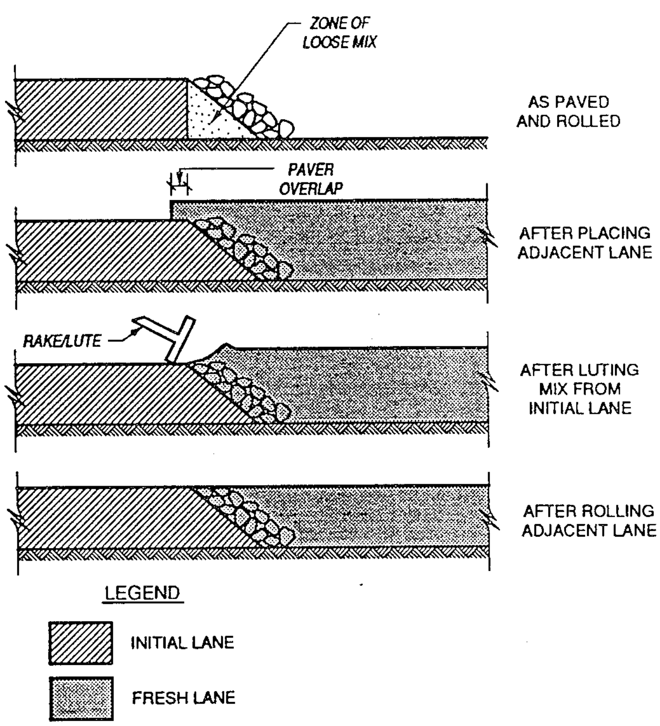

FIGURE 8. NONTREATED LONGITUDINAL JOINT CONSTRUCTION

Bumping Unconfined Edges. This method is similar to the one above but a crew member uses a lute to bump or manually shape the unconfined edge as the paver moves. Figure 9 illustrates the edge bumping technique. Compaction rolling occurs after this operation.

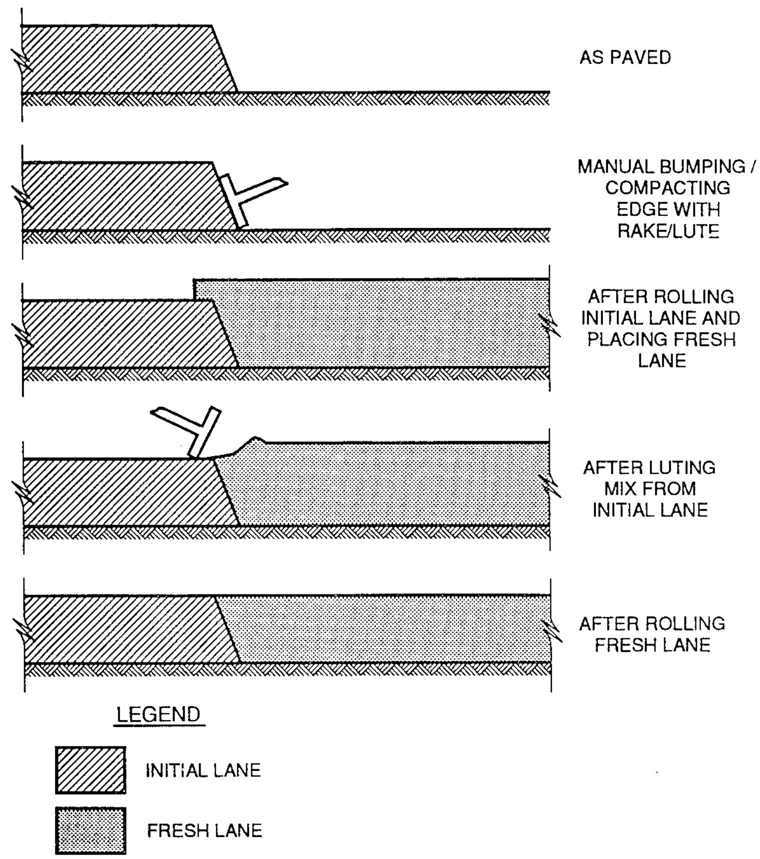

FIGURE 9. MANUAL EDGE BUMPING AT LONGITUDINAL JOINTS

Edge Cut and Removal Technique. When paving adjacent to a previously paved lane, a cutting device is often used to cut away loose and cold edges (those at or near surface air temperature). The low-density edge mix is removed prior to paving an adjoining lane. Usually a vertical to near vertical cut is used. Cutting wheels, if used, are usually mounted on one of the contractor's rollers, graders, or other piece of equipment. Internal combustion engine power saws, with water cooling the cutting blade, are also used. Figures 10-12 show edge cutting equipment. If enough effort is exerted, a potential source of time related joint disintegration and associated maintenance problems can be eliminated. Figure 13 summarizes the basic technique.

The objective is to remove low-density areas of mix along unconfined edges during construction before weather and traffic remove them at an inconvenient time later in the pavement's life.

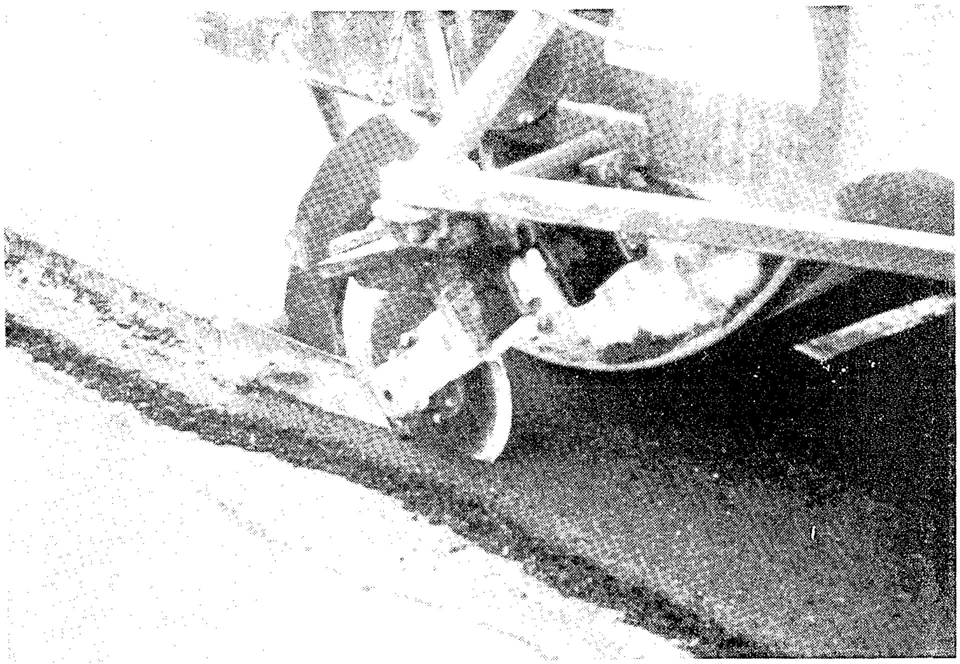

FIGURE 10. CUTTING BLADE ATTACHED TO A ROLLER

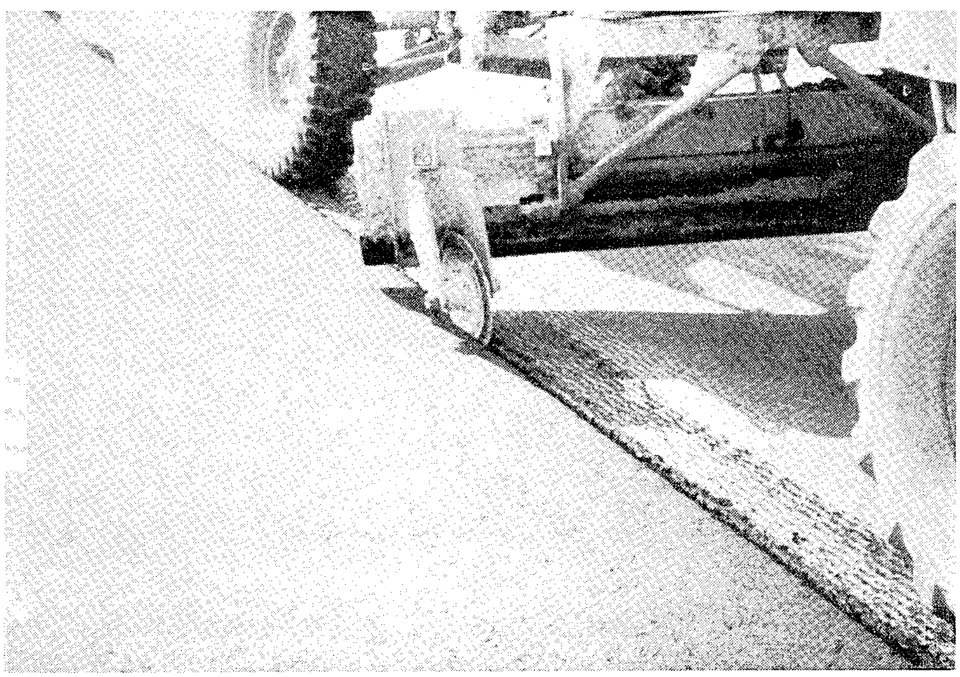

FIGURE 11. CUTTING BLADE ATTACHED TO A GRADER

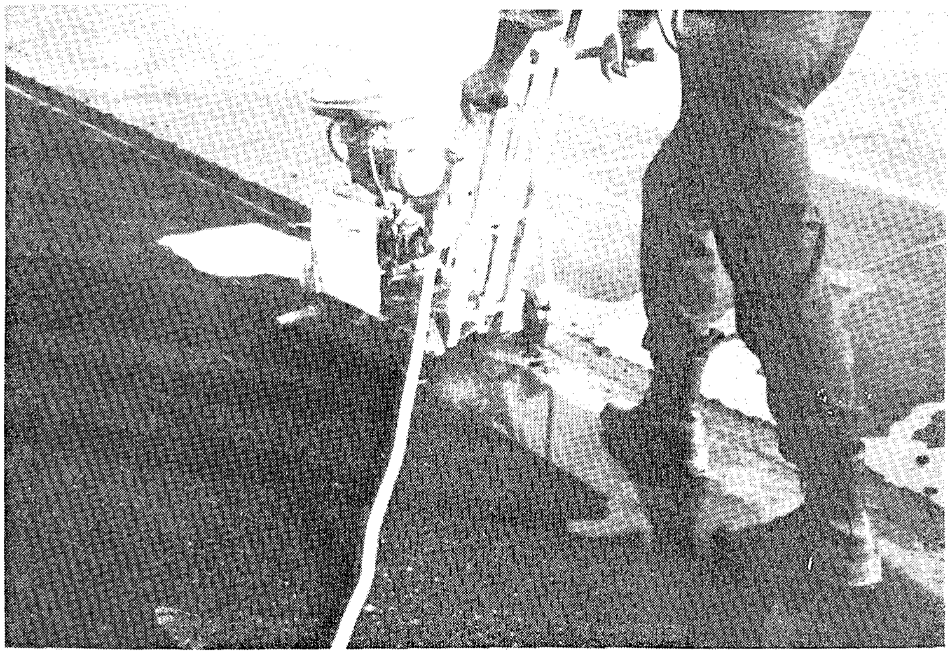

FIGURE 12. ENGINE-POWERED WATER-COOLED PAVEMENT SAW

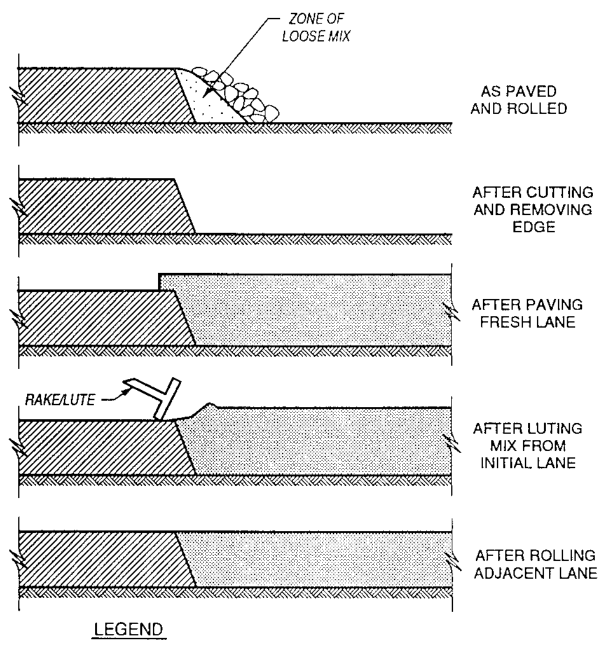

FIGURE 13. CUT AND REMOVAL JOINT CONSTRUCTION

Wedge or Tapered Edges. This technique uses attachments to the paver to build in a stable edge slope on the unconfined edge of the paved lane. Slopes of 1:6 and 1:3 vertical to horizontal have been used [16]. Arizona and Michigan DOTs have used 1:6 slopes with New Jersey DOT using 1:3. These slopes were selected by state transportation officials for highway traffic safety reasons. Figure 14 schematically shows this technique.

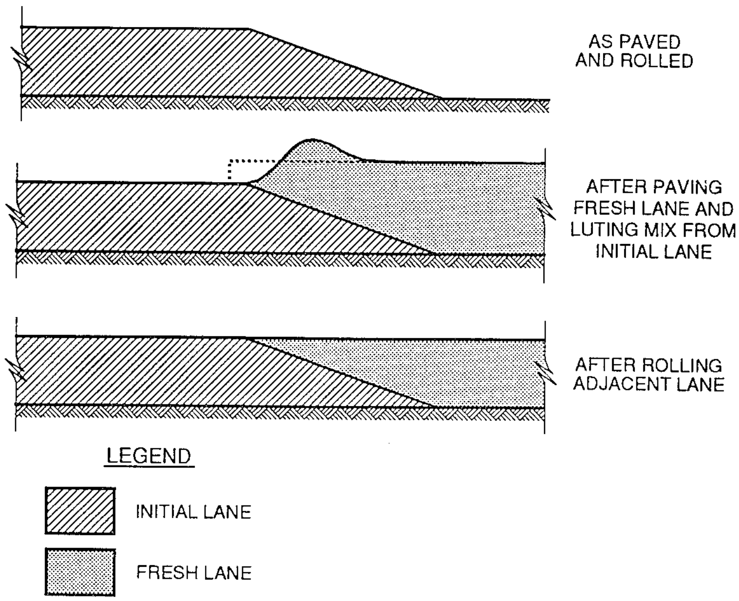

FIGURE 14. LONGITUDINAL WEDGE JOINT CONSTRUCTION

Compaction along the angled unconfined edge was applied with a small cylindrical-shaped wheel that was pulled by the paver at Michigan highway sites. Figure 15 shows the roller.

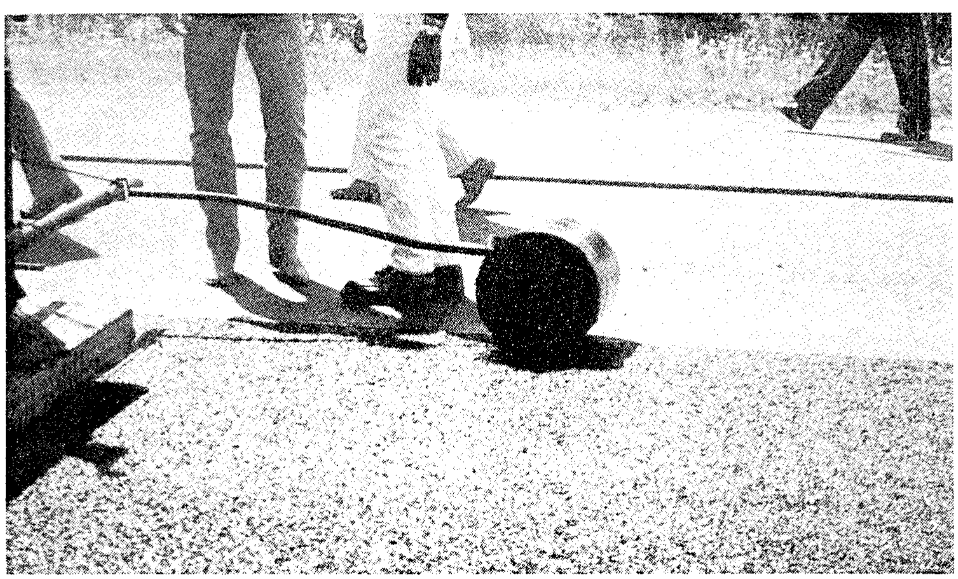

FIGURE 15. COMPACTING AN UNCONFINED WEDGE FACE
(HIGHWAY CONSTRUCTION)

The purpose of the technique is to eliminate edge drop off hazards when pavements must remain open to traffic. The wedge shape defines a uniform edge shape and is a better alternative to leaving edge shape and density to chance. A potential problem with this technique is that, over a period of time, wear and disintegration may occur at the low-angled joints and possibly lead to raveling or delamination along the confined side of the joint.

Figures 16 through 19 show this technique using a 1:6 slope at a 1992 Michigan DOT construction project along a section of Interstate 69.

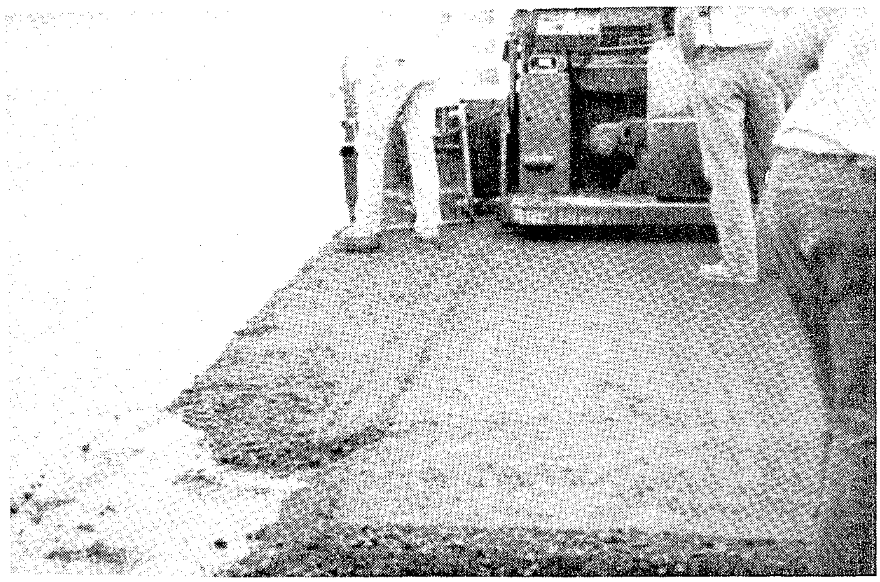

FIGURE 16. MICHIGAN HIGHWAY PAVING WITH WEDGE OR TAPERED JOINT PAVER ATTACHMENT

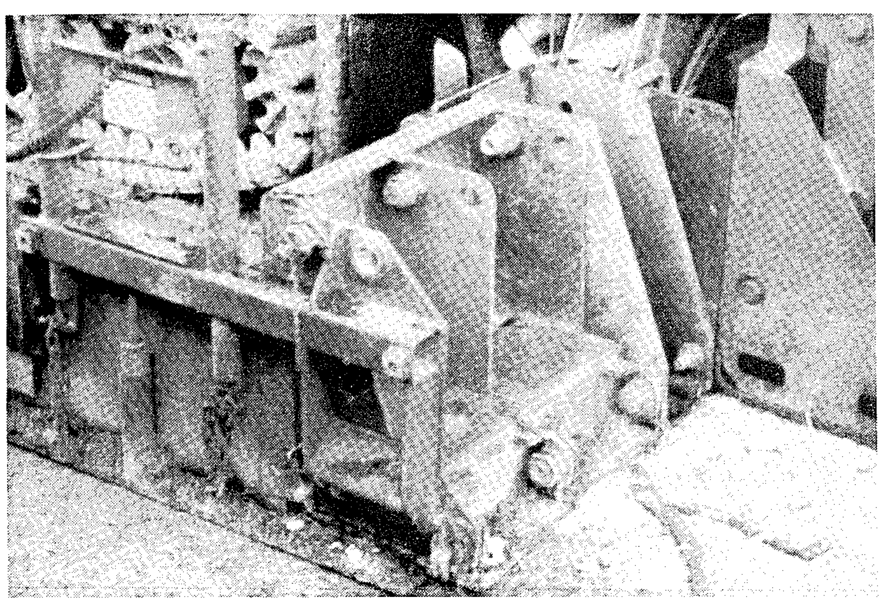

FIGURE 17. CLOSE-UP OF A WEDGE PLATE

FIGURE 18. COMPACTING A WEDGE-FORMED PAVING LANE

FIGURE 19. COMPLETED HIGHWAY LANE WITH TEMPORARY MARKINGS AT WEDGE

AW-2R Attachments to Hot-Mix Pavers. These are proprietary and patent-applied-for devices that were developed for attachment to hot-mix pavers [21]. According to Robert Sovik of AW-2R, the AS Jointer allowed an extra volume of hot mix to be shaped in a geometric prism shape above normal mat thickness in the joint areas adjacent to previously placed paving lanes. The shape was triangular or inverted v. Rolling equipment would compact this extra material against the confining mat and theoretically improve the likelihood of achieving higher joint density. This jointing technique has been used as early as October 1988 on a city street in Albany, New York. Later use of a revised version of this device has been documented by the New York State DOT in reference 18.

Other proprietary equipment has been developed by AW-2R since those early efforts [22]. Current developments include devices that are claimed to assist in constructing more dense joints. The Joint Maker was made to attach to pavers at locations behind the augers and ahead of the screed to force more mix into the joint area near existing lanes. Another device was developed to automatically adjust end gates of pavers and help distribute mix to maintain a constant overlap of mix as paving occurs next to an existing lane. According to Mr. Sovik, the device automatically follows the edge of an existing lane and adjusts the paver's side-to-side end gate movement and distribution of hot mix next to the confined edge. This device is the Edge Follower. Some of the AW-2R devices are in third generation development and have been used in hot-mix construction.

Some devices such as the Raker Plate simply assist in manipulating hot mix along longitudinal joints prior to roller compaction. Figures 20 and 21 show manual and mechanical means of moving and shaping mix along longitudinal joints.

FIGURE 20. MANUAL SHAPING OF OVERLAPPED MIX ALONG A LONGITUDINAL JOINT

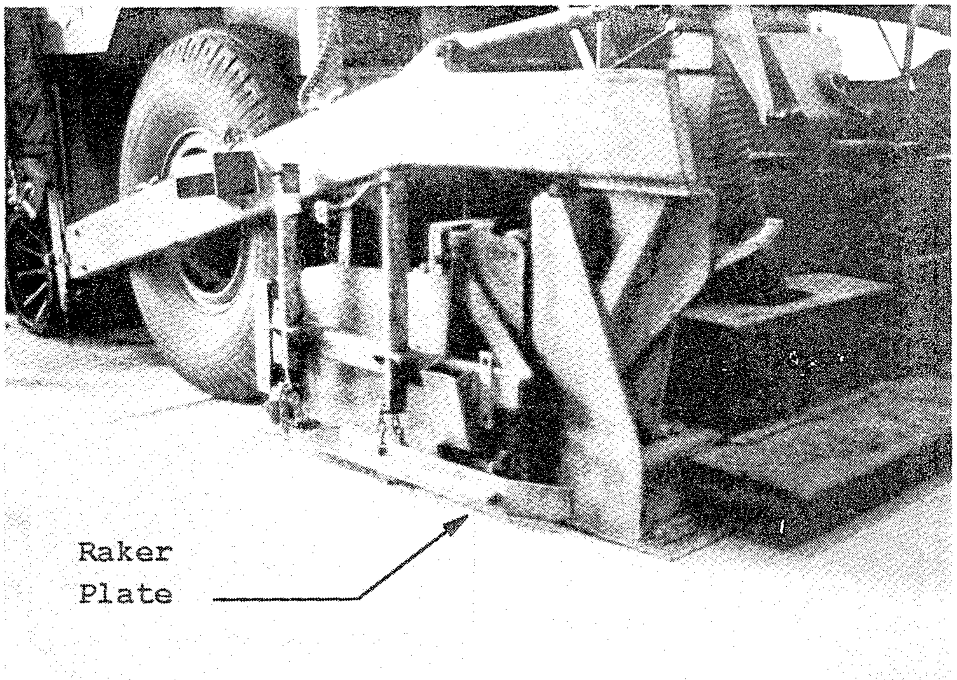

FIGURE 21. ANGLED "RAKER PLATE" ATTACHMENT FOR SHAPING OVERLAPPED MIX ALONG LONGITUDINAL JOINTS

Joint Matching Broom Mounted to Paver. This device was documented in a 1973 issue of Focus, a Federal Highway Administration publication [23]. It was used by an Alaska paving contractor to assist with longitudinal joint construction on highways. Basically, it was a rotating broom assembly with a scraper arrangement for cleaning spilled mix and shaping the mat's edge at the unconfined side of the paved mat. The device was mounted on the catwalk of a paver. The scrapper was angled so that as the paver moved, loose and spilled mix was guided toward the unconfined edge of the paving lane where the rotating broom swept it up and over the edge and broadcast it onto the interior surface of the paved mix. The broom helped shape the edge of the mat while it also cleaned the area where the next paving lane would be placed.

Longitudinal Confinement during Compaction. Additional techniques of confining a hot mix along longitudinal edges were discussed in a National Asphalt Pavement Association (NAPA) publication [24]. A hydraulically controlled, roller-mounted attachment was reported to have been used in construction in France and Germany. The device is claimed to provide restraint to lateral mix movement along unconfined paving mat edges. Japan's use of movable side forms for lateral restraint during compaction was also mentioned; it is apparently similar to wood form restraint at transverse joints.

Application of Heat to Cold Edge of Joint. This technique has been used on numerous projects with various devices. The idea is to apply controlled heat to cold longitudinal edge material prior to placing an adjacent hot lane to form a joint. Heating is normally done by a device that is attached to the paver ahead of the screed-auger area. Figure 22 shows a joint heater operation. Sources of heat are variable, but the technique has been called "infrared heating." For many years, this method was believed to enhance joint compaction, but recently its effectiveness has become questionable [9 and 14]. Refer to table 5 for extracted experimental data showing the possible impact of this technique.

FIGURE 22. PAVEMENT EDGE HEATER WITH ECHELON PAVING

An edge roller/cutter attachment for Bomag brand rollers was noted in a 1992 products publication [25]. It was capable of attaching to tandem rollers and using the roller's hydraulic pressure to restrain and/or cut unconfined edges of paving mats up to 4 3/4 inches thick.

TRANSVERSE JOINTING METHODS. Methods of constructing transverse joints are not as numerous as with longitudinal joints. Transverse joints are different, however, because they are placed perpendicular to longitudinal joints, require rolling operations to substantially deviate from normal routines, and are usually the beginning points for subsequent paving operations.

No Treatment with Edge Cut and Removal. This method of producing transverse joints can be accomplished by simply letting the paver run out of hot mix at the end of a paving lane, using hand work to fill in any gaps with hot mix, then proceed with compaction rolling. Prior to resuming paving, a volume of the cold mat is usually removed by cutting. Figure 23 shows this general technique.

Wood form Confinement. This method uses a wood board or other form of about the same thickness as the compacted mix to confine the mat during rolling; it provides a vertical or butt joint for subsequent paving. Figure 24 illustrates this technique. Heat is automatically applied to cold transverse joints because the paver, with its heated or warmed screeds, is normally started from these locations during later paving operations.

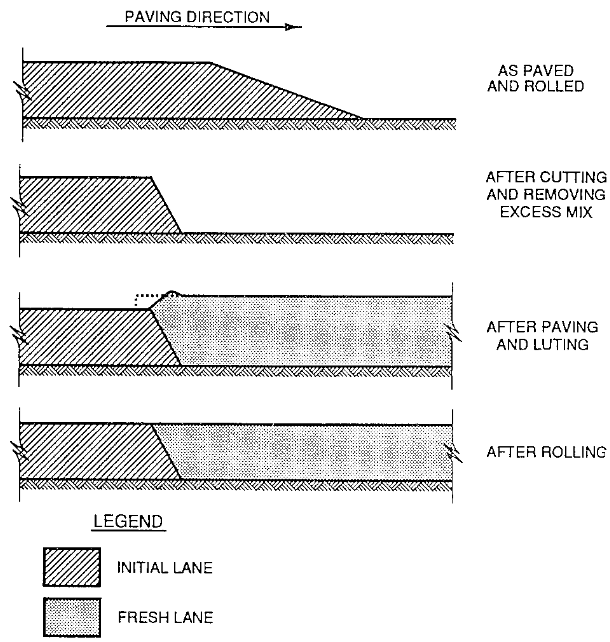

FIGURE 23. TRANSVERSE JOINT FORM AND CUT CONSTRUCTION

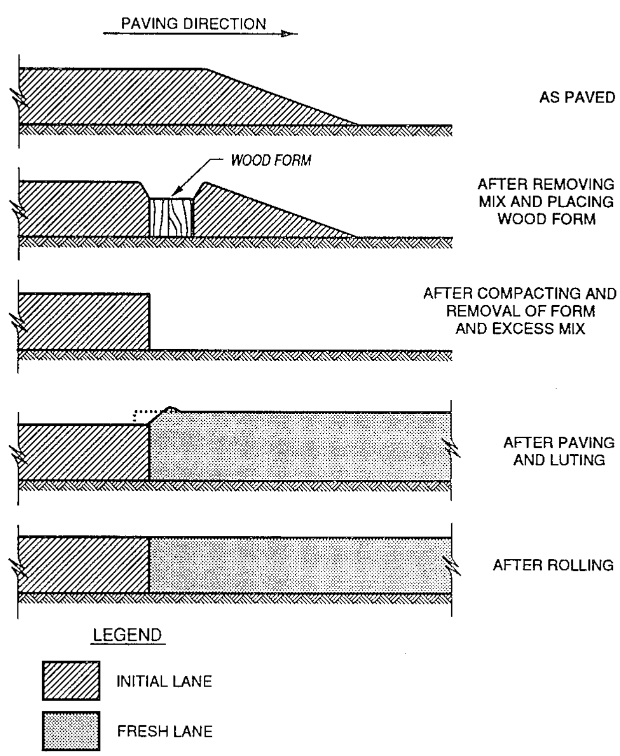

FIGURE 24. TRANSVERSE JOINT FORM AND REMOVE CONSTRUCTION

Adaptations of Other Longitudinal Joint Techniques. Although no information was found on other specific transverse jointing methods, it is not inconceivable that, if properly adapted, longitudinal jointing techniques could be used.

COMBINING JOINTING METHODS. Although discussed separately, the preceding mechanical methods of constructing joints can be used in combination. The only exceptions to this would be the use of methods that counteract each other, such as using wedge plates to form unconfined edges then cutting and removing the edges or forming transverse joints with wood board forms then cutting the edge away.

SUMMARY OF MECHANICAL JOINTING TECHNIQUES.

In this study, mechanical jointing methods were emphasized because of their likelihood of better consistency than manual techniques during pavement construction. Table 8 summarizes mechanical joint construction techniques that were found in the literature.

RELATIONSHIP OF JOINT FORMING TECHNIQUES TO THE PAVING PROCESS.

It should be noted that the preceding mechanical techniques for improving joint density are part of a process of constructing hot-mix asphalt concrete layers. Improved density uniformity across the entire paved area remains dependent on consistent and conscientious application of these techniques during paving. Good roller compaction, the concentration on edges, joints, and interior areas is also needed.

LITERATURE REVIEW SUMMARY.

This section summarized research studies, construction density data, and joint forming techniques that have been used on airport and highway hot-mix paving projects. Emphasis was placed on joint density improvement for better durability. The common thread connecting all the references was the search for better ways of assuring long lasting pavements and problem free joints.

Previous experiences have shown that hot-construction joints made by echelon pavers and good consistent rolling can produce high density joints. When echelon paving is not possible, other techniques such as using short paving lengths can help maintain high edge temperatures for warm or semi-hot joints. When cold joints are necessary, edge cutting and removal operations can be tailored to produce good joint densities. All are dependent on the assumption that good hot-mix construction practice, consistent joint forming techniques, and consistent rolling compaction are used.

TABLE 8. SUMMARY OF MECHANICAL JOINTING TECHNIQUES FROM THE LITERATURE

Organization or Researcher	Year Reported	Mechanical Device	Remarks
Alaska Division, Federal Highway Administration (FHWA)	1973	Joint-matching broom assembly attached to a hot-mix paver. Scraper attachments windrowed loose mix and a rotating broom swept it up and over the unconfined edge while shaping it. This broadcasting excess mix over the mat surface is not a good practice.	Device was developed to produce an aesthetic and geometric highway pavement. It was powered by the paver electrical system or an alternator and has a variable speed control up to 80 RPM.
Arizona DOT and Michigan DOT		Sloping wedge-shaping attachment for the paver (in the screed area); it worked by tapering the unconfined longitudinal edge of the hot mat 2 in. in 12 in. (1 on 6 slope).	Tapering was for highway safety by eliminating drop-offs at partially completed construction sites.
New Jersey DOT	1990	Another wedge making attachment for the paver; it uses a plate that shapes or tapers the mix about 2 in. in 6 in. (a 1 on 3 slope) on the unconfined edge. Paver mounted infrared heaters are standard with this method; they apply heat to cold tapered edges when adjoining lanes are placed.	This method was developed by New Jersey over a period of several years of experimentation.
New York DOT	1991	An inverted V-shaped plate attachment to the paver (in front of the screed) was used to shape and force hot mix into a mound in the vicinity of the confined longitudinal joint. The method was used on highway construction. Density comparisons were made on joints constructed with and without this device.	The device was developed by AW-2R, Inc. of New York State. Other paving aids have been developed by this company.

Mechanical aids, to improve mix distribution and density along paving lane edges, are viable means of achieving high density joints when they can be adjusted for consistent results. The literature revealed innovative methods that were used by individual contractors, states, and developers of proprietary equipment. As indicated, construction joint density has been investigated and emphasized on heavy-duty pavement structures. Not all of the studies showed the same conclusions; results of some studies conflicted with those of others. The common point, however, is that all of the cited studies and references were seeking solutions to the problem of building durable and high-density, hot-mix pavement layers. Techniques or methods that help increase constructed density at joints must show consistently higher results than normal methods before they are considered better.

Paver associated parameters, such as lane alignment and mix distribution within paving lanes, are only part of the solution to better joint density. Proprietary paver-attachable devices such as those developed by AW-2R may help increase joint density.

Paving lane edge restraint and amounts of roller compaction are other parts of the solution. Compaction rolling technique and effort, in passes, at interior and joint areas have a direct effect on density. They must be carefully controlled during airport hot-mix construction. Preventing large compaction related lateral displacements along unconfined edges should improve joint density. This has been done with confining forms and with proprietary roller attachments while compacting near lane edges. When restraints are not available, rolling should be limited to given distances from unconfined edges.

AIRPORT PAVEMENT CONSTRUCTION AND JOINT DENSITY

Three paving projects at two airports were studied for density improvement in construction joints. Both airports were located in the State of New York; they were Albany County Airport at Albany and Saratoga County Airport of Saratoga Springs. Albany County Airport had two projects, runway surface paving and apron paving. They were constructed by two different contractors. Saratoga County Airport constructed new taxiway and runway extensions using one of the two contractors that had paved at Albany County's airport. Each airport had sections of paving where longitudinal joints had been or were undergoing construction with the aid of a special paver attachment. The attachment was a proprietary Joint Maker device that had been developed by AW-2R Inc. of Clifton Park, NY.

Figures 25 and 26 show typical joint construction operations that were used on the projects. Figure 25 shows the proprietary paver attachment in use on a longitudinal joint. Figure 26 shows finish rolling near a transverse construction joint.

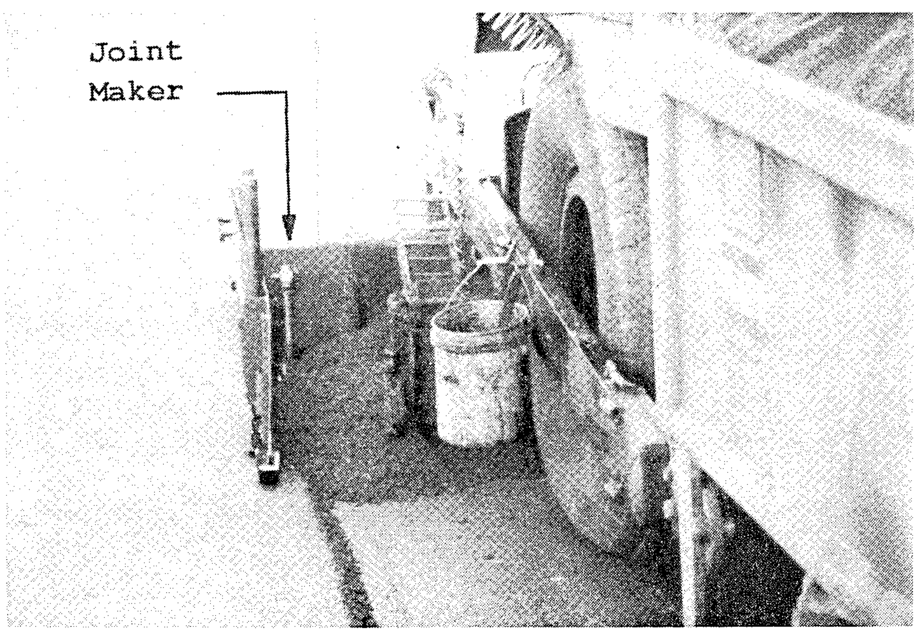

FIGURE 25. "JOINT MAKER" DEVICE USED ON LONGITUDINAL JOINTS

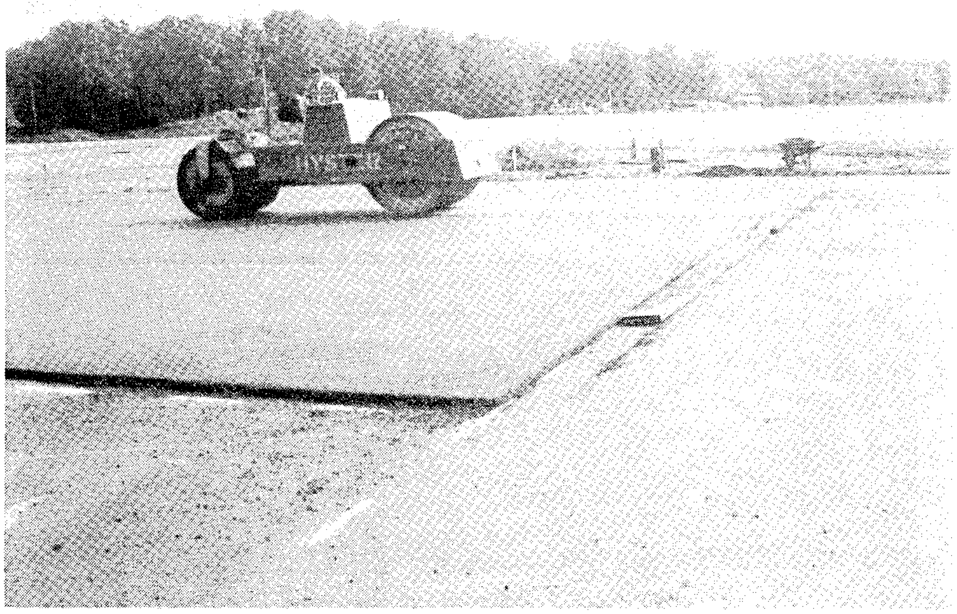

FIGURE 26. FINISH ROLLING NEAR A TRANSVERSE JOINT AT SARATOGA COUNTY AIRPORT

ALBANY COUNTY AIRPORT.

This airport is located about 7 miles from downtown Albany and is a small hub facility with regularly scheduled commercial air service. It is owned by Albany County. Its two runways are used by aircraft up to the DC-9 and B-727 class. The longest runway is designated 01/19 and is 7200 ft long and 150 ft wide with a grooved asphalt concrete surface. Typical elevation is 285-ft mean sea level (msl).

Two separate parts of the airport were paved during the period from July through October 1991. Each part of the work was constructed by different contractors. Contractor A worked on the runway asphalt paving and contractor B paved an apron area in the vicinity of a Page Aviation/Avjet facility. Figure 27 shows the completed runway at Albany County Airport.

SARATOGA COUNTY AIRPORT.

This airport is located about 3 to 4 miles from downtown Saratoga Springs. It is a general aviation facility at 433-ft msl elevation and is owned by Saratoga County. It has two runways; the longest is designated 14/32 with dimensions of 4700 ft long by 100 ft wide and is constructed mostly of concrete.

New runway and taxiway extensions were constructed at the ends of runway 5/23 with asphalt leveling and surface course placement in June 1992. Contractor B performed this work. Figure 28 shows surface mix construction at Saratoga County Airport.

FIGURE 27. COMPLETED ALBANY COUNTY AIRPORT RUNWAY

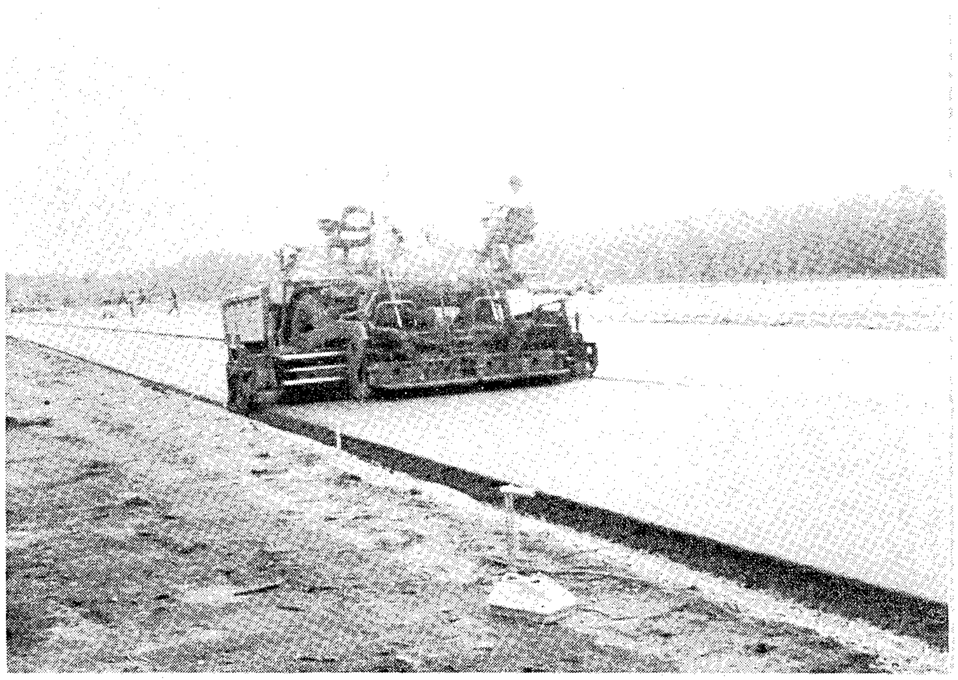

FIGURE 28. TAXIWAY SURFACE CONSTRUCTION AT SARATOGA COUNTY AIRPORT

CORE SAMPLING PLAN.

A general sampling plan was developed to allow comparisons between mat and joint densities at each paving project. A set of three 4-in.-diameter cores was used to define joint density within an approximately 1-ft.-wide strip along longitudinal construction joints. Similarly, at least two cores were used to determine lane interior or mat compacted density; one core was taken from the interior along each side of randomly determined joint sampling stations. This type of sampling could be repeated as often as necessary at random stations along any paved length or width.

Figure 29 illustrates the general core sampling plan that was used at each airport of this study. The sampling plan that is shown was for evaluating one or two different joint construction techniques that were used at the airports.

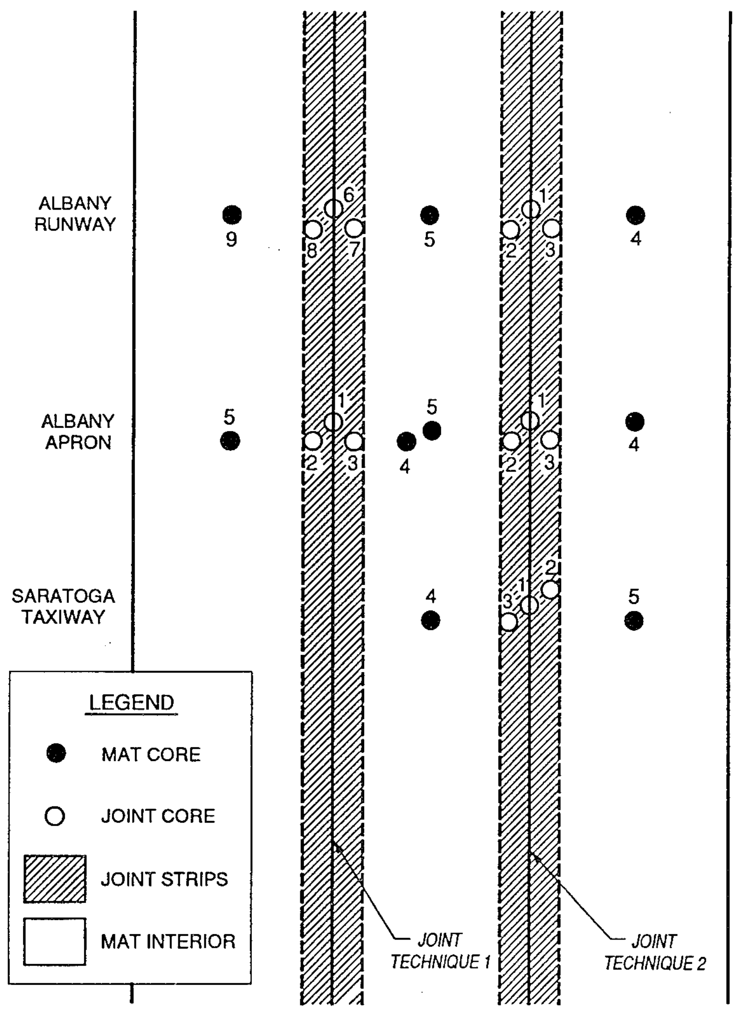

FIGURE 29. AIRPORT PAVEMENT CORE SAMPLING PLAN

CORE SAMPLING AND LABORATORY DENSITY TESTING.

Core samples were taken from longitudinal joint areas where the special device had been used and from areas where hand luting only had been used during construction. Cores were also taken from the interior sections of paving lanes in the vicinity (same stationing) of the joints. In all cases, the sample cores penetrated the newly paved overlay thickness.

The specimens were transported to WES and tested according to the recommendations in FAA specification P-401 "Plant Mix Bituminous Pavements." After inspecting the cores, they were saw cut at the locations of apparent interfaces between layers. The cores were tested for density according to ASTM D 2726. Tables 9 through 11 summarize density data from the cores.

TABLE 9. CORE DENSITY SUMMARY ALBANY COUNTY AIRPORT APRON

Core	Layer	Thickness (in.)	Density (pcf)
A1	Top (J)	2 3/4	128.7
	Second	2	143.1
A2	Top (J)	3	138.4
	Second	4 1/2	148.9
A3	Top (J)	3	137.9
	Second	2	141.2
A4	Top (M)	2 1/2	146.7
	Second	2 1/4	142.8
A5	Top (M)	2 1/2	144.4
	Second	1 3/4	140.4
B1	Top (J)	2 1/2	134.5
	Second	2 1/4	140.6
B2	Top (J)	2 1/2	131.1
	Second	2 1/8	141.9
B3	Top (J)	2 1/4	145.7
	Second	1 3/4	143.4
B4	Top (M)	2 1/4	147.8
	Second	2	147.8
B5	Top (M)	2	144.8
	Second	1 1/4	136.1
C1	Top (J)	2 1/4	129.6
	Second	2	137.7
C2	Top (J)	2	129.2
	Second	2 1/2	139.2
C3	Top (J)	2 1/4	140.4
	Second	2 1/4	143.4
C4	Top (M)	2 1/4	146.5
	Second	2	147.8
C5	Top (M)	2	146.7
	Second	2 1/4	146.6

TABLE 9. CORE DENSITY SUMMARY ALBANY COUNTY AIRPORT APRON (CONTINUED)

Core	Layer	Thickness (in.)	Density (pcf)
D1	Top (J) Second	2 1 1/4	132.7 129.3
D2	Top (J) Second	2 1/4 2	144.9 141.9
D3	Top (J) Second	2 1/4 2 1/2	142.2 142.7
D4	Top (M) Second	2 1/2 2 1/4	147.6 150.3
D5	Top (M) Second	2 1/2 2 3/4	141.9 145.0
(J) indicates joint core; (M) indicates mat core.			

TABLE 10. CORE DENSITY SUMMARY ALBANY COUNTY AIRPORT RUNWAY

Core	Layer	Thickness (in.)	Density (pcf)
81-1	Top (J) Second	1 1/4 3 1/8	138.8 146.2
81-2	Top (J) Second	1 1/4 3 1/8	146.4 144.7
81-3	Top (J) Second	1 1/2 3	149.5 146.4
81-4	Top (M) Second	1 1/2 3 1/2	144.1 143.5
81-5	Top (M) Second	1 1/4 3 1/4	146.3 147.5
81-6	Top (J) Second	2 3 1/4	147.4 147.8
81-7	Top (J) Second	1 3/4 3 1/2	147.1 147.0
81-8	Top (J) Second	2 3 1/4	138.7 146.5
81-9	Top (M) Second	2 1/4 3 1/2	145.7 143.5
126-1	Top (J) Second	1 1/2 3 1/2	135.3 144.8
126-2	Top (J) Second	1 1/2 3 1/2	144.9 142.7
126-3	Top (J) Second	1 1/2 3 3/4	140.7 144.4
126-4	Top (M) Second	1 1/2 3 1/2	142.7 144.8

TABLE 10. CORE DENSITY SUMMARY ALBANY COUNTY AIRPORT RUNWAY (CONTINUED)

Core	Layer	Thickness (in.)	Density (pcf)
126-5	Top (M)	1 1/2	145.6
	Second	4	146.4
126-6	Top (J)	2	139.0
	Second	3 1/2	145.1
126-7	Top (J)	2	145.0
	Second	3 1/2	145.9
126-8	Top (J)	2 1/4	143.8
	Second	3 1/4	145.0
126-9	Top (M)	2 1/2	147.3
	Second	3 1/2	147.7
273-1	Top (J)	1 1/2	146.6
	Second	2 1/4	148.1
273-2	Top (J)	1 1/2	140.2
	Second	2 1/4	146.7
273-3	Top (J)	1 3/4	148.0
	Second	2 1/8	147.7
273-4	Top (M)	1 1/2	147.1
	Second	2 1/4	146.9
273-5	Top (M)	1 3/4	147.3
	Second	2 1/2	145.1
273-6	Top (J)	2	142.7
	Second	2 1/4	147.1
273-7	Top (J)	1 1/2	147.0
	Second	2 3/4	145.3
273-8	Top (J)	2	141.1
	Second	2 1/2	144.8
273-9	Top (M)	2 1/2	147.3
	Second	2 1/2	146.9
(J) indicates joint core; (M) indicates mat core.			

TABLE 11. CORE DENSITY SUMMARY SARATOGA COUNTY AIRPORT TAXIWAY EXTENSION

Core	Layer	Thickness (in.)	Density (pcf)
1-1	Top (J) Second	2 1/4 1 1/4	132.0 142.7
1-2	Top (J) Second	2 2	137.4 144.5
1-3	Top (J) Second	1 3/4 2 1/8	142.6 138.4
1-4	Top (M) Second	2 2	145.0 146.8
1-5	Top (M) Second	2 1 1/2	144.0 149.0
2-1	Top (J) Second	2 1/2 2 1/4	137.4 140.0
2-2	Top (J) Second	2 1/2 2 1/4	141.5 142.7
2-3	Top (J) Second	2 1/2 2 1/4	146.2 136.4
2-4	Top (M) Second	3 2	148.3 145.2
2-5	Top (M) Second	2 1/2 2 1/8	150.1 140.8
3-1	Top (J) Second	1 7/8 2	133.1 138.8
3-2	Top (J) Second	2 1 3/4	140.7 143.2
3-3	Top (J) Second	2 1 7/8	144.0 131.3
3-4	Top (M) Second	2 1/2 2	147.7 144.6
3-5	Top (M) Second	2 1/4 1 7/8	150.4 140.4
(J) indicates joint core; (M) indicates mat core.			

ANALYSES OF DENSITY DATA.

After density data was summarized, it was input to the SAS/STAT system of statistical analysis tools and analyzed using an analytical model that was based on the sampling plan and experiment design that developed during the pre-coring stages of the study. Procedure GLM, a general linear models data analysis program [26], was used to compute the analyses of variance (ANOVAs) for each project and each mat or joint area within each project. Statistical testing was performed during each analysis at the 5 percent level of significance; these tests included F-tests, Bonferonni multiple comparisons, t-tests, and others on the means and differences between means.

GENERAL ANOVAs. Results of the ANOVAs for the surface layer density of asphalt concrete mix are given in tables 12 through 14. They show that generally there was no statistically significant difference between the Joint Maker technique (treatment 2) and the manual luted joint technique (treatment 1) at either Albany County Airport project. Analyses also indicated that between station densities were not significantly different at either Albany County Airport project; there was no statistically identifiable difference between manual and mechanically assisted joint construction along the areas that were sampled.

For the Saratoga County Airport, where the only joint forming method was the Joint Maker technique, similar conclusions about station to station densities were reached from the ANOVA analyses. The ANOVA for mat areas show that the mat densities are very close to being statistically different. This indicates that at least one of the mat areas exhibited densities that were nearly very different than the average. Observing average densities shows this fact.

TABLE 12. ANALYSES OF VARIANCE FOR ALBANY COUNTY AIRPORT RUNWAY SURFACE MIX

Area	Source	Degrees of Freedom	Mean Square	F Ratio
Joint	Station	2	18.320	1.40 (2,6) NS
	Core in station	6	13.056	
	Joint Treatment	1	0.109	0.02 (1,2) NS
	Station*Treat.	2	5.434	0.22 (2,6) NS
	Core*Treat.	6	25.126	
	Total	17		
Mat	Station	2	3.823	1.71 (2,6) NS
	Core in station	6	2.238	
	Total	8		

Numbers in parentheses are degrees of freedom for numerator and denominator.

NS = Not statistically significant at 5% level.

TABLE 13. ANALYSES OF VARIANCE FOR ALBANY COUNTY AIRPORT APRON SURFACE MIX

Area	Source	Degrees of Freedom	Mean Square	F Ratio
Joint	Station	1	60.301	1.16 (1,4) NS
	Core in station	4	52.022	
	Joint Treatment	1	0.608	0.04 (1,1) NS
	Station*Treat.	1	17.041	0.52 (1,4) NS
	Core*Treat.	4	32.792	
	Total	11		
Mat	Station	1	0.605	0.13 (1,6) NS
	Core in station	6	4.486	
	Total	7		
Numbers in parentheses are degrees of freedom for numerator and denominator. NS = Not statistically significant at 5% level.				

TABLE 14. ANALYSES OF VARIANCE FOR SARATOGA COUNTY AIRPORT TAXIWAY EXTENSION SURFACE MIX

Area	Source	Degrees of Freedom	Mean Square	F Ratio
Joint	Station	2	14.363	0.55 (2,6) NS
	Core in station	6	26.242	
	Total	8		
Mat	Station	2	14.272	7.43 (2,3) NS
	Core in station	3	1.9222	
	Total	5		
Numbers in parentheses are degrees of freedom for numerator and denominator. NS = Not statistically significant at 5% level.				

COMPARISONS OF AVERAGE DENSITIES. Figures 30 through 32 illustrate the average density distribution along the one-ft-wide strip along longitudinal construction joints for each different construction project. On each figure, the average mat construction density is shown and joint density across the strip is indicated in pcf and percentages of mat average density. This ratio of joint to mat density is not complicated and allows a quick indication of joint density relative to mat constructed density.

Albany County Airport runway data indicated that the project average mat density was about 145.9 pcf. Figure 30 shows that average manual luting (treatment 1) density typically varied across the joint strip from about 96 to 100 percent of project average mat density; average joint density for this technique was about 143.5 pcf or 98.4 percent of project average mat density.

Joint Maker (treatment 2) average densities were about the same as luting, about 143.4 pcf or 98.2 percent of project average mat density. In the joint strip, average core densities varied from around 96 to 100 percent of project average mat density. This figure helps the visualization of results from the ANOVAs.

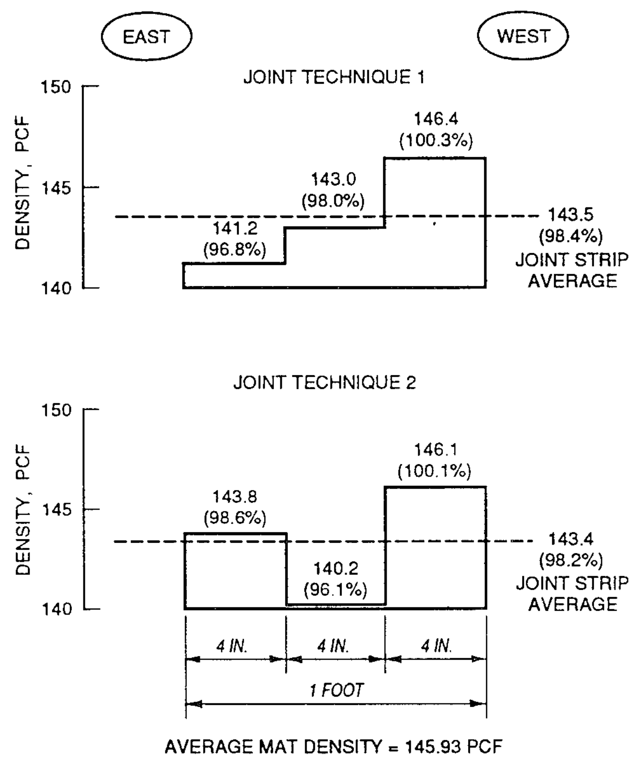

FIGURE 30. ALBANY COUNTY AIRPORT RUNWAY JOINT STRIP SUMMARY

Figure 31 summarizes average density results for the surface of the Albany County Airport apron paving project. Project average mat density was 145.8 pcf. Manual joint luting (treatment 1) produced an average strip density of approximately 136.5 pcf or 93.6 percent of average mat density. The joint strip was further defined by 4-inch-diameter cores that averaged from about 90 to 97 percent of average mat density. The Joint Maker attachment (treatment 2) produced similar results, an average of 136.1 pcf or 93.3 percent of average mat density. Again, the density in the joint strip varied from 90 to 97 percent of average mat density. For both jointing techniques, a minimum density of 90 percent of average mat density occurred exactly at the junction of the two paving lanes. About 93 percent average mat density existed toward the southerly side of the joint strip and about 97 percent average mat density occurred to the northerly side of the joint strip.

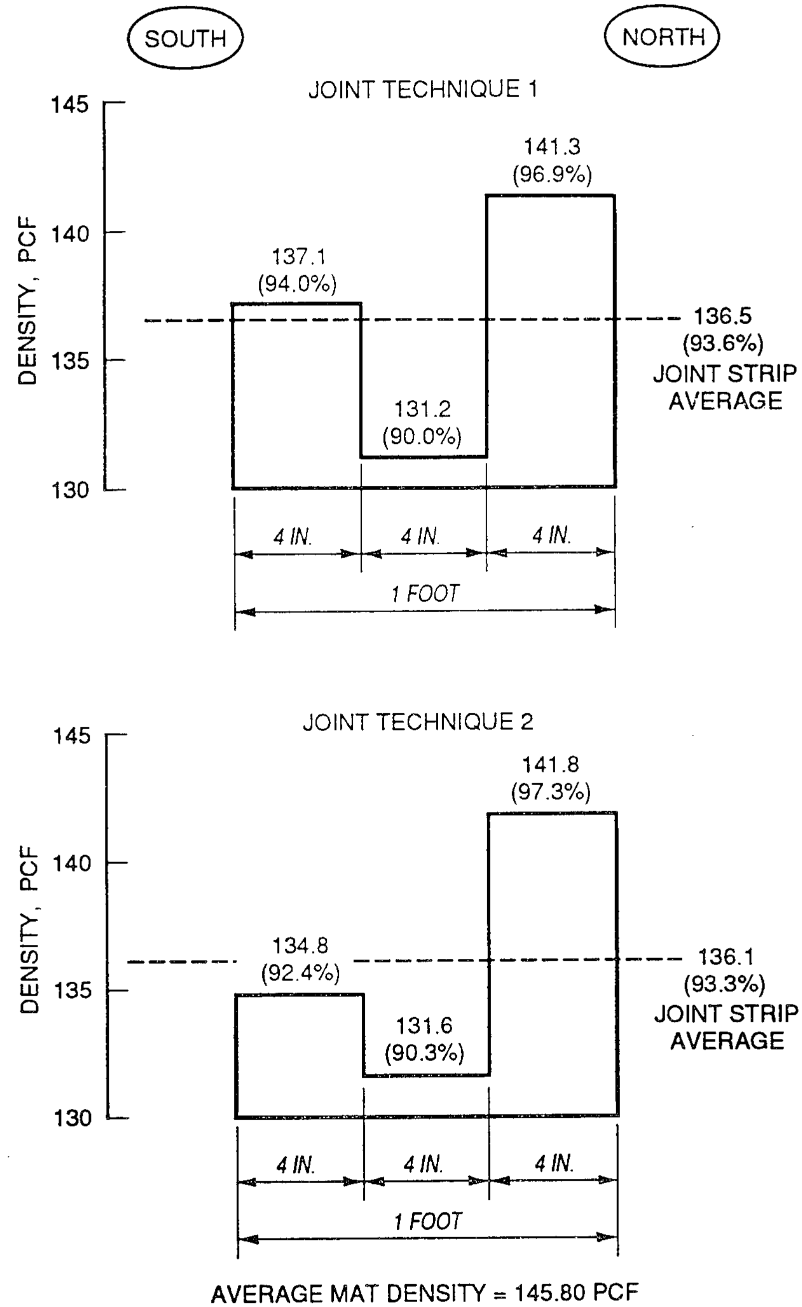

FIGURE 31. ALBANY COUNTY AIRPORT APRON JOINT STRIP SUMMARY

Figure 32 shows density average results for the surface mix at the Saratoga County Airport taxiway extension; only the Joint Maker technique was used on the joints. Average longitudinal joint data are given in pounds per cubic ft (pcf) and in percent project average mat density. Here, the average mat density was about 147.6 pcf. The average joint strip density was 139.4 pcf or 94.5 percent of the average mat. Typical densities across the 1-ft-wide joint strip ranged from almost 91 to 98 percent. Similar to the finding at Albany County Airport's apron, minimum density at Saratoga County Airport occurred at the junction of the two paving lanes. Higher average density occurred on each side of that junction, about 95 and 98 percent of average mat density.

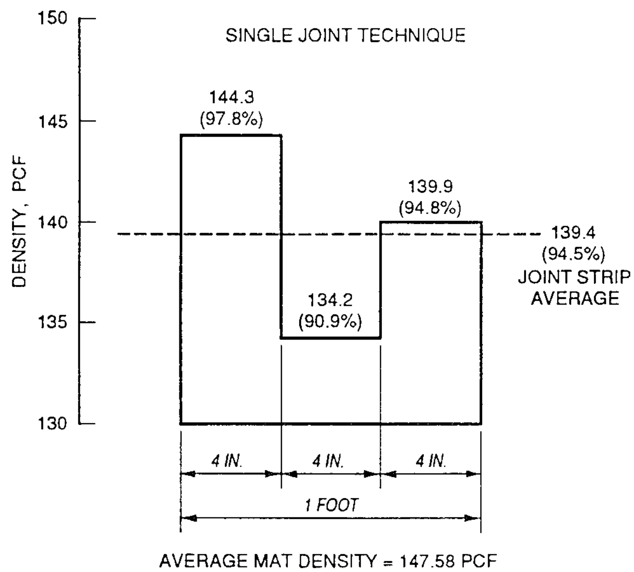

FIGURE 32. SARATOGA COUNTY AIRPORT TAXIWAY JOINT STRIP SUMMARY

Average densities indicated that the Albany County Airport runway construction project produced the highest density joint strips, slightly more than 98 percent of project average mat density. Minimum average core density was 96.5 percent. Both other projects, Albany County Airport's apron and Saratoga County Airport's taxiway extension, produced average joint strip densities of from 93.5 to 94.5 percent of average mat; average minimum density in the joint strip was between 90 and 91 percent of average mat density.

COMPONENTS OF VARIANCE AND CONSTRUCTION TECHNIQUE VARIABILITY.

Variance of the surface mix construction was computed for each project and was defined by representative areas of mix construction. Construction technique variance and other variance components were estimated from the surface mix core data. The more commonly used standard deviation is simply the square root of the variance.

Table 15 summarizes variance component estimates from core density analyses of the airport surface construction. Jointing technique variance estimates were obtained by pooling non-significant technique terms in the Albany County Airport projects. Observation of joint density variance within the 1-ft-wide strip indicated that the Albany County Airport runway surface construction was the least variable of three projects; most of its variability (95%) was due to joint construction techniques that generated a standard deviation of 4.2 pcf. The other two projects at Albany County Airport's apron and Saratoga County Airport's taxiway were characterized by joint construction techniques that were characterized by standard deviations of 6.3 and 5.1 pcf, respectively. It was noted that projects with the two higher joint technique standard deviations were constructed by the same contractor; contractor B.

TABLE 15. ESTIMATED VARIANCE COMPONENTS OF FAA PROJECT SURFACE LAYER DENSITY

Project	Area	Estimated Variance Components			
		Station	Core in Station	Joint Technique	Total
Albany County Airport Runway	Joint	0.8774 4.7%	0 0%	17.9700 95.3%	18.7474 100%
	Mat	0.5281 19.1%	2.2389 80.9%	None	2.7670 100%
Albany County Airport Apron	Joint	1.3799 3.5%	13.6095 34.2%	24.8025 62.3%	39.7919 100%
	Mat	0 0%	4.4858 100%	None	4.4858 100%
Saratoga County Airport Taxiway	Joint	0 0%	26.2422 100%		26.2422 100%
	Mat	6.1750 76.3%	1.9217 23.7%	None	8.0957 100%

Variance units are squared pcf.

Joint construction variances at Albany County Airport projects were computed by pooling nonsignificant technique terms in ANOVA.

Numbers in parentheses are percentages of total variance.

The table also shows that mat constructed density variability was generally much lower than joint variability. Variability between cores taken from the same stationing was the dominant contributor to mat density variability. Mat station-to-station variability was generally lower than that of joints. This indicated more consistent density along the interior than at paving lane joints. Construction at the Saratoga County Airport taxiway was the exception because its mat variability between stations was the reverse of both Albany County Airport projects; it was three times higher than that between cores. This data was probably indicating that more construction emphasis was placed on joint construction at Saratoga County Airport than on the central paving lane areas.

POSSIBLE CONSTRUCTION CRITERIA.

The concept of density uniformity can be expressed mathematically for construction quality control or quality assurance data. Uses could include ranking project construction on a relative basis and/or further development of specifications that base contract payment on combined results of density testing and overall uniformity of the project.

Differences between joint strip density and mat interior density have been expressed as separate ratios of constructed mat and joint density to a reference quality control/assurance compacted density. This has been the standard practice for airport construction. Separate relative density ratios, alone, have little meaning without noting the basis for the comparisons, the value of the reference density. Even when the reference density is given, the real meaning of density uniformity may be elusive.

The following equations have been used for project quality determinations at joint and mat areas:

$$\text{Relative Mat Density} = \left(\frac{\bar{\gamma}_{MAT}}{\bar{\gamma}_{REF}}\right) \text{x } 100\%$$

where $\bar{\gamma}_{\mathrm{MAT}}$ = Average mat density,

$\bar{\gamma}_{REF}$ = Compaction reference density.

$$\text{Relative Joint Density} = \left(\frac{\bar{\gamma}_{JOINT}}{\bar{\gamma}_{REF}}\right) \text{x } 100\%$$

where $\bar{\gamma}_{JOINT}$ = Average joint density.

When summarizing data from the literature, a simple ratio of joint average density to mat average density was used as an alternative indicator of joint construction durability relative to mat construction durability.

An easily comprehensible comparison of average density uniformity can be shown as an equation that divides the difference between average interior density and average joint density by the joint strip density. The equation is as follows:

$$\text{Density Uniformity Index} = \left(\frac{\bar{\gamma}_{\mathrm{MAT}} - \bar{\gamma}_{JOINT}}{\bar{\gamma}_{JOINT}}\right) \text{x } 100\%$$

Results of quality control or quality assurance testing can be input to this relationship for either moving averages or overall project average density uniformity indices. A variation of the equation could use the value of average minimum joint strip density when interest is in the widest possible density difference. Table 16 shows results of using the density uniformity index on select project data from the literature and the FAA airport data from this study. The table indicates that the density uniformity index can be used as a relative means of ranking paving projects from most to least uniform construction.

This index could also serve as an indicator for the basis of payment in contract specification documents. The table also illustrates how the choice of joint density value (either the average value of the joint strip or the average of the minimum joint values) impacts the index value. A range in density uniformity index was calculated when both joint density averages were used.

TABLE 16. SUMMARY DENSITIES AND DENSITY UNIFORMITY INDICES FOR VARIOUS SURFACE MIX CONSTRUCTION PROJECTS

Project	Average Mat Density (pcf)	Average Joint Density (pcf)		Density Uniformity Index (%)	
		Strip	Minimum	Strip	Minimum
WES Asphalt Tests	146.66	142.23	--	3.11	--
WES Rubberized-Tar Tests	150.41	140.18	--	7.30	--
Morristown Airport	151.50	145.60	--	4.05	--
Rochester Airport	150.70	143.30	--	5.16	--
Albany County Airport Runway	145.93	143.45	140.70	1.73	3.72
Albany County airport Apron	145.80	136.30	131.40	6.97	10.96
Saratoga County Airport Taxiway	147.58	139.40	134.90	5.87	9.40

Index values of zero indicate no difference in average density of mat and joint areas. Higher index values directly indicate greater relative differences between densities and related durability of the two types of hot-mix areas.

The three FAA projects that were investigated during this study, shown below the double horizontal line in the table, can be ranked on the basis of density uniformity. From average joint strip densities, the most uniform surface mix construction was performed at the Albany County Airport runway and the least uniform construction occurred at the Albany County Airport apron. Surface paving at the Saratoga County Airport was similar to Albany County Airport's apron but exhibited slightly higher average joint density.

A comparison of relative project densities can be made using data that was extracted from the literature. Table 17 shows comparisons of relative constructed densities that are based on average values from two experimental WES projects and two FAA surface paving projects. From relative laboratory densities, the average mat compaction range fell within a range of about 97 to 99 percent. Joint densities ranged from 92 to slightly less than 94 percent of laboratory density, a significant finding. This shows that jointing techniques used on these projects averaged about 5 percent lower relative laboratory compaction than mat interior density. These results were similar to those that were calculated from Livneh's paper.

With joint-to-mat density ratios or density uniformity indices, the numbers show more information; a way of ranking the construction is evident. Both the ratio and index values rank projects in order of constructed density consistency. Ranking in decreasing order of density consistency is WES asphalt, Morristown Airport, Rochester Airport, and WES rubberized-tar projects. If either of these ratios is used, it is necessary to include laboratory compacted density values to properly reference the construction to the design.

TABLE 17. AVERAGE CONSTRUCTED DENSITY SUMMARY OF PROJECTS FROM THE LITERATURE BASED ON 75 BLOW MIX DESIGNS

Project	Constructed Density, %			
	Laboratory		Joint/Mat Average Ratio	Density Uniformity Index
	Mat/Lab	Joint/Lab		
WES Asphalt	96.8 (151.55)	93.8	97.0	3.1
WES Rubberized Tar	98.7 (152.38)	92.0	93.2	7.3
Morristown Airport	97.0 (156.20)	93.2	96.1	4.1
Rochester Airport	98.2 (153.40)	93.4	95.1	5.2

Numbers in parentheses are average laboratory compacted densities of plant produced hot mix; units are pcf.

Laboratory density must be included with either constructed density percentage.

QUESTIONNAIRE: INFORMATION DEVELOPMENT

The third major phase of this study was developing data from a survey of groups and organizations that were involved in airport flexible pavement construction. A questionnaire was developed, approved by the FAA, and mailed. For the respondents' information to be meaningful, a series of questions were assembled that solicited information in the general areas of specifications, construction processes and methods, and experiences gained through constructing hot-mix flexible surfaces. This section presents details of the survey questions and responses; it also summarizes overall findings.

DESCRIPTION OF QUESTIONNAIRE.

The first section of the questionnaire requested basic information from each respondent; this included official organization or company name, address, contact person, and telephone number. This part allowed the respondent to select a grouping category for its organization or company. Choices were "pavement owner," "specifier" (specification personnel), "paving contractor," "association," and "other." "Other" was a catchall category with a blank space for additional information. The general makeup of the main part of the survey included 12 multiple choice and limited fill-in items, one construction process ranking item, and two written descriptive items for a total of 15 items.

MAILING AND RESPONSE.

During February and March of 1992, approximately 285 questionnaires were mailed to U.S. and foreign organizations or companies that were involved with pavement construction. Federal aviation and defense related airfield organizations, state and federal highway organizations, pavement related associations, and select United Kingdom (U.K.) and Australian organizations were included in the mailings.

By mid-May all responses had been returned. A total of 131 separate questionnaires were received with useable information such as technical data and fully completed surveys. One respondent had submitted two surveys and two respondents did not answer questions. Overall response to the questionnaire was about 45 percent of the mailing.

PERSONAL COMPUTER DATABASE.

As questionnaires were returned, the information was input to a personal computer database for easier retrieval of the large amount of data. The database was designed to allow for summarizing data from all respondents, by specific category groups (i.e., association, specifier, etc.), or by subgroups (i.e., owner and specifier, owner and specifier and other, etc.) for each question. Database summaries allowed visualization of interrelationships between respondent groupings.

RELATIONSHIPS BETWEEN RESPONDENT GROUPS.

Figure 33 illustrates the overall relationships between groups that responded. It shows no hard lines separated pavement owners from specifiers (specification personnel) or any of the remaining major groupings. There were indications that association and contractor groups were distinct from each other and distinct from owner, specifier, and other groups. These distinctions and lack of hard distinctions can also be seen in responses to individual survey questions.

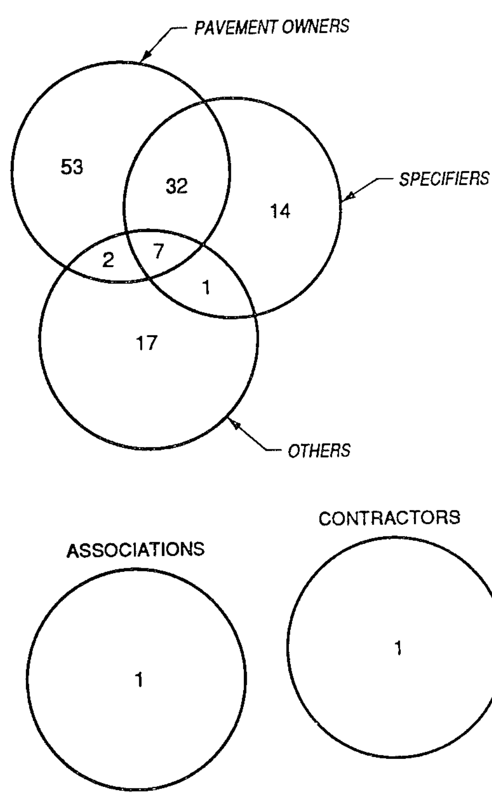

FIGURE 33. THE 1992 QUESTIONNAIRE RESPONSE BY GROUPS AND SUBGROUPS

The total response was 128 completed surveys. Table 18 lists all respondents by organizational grouping shown on returned questionnaires. The last entries show that two respondents returned questionnaires with organization information only and no answers. If their surveys are counted, total response was 130 returns.

TABLE 18. LIST OF 1992 QUESTIONNAIRE RESPONDENTS BY GROUP SELECTION (SHEET 1 OF 5)

ASSOCIATION ONLY
Australian Asphalt Pavement Association, Hawthorn, Victoria, Australia 3122
PAVING CONTRACTOR ONLY
Boral Asphalt, Wentworthville, NSW Australia 2145
SPECIFIER ONLY
Florida DOT Aviation Office, Tallahassee, FL 32399 Crawford, Murphy and Tilly, St. Louis, MO 63102 Greater Baton Rouge Airport District, Baton Rouge, LA 70807 Ohio DOT Division of Aviation, Columbus, OH 43235 Schmitz, Kalda and Associates, Sioux Falls, SD 57102 U.S. Army Engineer District Alaska, Anchorage, AK 99506 Calocerinos and Spina Engineers, P.C., Liverpool, NY 13088 Mississippi State Highway Department, Jackson, MS 39215 Arkansas State Highway and Transportation Department, Little Rock, AR 72203 Wyoming DOT, Cheyenne, WY 82002 Indiana DOT, Indianapolis, IN 46219 Rhode Island DOT Materials Section, Providence, RI 02903 Pennsylvania DOT MTD Laboratory, Harrisburg, PA 17120 Port of San Diego, San Diego, CA 92112
OTHER ONLY
Arkansas Department of Aeronautics, Little Rock, AR 72202 North Carolina DOT Division of Aviation, Raleigh, NC 27611 South Carolina Aeronautics Commission, Columbia, SC 29228 Cedar Rapids Municipal Airport, Cedar Rapids, IA 52404 Iowa DOT Office of Aeronautics, Des Moines, IA 50321 City of Kansas City, MO Aviation Department, Kansas City, MO 64195

TABLE 18. LIST OF 1992 QUESTIONNAIRE RESPONDENTS BY GROUP SELECTION (SHEET 2 OF 5)

OTHER ONLY (Continued)
Michigan DOT Bureau of Aeronautics, Lansing, MI 48917 Virginia Department of Aviation, Richmond, VA 23231 Tri-State Airport Authority, Huntington, WV Jacksonville Port Authority, Jacksonville, FL 32229 Wyoming DOT Aeronautics Division, Cheyenne, WY Texas DOT Division of Aviation, Austin, TX 78711 Federal Aviation Administration, Ft. Worth, TX 76193 Arizona DOT Aeronautics Division, Phoenix, AZ 85034 Nevada DOT, Carson City, NV 89712 West Virginia Division of Highways, Charleston, WV 25311 Connecticut DOT Division of Materials, Rocky Hill, CT 06067
PAVEMENT OWNER ONLY
Regional Airport Authority of Louisville, Louisville, KY 40209 Gulfport-Biloxi Regional Airport, Gulfport, MS 39505 Cedar City Municipal Airport, Cedar City, UT 84720 Montgomery Airport Authority, Montgomery, AL 36102 City of Houston Aviation Department, Houston, TX 77032 Burbank-Glendale-Pasadena Airport Authority, Burbank, CA 91505 San Joaquin County Department of Aviation, Stockton, CA 95206 Sarasota-Manatee Airport Authority, Sarasota, FL 34278 Missoula International Airport, Missoula, MT 59802 Airport Authority of Washoe County, Reno, NV 89510 Volusia County Airport Department, Daytona Beach, FL 32114 Honolulu International Airport, Honolulu, HI 96819 Metropolitan Airports Commission, Minneapolis, MN 55450 Mueller Municipal Airport, Austin, TX 78723 Port of Seattle, Seattle-Tacoma International Airport, Seattle, WA 98111 St. Petersburg-Clearwater International Airport, Clearwater, FL 34622 Fort Wayne-Allen County Airport Authority, Fort Wayne, IN 46809 Salina Airport Authority, Salina, KS 67401 Grand Forks Regional Airport Authority, Grand Forks, ND 58203 U.S. Air Force, Randolph AFB, TX City of Phoenix Aviation Department, Phoenix, AZ 85034 Lincoln Airport Authority, Lincoln, NE 68501 Omaha Airport Authority, Omaha, NE 68119

TABLE 18. LIST OF 1992 QUESTIONNAIRE RESPONDENTS BY GROUP SELECTION (SHEET 3 OF 5)

PAVEMENT OWNER ONLY (Continued)
Columbus Municipal Airport Authority, Columbus, OH 43219
Memphis-Shelby County Airport Authority, Memphis, TN 38130
New Hampshire DOT, Concord, NH 03302
U.S. Air Force, Langley AFB, VA 23665
Oklahoma DOT, Oklahoma City, OK 73105
Department of Airports, Los Angeles, CA 80009
Lambert-St. Louis International Airport, St. Louis, MO 63145
City of Naples Airport Authority, Naples, FL 33942
U.S. Air Force, Scott AFB, IL 62225
City of Cleveland Department of Port Control, Cleveland, OH 44135
Manchester Airport, Manchester, NH 03103
County of Allegheny Department of Aviation, Pittsburgh, PA 15231
University of Illinois-Willard Airport, Champaign-Urbana, IL
City of Chicago Department of Aviation, Chicago, IL 60602
Metropolitan Washington Airports Authority, Washington, DC
Iowa DOT, Ames, IA 50010
Johnson Controls World Services, Inc., Teterboro, NJ 07608
Texas DOT Materials and Tests Division, Austin, TX 78701
Washington DOT, Olympia, WA
Capital Region Airport Commission, Richmond, VA 23231
Birmingham Airport Authority, Birmingham, AL 35212
New Mexico State Highway and Transportation Department, Santa Fe, NM 87504
Ohio DOT, Columbus, OH 43110
Maryland Aviation Administration, Baltimore, MD 21240
Greater Orlando Aviation Authority, Orlando, FL 32827
Arizona DOT, Phoenix, AZ 85009
Maryland State Highway Administration, Brooklandville, MD 21022
Massachusetts Highway Department, Wellesley Hills, MA 02181
South Carolina Department of Highways and Public Transportation Columbia, SC 39202
Federal Airports Corporation, Botany, NSW Australia 2019
COMBINATIONS: PAVEMENT OWNER, SPECIFIER, AND OTHER
* Pavement Owner and Other Only *
City of Albuquerque Aviation Department, Albuquerque, NM 87119
Pioneer Asphalts-Australia, Clayton, Victoria Australia 3168

TABLE 18. LIST OF 1992 QUESTIONNAIRE RESPONDENTS BY GROUP SELECTION (SHEET 4 OF 5)

COMBINATIONS: PAVEMENT OWNER, SPECIFIER, AND OTHER (Continued)
* Specifier and Other Only *
Wisconsin DOT Bureau of Aeronautics, Madison, WI 53707
* Pavement Owner and Other Only *
City of Albuquerque Aviation Department, Albuquerque, NM 87119
Pioneer Asphalts-Australia, Clayton, Victoria Australia 3168
* Specifier and Other Only *
Wisconsin DOT Bureau of Aeronautics, Madison, WI 53707
* Pavement Owner and Specifier and Other *
Aeronautics Commission, Bismark, ND 58502
Nebraska Department of Roads, Lincoln, NE 68509
Alaska DOT Central Region, Anchorage, AK 99507
Airports Commission, San Francisco, CA 94128
New York State DOT, Albany, NY 12232
Illinois DOT Materials and Physical Research, Springfield, IL 62704
Utah DOT, Salt Lake City, UT 84119
* Pavement Owner and Specifier Only *
St. Joseph County Airport Authority, South Bend, IN 46628
Colorado Springs Airport, Colorado Springs, CO 80917
Dallas/Ft. Worth Airport Maintenance, Dallas/Ft. Worth, TX 75261
Massachusetts Port Authority, Boston, MA 02116
Tulsa Airport Authority, Tulsa, OK 74158
City of Alamogordo, Alamogordo, NM 88310
Oregon DOT Highway Operations, Salem, OR 97310
Salt Lake City Airport Authority, Salt Lake City, UT 84122
San Jose International Airport, San Jose, CA 95110
Hawaii DOT Highway Division, Materials, Honolulu, HI 96819
Spokane International Airport, Spokane, WA 99219
Kansas DOT Materials and Research Bureau, Topeka, KS 66612
Alabama Highway Department, Montgomery, AL 36130

TABLE 18. LIST OF 1992 QUESTIONNAIRE RESPONDENTS BY GROUP SELECTION (SHEET 5 OF 5)

COMBINATIONS: PAVEMENT OWNER, SPECIFIER, AND OTHER (Continued)
* Pavement Owner and Specifier Only (continued) *
Air Force Civil Engineering Support Agency, Tyndall AFB, FL 32403
Idaho Transportation Department, Boise, ID 83707
City of Des Moines, Engineering, Des Moines, IA 50309
New Hampshire DOT Material and Research Bureau, Concord, NH 03302
Georgia DOT, Atlanta, GA 30334
Maine DOT, Augusta, ME 04333
Wisconsin DOT Division of Highways, Madison, WI 53707
Florida DOT, Gainesville, FL 32602
Michigan DOT, Lansing, MI 48909
Missouri Highway and Transportation Department, Jefferson City, MO 65101
Montana DOT, Helena, MT 59620
North Carolina DOT, Raleigh, NC 27611
U.S. Air Force, Sheppard AFB, TX 76311
California DOT, Sacramento, CA 95814
Oklahoma DOT Materials Division, Oklahoma City, OK 73105
Colorado DOT, Denver, CO 80222
New Jersey DOT, Trenton, NJ 08625
South Dakota DOT, Pierre, SD 57532
D.C. Department of Public Works, Washington, D.C. 20009
NONANSWERED QUESTIONNAIRES WITH USEFUL INFORMATION
Delaware Aeronautics Administration, Dover, DE 19903
National Asphalt Pavement Association, Landham, MD 20706

TABLE 19. 1992 JOINT CONSTRUCTION QUESTIONNAIRE RESPONSES (SHEET 1 OF 8)

Respondent Group TOTALS †	All 130	Owner 94	Specifier 54	Other 27	Assoc'n 1	Contractor 1	Owner Specifier 39	Owner Other 9	Specifier Other 8	Owner Spec Other 7
A. Specifications										
1. Do the typical hot-mix specifications that you (your organization) work with address joint density between adjoining paving mats? Check one answer.										
None of the time	16.0%	14.8%	22.2%	11.1%	0%	0%	19.0%	0%	0%	0%
Some of the time	0	0	0	0	0	0	0	0	0	0
Most of the time	77.8	77.0	70.4	77.8	100.0	100.0	71.4	66.7	60.0	60.0
Don't know	6.2	8.2	7.4	11.1	0	0	9.5	33.3	40.0	40.0
TOTAL RESPONSES	81	61	27	18	1	1	21	6	5	5
2. What kind of hot-mix jobs that you (your organization) deal with require more than normal effort to obtain specified joint density? Check all that apply.										
Airport/ airfield	47.9%	48.7%	32.8%	80.0%	25.0%	50.0%	35.7%	77.8%	75.0%	71.4%
Interstate hwy	7.4	7.7	7.5	8.0	25.0	50.0	11.9	11.1	12.5	14.3
City street	9.2	12.0	10.4	0	25.0	0	16.7	0	0	0
County road	4.9	6.0	4.5	0	25.0	0	7.1	0	0	0
Other	4.3	4.3	4.5	4.0	0	0	4.8	0	0	0
Don't know	8.0	8.5	10.4	8.0	0	0	11.9	11.1	12.5	14.3
No answer	18.4	12.8	29.9	0	0	0	11.9	0	0	0
TOTAL RESPONSES	163	117	67	25	4	2	42	9	8	7

† **NOTE:** Group totals shown do not add up to the overall total response; some respondents selected multiple organization identifiers on the questionnaire causing overlapping groups. Numbers of respondents in each separate group included: 53 owners only, 17 others only, 14 specifiers only, 32 owner and specifier only, 2 owner and other only, 1 specifier and other only, 7 owner and specifier and other only, 1 contractor only, 1 association only, and 2 nonanswered responses.

TABLE 19. 1992 JOINT CONSTRUCTION QUESTIONNAIRE RESPONSES (SHEET 2 OF 8)

Respondent Group TOTALS †	All 130	Owner 94	Specifier 54	Other 27	Assoc'n 1	Contractor 1	Owner Specifier 39	Owner Other 9	Specifier Other 8	Owner Spec Other 7
A. Specifications										
3. Do your typical specifications define how to make or compact the joints? Check all that apply.										
Yes longitudinal joints	45.5%	44.2%	47.1%	46.7%	50.0%	50.0%	44.4%	50.0%	50.0%	50.0%
Yes transverse joints	42.7	42.3	41.4	42.2	50.0	50.0	41.3	37.5	35.7	33.3
No	10.9	12.2	11.5	11.1	0	0	14.3	12.5	14.3	16.7
Don't know	0.9	1.3	0	0	0	0	0	0	0	0
TOTAL RESPONSES	211	156	87	45	2	2	63	16	14	12
4. With regard to payment, do your typical specifications include any of the following conditions on hot-mix joint construction? Check all that apply.										
Full pay regardless of density	41.7%	37.5%	51.9%	41.7%	100.0%	0%	51.4%	20.0%	33.3%	25.0%
Higher pay for spec density	0	0	0	0	0	0	0	0	0	0
Lower pay for lower density	48.3	53.4	36.5	50.0	0	100.0	42.9	60.0	44.4	50.0
Don't know	6.7	9.1	3.8	8.3	0	0	5.7	20.0	22.2	25.0
No answer	3.3	0	7.7	0	0	0	0	0	0	0
TOTAL RESPONSES	120	88	52	24	1	1	35	10	9	8

† **NOTE:** Group totals shown do not add up to the overall total response; some respondents selected multiple organization identifiers on the questionnaire causing overlapping groups. Numbers of respondents in each separate group included: 53 owners only, 17 others only, 14 specifiers only, 32 owner and specifier only, 2 owner and other only, 1 specifier and other only, 7 owner and specifier and other only, 1 contractor only, 1 association only, and 2 nonanswered responses.

TABLE 19. 1992 JOINT CONSTRUCTION QUESTIONNAIRE RESPONSES (SHEET 3 OF 8)

Respondent Group TOTALS †	All 130	Owner 94	Specifier 54	Other 27	Assoc'n 1	Contractor 1
B. Construction Processes and Joint Techniques						
1. Rank the importance of the following processes (1,2,3, or 4) in construction improved hot-mix construction joints. 1 = most important and 4 = least important.						
Mix Production	3 (2.60) ‡	3 (2.63)	3 (2.89)	3 (2.42)	3 (3.0)	4 (4.0)
Mix Transport	4 (3.60)	4 (3.62)	4 (3.69)	4 (3.62)	4 (4.0)	3 (3.0)
Paving Operation	2 (1.87)	2 (1.78)	2 (1.83)	2 (2.15)	1 (1.0)	1 (1.0)
Rolling Operation	1 (1.72)	1 (1.69)	1 (1.59)	1 (1.81)	2 (2.0)	2 (2.0)
TOTAL RESPONSES	122	90	54	26	1	1

Respondent Group TOTALS †	owner specifier 39	owner other 9	specifier other 8	owner specifier other 7
Mix Production	3 (3.05)	3 (2.50)	3 (2.44)	3 (2.63)
Mix Transport	4 (3.69)	4 (3.90)	4 (3.89)	4 (3.88)
Paving Operation	2 (1.72)	2 (1.90)	2 (2.00)	2 (1.88)
Rolling Operation	1 (1.54)	1 (1.70)	1 (1.67)	1 (1.63)
TOTAL RESPONSES	39	10	9	8

† **NOTE:** Group totals shown do not add up to the overall total response; some respondents selected multiple organization identifiers on the questionnaire causing overlapping groups. Numbers of respondents in each separate group included: 53 owners only, 17 others only, 14 specifiers only, 32 owner and specifier only, 2 owner and other only, 1 specifier and other only, 7 owner and specifier and other only, 1 contractor only, 1 association only, and 2 nonanswered responses.

‡ **NOTE:** Numbers in parentheses are the average computed numerical rankings from responses.

TABLE 19. 1992 JOINT CONSTRUCTION QUESTIONNAIRE RESPONSES (SHEET 4 OF 8)

Respondent Group TOTALS †	All 130	Owner 94	Specifier 54	Other 27	Assoc'n 1	Contractor 1	Owner Specifier 39	Owner Other 9	Specifier Other 8	Owner Spec Other 7
B. Construction Processes and Joint Techniques										
***4. If you use "special" construction methods on projects when hot-mix joint density will be closely checked, which of the following operations do you perform? Check all that apply.**										
Heat cold edges	18.3%	20.1%	13.8%	16.1%	0%	0%	15.4%	20.0%	15.4%	16.7%
Cut cold edges	29.3	29.9	26.2	25.8	50.0	0	25.0	33.3	30.8	33.3
Paver attachments	8.5	10.4	4.6	0	0	0	5.8	0	0	0
Other	8.5	8.2	10.8	12.9	0	0	11.5	13.3	15.4	16.7
No special method used	33.5	29.9	43.1	38.7	50.0	0	40.4	26.7	30.8	25.0
Don't know	1.8	1.5	1.5	6.5	0	0	1.9	6.7	7.7	8.3
TOTAL RESPONSES	164	134	65	31	2	0	52	15	13	12
5. How are joint densities checked? Check all that apply.										
Cores	41.4%	43.1%	29.2%	35.1%	50.0%	50.0%	29.6%	28.6%	18.2%	20.0%
Nuclear gages	35.4	36.5	31.9	40.5	50.0	50.0	37.0	42.9	36.4	40.0
Other	0	0	0	0	0	0	0	0	0	0
Not checked	23.2	20.4	38.9	24.3	0	0	33.3	28.6	45.5	40.0
TOTAL RESPONSES	181	137	72	37	2	2	54	14	11	10

† **NOTE:** Group totals shown do not add up to the overall total response; some respondents selected multiple organization identifiers on the questionnaire causing overlapping groups. Numbers of respondents in each separate group included: 53 owners only, 17 others only, 14 specifiers only, 32 owner and specifier only, 2 owner and other only, 1 specifier and other only, 7 owner and specifier and other only, 1 contractor only, 1 association only, and 2 nonanswered responses.

*Questions 2 and 3 were answered in both words and excerpts from specification documents. These responses were not included in the computerized database but were filed for reference.

TABLE 19. 1992 JOINT CONSTRUCTION QUESTIONNAIRE RESPONSES (SHEET 5 OF 8)

Respondent Group TOTALS †	All 130	Owner 94	Specifier 54	Other 27	Assoc'n 1	Contractor 1	Owner Specifier 39	Owner Other 9	Specifier Other 8	Owner Spec Other 7
B. Construction Processes and Joint Techniques										
6. Where are density tests run? Check all that apply.										
Exactly in joint	26.2%	27.9%	21.1%	21.9%	33.3%	0%	23.3%	18.2%	14.3%	14.3%
Distance on each side	25.0	25.6	17.5	28.1	33.3	100.0	20.9	27.3	14.3	14.3
Mat interior	41.7	40.3	50.9	40.6	33.3	0	48.8	36.4	42.9	42.9
Don't know	5.4	6.2	5.3	9.4	0	0	7.0	18.2	28.6	28.6
No answer	1.8	0	5.3	0	0	0	0	0	0	0
TOTAL RESPONSES	168	129	57	32	3	1	43	11	7	7
7. Are transverse joint densities normally checked?										
Yes	21.6%	26.4%	12.0%	13.6%	0%	0%	13.9%	25.0%	14.3%	16.7%
No	69.0	64.4	86.0	68.2	100.0	100.0	83.3	62.5	71.4	66.7
Other special jobs	4.3	3.4	0	9.1	0	0	0	0	0	0
Don't know	5.1	5.7	2.0	9.1	0	0	2.8	12.5	14.3	16.7
TOTAL RESPONSES	116	87	50	22	1	1	36	8	7	6

† **NOTE:** Group totals shown do not add up to the overall total response; some respondents selected multiple organization identifiers on the questionnaire causing overlapping groups. Numbers of respondents in each separate group included: 53 owners only, 17 others only, 14 specifiers only, 32 owner and specifier only, 2 owner and other only, 1 specifier and other only, 7 owner and specifier and other only, 1 contractor only, 1 association only, and 2 nonanswered responses.

TABLE 19. 1992 JOINT CONSTRUCTION QUESTIONNAIRE RESPONSES (SHEET 6 OF 8)

Respondent Group TOTALS †	All 130	Owner 94	Specifier 54	Other 27	Assoc'n 1	Contractor 1	Owner Specifier 39	Owner Other 9	Specifier Other 8	Owner Spec Other 7
C. Experience and Suggestions										
1. Based on your experience, which of the following produce higher density in hot-mix construction joints? Check all that apply.										
Experienced paving crew	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Raking and luting	15.5	14.6	17.5	19.7	33.3	50.0	17.5	23.5	20.0	21.4
Mechanical paver attachments	9.7	10.3	10.2	7.0	0	0	10.2	8.8	10.0	10.7
Experienced roller operators	30.4	29.2	28.8	33.8	33.3	50.0	27.7	29.4	30.0	28.6
Constant rolling technique	14.4	16.6	15.3	8.5	0	0	17.5	11.8	10.0	10.7
Special rollers	2.6	3.0	2.3	2.8	0	0	2.9	2.9	3.3	3.6
Paving & rolling coordination	25.7	25.2	24.9	26.8	33.3	0	24.1	23.5	26.7	25.0
Don't know	1.6	1.0	1.1	1.4	0	0	0	0	0	0
TOTAL RESPONSES	381	301	177	71	3	2	137	34	30	28

† **NOTE:** Group totals shown do not add up to the overall total response; some respondents selected multiple organization identifiers on the questionnaire causing overlapping groups. Numbers of respondents in each separate group included: 53 owners only, 17 others only, 14 specifiers only, 32 owner and specifier only, 2 owner and other only, 1 specifier and other only, 7 owner and specifier and other only, 1 contractor only, 1 association only, and 2 nonanswered responses.

TABLE 19. 1992 JOINT CONSTRUCTION QUESTIONNAIRE RESPONSES (SHEET 7 OF 8)

Respondent Group TOTALS †	All 130	Owner 94	Specifier 54	Other 27	Assoc'n 1	Contractor 1	Owner Specifier 39	Owner Other 9	Specifier Other 8	Owner Spec Other 7
C. Experience and Suggestions										
2. Which construction techniques generally provide higher construction joint density?										
Normal method	54.1%	58.1%	48.8%	42.9%	100.0%	100.0%	54.8%	44.4%	42.9%	42.9%
Special	18.4	17.6	17.1	28.6	0	0	16.1	33.3	28.6	28.6
Don't know	27.6	24.3	34.1	28.6	0	0	29.0	22.2	28.6	28.6
Not involved in constructing/ evaluating joints	0	0	0	0	0	0	0	0	0	0
TOTAL RESPONSES	98	74	41	21	1	1	31	9	7	7

† **NOTE:** Group totals shown do not add up to the overall total response; some respondents selected multiple organization identifiers on the questionnaire causing overlapping groups. Numbers of respondents in each separate group included: 53 owners only, 17 others only, 14 specifiers only, 32 owner and specifier only, 2 owner and other only, 1 specifier and other only, 7 owner and specifier and other only, 1 contractor only, 1 association only, and 2 nonanswered responses.

TABLE 19. 1992 JOINT CONSTRUCTION QUESTIONNAIRE RESPONSES (SHEET 8 OF 8)

Respondent Group TOTALS †	All 130	Owner 94	Specifier 54	Other 27	Assoc'n 1	Contractor 1	Owner Specifier 39	Owner Other 9	Specifier Other 8	Owner Spec Other 7
C. Experience and Suggestions										
3. Which technique gives the best looking construction joints?										
Normal	53.8%	61.6%	52.0%	36.0%	100.0%	0%	61.1%	44.4%	25.0%	28.6%
Special	14.5	12.8	14.0	24.0	0	100.0	13.9	22.2	37.5	28.6
Don't know	31.6	25.6	34.0	40.0	0	0	25.0	33.3	37.5	42.9
TOTAL RESPONSES	117	86	50	25	1	1	36	9	8	7
4. Which technique gives the longest lasting joints without raveling?										
Normal	44.8%	51.8%	38.8%	29.2%	100.0%	0%	45.7%	37.5%	25.0%	28.6%
Special	18.1	17.6	18.4	33.3	0	0	20.0	37.5	50.0	42.9
Don't know	37.1	30.6	42.9	37.5	0	100.0	34.3	25.0	25.0	28.6
TOTAL RESPONSES	116	85	49	24	1	1	35	8	8	7

† **NOTE:** Group totals shown do not add up to the overall total response; some respondents selected multiple organization identifiers on the questionnaire causing overlapping groups. Numbers of respondents in each separate group included: 53 owners only, 17 others only, 14 specifiers only, 32 owner and specifier only, 2 owner and other only, 1 specifier and other only, 7 owner and specifier and other only, 1 contractor only, 1 association only, and 2 nonanswered responses.

SUMMARY OF QUESTIONNAIRE RESPONSES.

Questions in the survey were not intended to be tricky or unclear; subjective and objective responses were solicited. A tabular summary of responses is provided in table 19. Discussion of survey results is provided in the following question by question summary.

A. Specifications.

1. Do the typical hot-mix specifications that you (your organization) work with address joint density between adjoining paving mats? Check one answer.

Only 62 percent of those completing the questionnaire answered this question; the lowest response of the entire survey. This response implies that close to 40 percent of those answering the remainder of this survey were skeptical about answering the first question. This was possibly due to misunderstanding the question or other reasons.

The majority of the 81 responses, 78 percent, indicated that their hot-mix specifications addressed the subject of joint density most of the time. Sixteen percent indicated none of the time, and about 6 percent did not know if their specifications mentioned density of joints.

Group and subgroup response trends were the same as the overall trend. Only 49 percent of the specifier group answered this question; the subgroup of owners and specifiers was the dominant reason because they gave only a 52 percent response.

2. What kind of hot-mix jobs that you (your organization) deal with require more than normal effort to obtain specified joint density? Check all that apply.

Most groups answered this question with about the same distribution or pattern as the overall response. Airport or airfield paving was identified by 48 percent of respondents as requiring more effort to attain specified density in joints. Other significant responses included city street work at 9 percent and interstate highway work at 7 percent. Eight percent of respondents did not know the answer.

3. Do your typical specifications define how to make or compact the joints? Check all that apply.

Overall, 88 percent answered yes to this question. Eleven percent said no and 1 percent did not know. The component parts of the positive answers indicated that about 45 percent defined how to make longitudinal joints and 43 percent defined how to make transverse joints (called lateral joints on the questionnaire). This response trend was about the same across all groups and subgroups. It was noted that the don't know answers came from the owner-only subgroup of 55 respondents. The general implication is that most hot-mix construction specifications define how to make both longitudinal and transverse construction joints.

4. With regard to payment, do your typical specifications include any of the following conditions on hot-mix joint construction? Check all that apply.

Overall, about 48 percent of respondents claimed that their specifications include lower pay provisions for lower joint density. Similarly, 42 percent said their payment conditions were for full pay regardless of joint density. No specifications typically called for higher pay for the specified work. Seven percent did not know if their specifications included pay provisions based on construction joint density. Finally, 3 percent did not answer this question; the specifier-only group gave no responses.

Response trends for almost all other groups and subgroups were similar. The association group, one of the only two distinct groups and one of the two smallest response groups, was the exception. Its response trend was for full pay regardless of density.

B. Construction Processes and Joint Construction Techniques

1. Rank the importance of the following processes (1,2,3, or 4) in constructing improved hot-mix construction joints. 1 = most important and 4 = least important.

The overall ranking from most to least important was rolling operations, paving operations, mix production, and mix transportation, respectively. This same ranking was found for most groups and subgroups. However, contractor and association groups ranked the processes as paving, then rolling operations, mix production, and mix transportation in order of importance.

2. Describe your normal method of constructing a longitudinal (long) joint.

3. Describe your normal method of constructing a lateral joint at the end of a length of paving.

Both these items were answered in both words and excerpts from specification documents. These responses were not included in the computerized database but were filed for reference.

4. If you use special construction methods on projects when hot-mix joint density will be closely checked, which of the following operations do you perform? Check all that apply.

The overall response indicated that the majority, 34 percent, used no special methods to help attain acceptable joint density. Twenty-nine percent responded that cutting and removing cold edges of paved mat was the preferred method of constructing joints on projects where joint density was checked. Similarly, 18 percent chose heating the cold edges prior to placing hot mix next to a cold edge. Paver attachments for better distribution of hot mix and other methods were equal at 8.5 percent each. Only about 2 percent indicated they did not know. This trend in responses was about the same across all groups and subgroups except the contractor group; it did not respond to this item.

5. How are joint densities checked? Check all that apply.

Overall, coring was considered the first choice for checking joint density with 41 percent. Nuclear density gages was next with about 36 percent response. Twenty-three percent indicated that joint densities were not checked. None of the groups or subgroups indicated that other methods were used to check density of the constructed hot-mix pavement. This trend held for most of the groups and major subgroups.

6. Where are the density tests run? Check all that apply.

The all group response indicated that 42 percent checked the pavement for density in the mat or interior portion. For joint density, 26 percent chose locations exactly in the construction joint and 25 percent said tests were run on the area adjacent to construction joints. About 5 percent did not know where densities were run. Similar trends existed among most of the groups and subgroups. The contractor group was the exception; its preference was for testing in areas adjacent to the joint. This exception could be due to the fact that the contractor group was small and that its response was indicating Australian practice.

7. Are lateral (transverse) joint densities normally checked?

Most responses were negative for this question with a 69 percent majority. About 22 percent said yes. Only 4 percent gave a conditional yes for special jobs. Five percent did not know if transverse joints were checked for density.

C. Experience and Suggestions

1. Based on your experience, which of the following produce higher density in hot-mix construction joints? Check all that apply.

Based on the experience of those completing the questionnaires, roller operator experience and good coordination between paving and rolling operations were of primary importance in producing higher constructed joint densities. Manual raking and luting, and constant rolling technique were of lesser importance.

This result can be related to the process ranking item B1 where rolling and paving operations were ranked first and second in importance for improved construction joints. Both overall responses seem consistent.

Most groups and subgroups had similar responses. The contractor group, again, was the exception. Its response was equally split between raking and luting, and experienced roller operators.

2. Which construction techniques generally provide higher construction joint density?

Overall response to this question was only about 75 percent of the response to the survey. Normal construction techniques gave higher joint densities according to the experience of the majority; 54 percent. Special construction methods, as provided in survey item B4, received only about an 18 percent response.

Almost 28 percent did not know which construction techniques gave higher construction joint densities. This was a significant finding because all respondents were involved with designing and/or constructing and evaluating asphalt hot-mix construction. This implies that a considerable group of people in the hot-mix pavement construction community have unclear ideas about specific techniques that improve the density of joints. The lack of response from the other 25 percent of survey respondents also tends to confirm this finding.

3. Which construction technique gives the best looking construction joints?

The question was not about aesthetics only. Experience has indicated that if paving joints look uniform and tight, they generally have higher densities than those that look more open and exhibit a different texture than the rest of the paved area. For the total survey response, 54 percent selected normal techniques. Special techniques received only about 15 percent of responses. Again a significant percentage of those responding checked the don't know answer; this time it was about 32 percent of the 117 responses. This tends to indicate that a considerable group of those responding either do not see the finished pavement or do not know how to discern good joint appearance.

Responses across most groups and subgroups were similar, except for the "other" respondents. Forty percent of "others" checked the don't know choice, 36 percent checked normal, and 24 percent of the group of 25 respondents checked special. Although these normal and don't know percentage trends were opposite the remaining groups' trends, the percentage of those that did not know was a significant finding.

4. Which technique gives the longest lasting joints without raveling?

There were 116 overall responses to this question; normal techniques had a 45 percent share and "special" polled about 18 percent. The don't know category totaled 37 percent; this was another significant finding. Group and subgroup responses were similar. Again, a rather high number of those responding to the survey claimed that they did not know which type of jointing technique produced the longest lasting and ravel resistant construction joint.

SUMMARY OF QUESTIONNAIRE FINDINGS.

This survey indicated that listed group categories on the survey were not totally mutually exclusive. Owner, specifier, and other categories overlapped, but association and contractor groups were separate and distinct. The difference in emphasis of association and contractor groups could be seen in response to the construction process ranking item, question B1. While other groups and subgroups ranked compaction rolling and paving operations as first and second in order of importance, the association and contractor groups ranked paving first and rolling second. The contractor group responded that it checked joint density only at locations to the sides of indicated joints while other respondent groups and subgroups checked joint density at indicated joint locations and a distance to the sides of each joint. Contractor and association groups also indicated that only normal methods of construction produced higher joint density. Other groups and subgroups indicated a similar trend but normal methods was the majority response.

Overall general findings of the specification part of the survey are as follows:

- Most of the time, hot-mix specifications were concerned with density along both longitudinal and transverse joints of the pavement construction.
- About 48 percent of responses indicated that airfield/airport hot-mix paving projects required more effort to produce specified joint density.
- Nearly 90 percent of responses indicated that their specifications defined how to make joints or compact the mix at construction joints.
- About 50 percent of specifications require lower pay for density less than specified and 42 percent of specifications are based on full payment regardless of density.
- Although about half of the respondents indicated that normal joint construction methods gave good results, between 28 and 38 percent of them did not know which jointing techniques provided more durable and longer lasting construction.
- This survey summarized opinions and facts that represent the cumulative and predominant snapshot of airport and highway hot-mix construction in early 1992. Opinions change and technology goes through developmental changes.

SUMMARY FINDINGS AND RECOMMENDATIONS

The three phases of this study: the literature review, construction review and interviews, and the questionnaire led to interesting findings concerning airport hot-mix specifications and joint construction.

FINDINGS.

Increased demands of air transportation and aircraft design changes have driven the system of airport flexible pavement mix design and construction. Mix design technology has developed and has improved the quality of mixes that support air traffic. Construction equipment developments, such as vibratory rollers, have allowed application of more energy to hot mixes during construction. Construction specifications have also developed from early specifications that required a minimum level of quality control and assurance during construction to those that require extensive quality-control/quality-assurance work to ensure constructed quality level documentation.

The past thirty years or more have been a period that has seen the flexible pavement community perform research and produce technical literature on hot-mix joint construction. Manuals, textbooks, engineering technical papers and reports on hot-mix construction have formed a base of information on joint construction. State departments of transportation (DOTs) and other organizations have produced quantitative and qualitative construction specifications. Their experiences have prompted them to use innovative and locally accepted methods and techniques of construction.

Joints or junctions of paving lanes in hot-mix paving construction are areas that are different from interior portions of paving. On airfields, joints accumulate into substantial lengths of potential problem areas if they are not constructed properly. Joints are areas where wear and weathering can initiate progressive deterioration of pavement surfaces. Poor construction techniques can lower the durability (indicated by density), shorten effective life between overlays, and increase pavement maintenance costs.

Joint construction is performed with manual and mechanical methods or techniques. Joint forming techniques are applied to confined and unconfined edges of paving lanes; the edges are oriented in either longitudinal or transverse directions. Manual techniques, performed by the paving crew, are apparently variable and dependent on the consistency of the paving crew. They consist of:

1. Raking and luting.

2. Bumping or packing unconfined edges.

3. Shoveling and moving hot mix.

4. Placing or removing forms to accomplish construction of a joint.

5. Aligning the paver for proper overlap and distribution of mix against an existing paved lane.

It is reasonable to believe that mechanical jointing techniques can be more consistent in mix distribution and repetitive operations than manual construction techniques. Current mechanical jointing techniques consist of:

1. Applying extra heat to cold edges before placing adjacent paving lanes. This technique has generally given from none to slight density improvement in joints.

2. Forming wedge shapes along unconfined edges of paving lanes. This technique has been used with staged highway construction for improved traffic safety.

3. Distributing mix to selected areas of paving lanes. This includes attachments (some are proprietary) to the following parts of a paver:

    a. Screed for varying the distribution of hot mix.

    b. The area behind the augers and in front of the screed for use near joint locations.

    c. An end gate controller that attaches to hydraulically controlled end gates to assist in mating a fresh paving lane to an existing lane.

    d. A shaped metal plate attachment that is mounted to the confined side of the paver to mechanically move and shape (lute) overlapped mix from the surface of existing lanes to an area along longitudinal joints before compaction rolling.

4. Confining mix during rolling compaction with a roller-attached device that can also cut edges from unconfined sides of paving lanes.

5. Equipment-mounted cutting blades for use in removing loose mix at unconfined edges of paving lanes.

At least two companies currently market mechanical devices that were developed to assist in hot-mix distribution during paving and confinement during rolling; each are claimed to improve joint density. The devices were designed for mounting on existing hot-mix paving and roller equipment. The effectiveness of these devices in improving joint density should be thoroughly evaluated.

The literature review also revealed several other techniques worth considering in developing improved jointing techniques and specifications.

1. Echelon paving, with two or more pavers staggered and offset from each other, could be used to minimize the density lowering effects of unconfined edge cooling, rolling limitations, etc. This produces hot construction joints and higher joint density when

relatively short distances exist between two pavers. Echelon paving requires a high output hot-mix production plant and adequate numbers of rolling compaction equipment. Hot joints occur when the cool lane edge has a temperature of not more than about 50-60°F lower than a fresh hot lane or has cooled for less than 1-1/2 hours before paving next to it.

2. Preselect or design paving lane widths along central portions of runways and or taxiways to minimize direct wheel traffic application to longitudinal joints. Offset joint spacing in successive pavement layers should be considered and dimensions included in design and specification documents.

3. When cold joints are necessary, the most reasonable method of construction to prevent later maintenance problems is to cut and remove a width of loose edge material before paving next to it. A two to six inch width of cut may be sufficient in most cases. Cold joints occur when one paved lane has cooled overnight or is well below 180°F when a hot lane is placed next to it.

4. When compacting, roller operators should be careful not to compact too close to unconfined edges of hot mix. Operators should prevent excessive distortion to areas that are adjacent to where subsequent paving will occur. The allowable uncompacted distance from the unconfined edge is a function of loose mix thickness. Thin pavements such as two inch loose thickness may be rolled closer to the edge than those that have a four inch loose thickness. A good estimate of this uncompacted distance is 1-1/2 inches per loose lift thickness in inches. Using this estimate will typically produce uncompacted strips extending inward from the free edge two to six inches. These strips may be effectively compacted if fresh mix is placed adjacent to them before the edge cools. If the uncompacted strip is cold before hot mix is placed, the 2- to 6-inch strip should be cut and removed prior to paving an adjacent lane (as discussed in item 3 above). Rolling patterns should be tailored to attain target density in joint and interior areas of paving lanes; this will require more effort on the part of the contractor.

5. No single large-scale scientific evaluation of several hot-mix construction jointing techniques was found in the literature.

6. Specify, in a general manner, where joint core testing will be done. The relative locations and numbers of joint and mat cores should be indicated. For example, if only one joint core is specified, a probable result will be the use of the highest density found in the vicinity of the joint. If three cores are specified, in the joint centerline and both sides of it, densities can be averaged to get a better representation of the true in-place joint construction. Locations or stationing of mat and joint core groups should be randomly determined.

Construction density studies of typical airfield mixes by the Corps of Engineers, the FAA, and Livneh have provided interesting results. Data from five projects where relative Marshall density characterized construction (Livneh's data from table 5 and combined FAA and WES data from table 17), indicated the following:

1. Project mat constructed density ranged from 96.8 to 100.2 percent of laboratory compacted density. Project constructed joint density ranged from 92.0 to 95.8 percent laboratory density. Only Livneh's hot-joint technique provided joint densities that averaged greater than 96 percent; his average was approximately 96.8 percent of lab density.

2. Comparing the above results with those of table 6 (Rollings and Rollings), shows that generally the range of project mat and joint densities relative to laboratory compacted field produced density are similar. Observation shows that project averages from table 5 and table 17 projects are skewed toward the lower end of the desired joint density range indicated in table 6.

Construction density from projects examined directly during this study, at Albany County and Saratoga County Airports, indicated no significant difference between manual and mechanical jointing techniques used on the surface mixes. Variability along one-foot-wide joint strips indicated that construction technique variance was the largest contributor to construction density variability. This variability also appears directly correlated with the construction project and/or the contractor. If this is true, each contractor's joint construction methods on a given paving project may be characterized by a jointing technique variance quantity.

Responses to a survey on current hot-mix joint construction and specifications were also interesting and revealing. Most respondents believed that airfield hot-mix paving required more effort than highway and other paving. A significant finding was that many of the respondents did not know which jointing techniques actually produced higher densities that helped the pavement last longer. There was also a lack of recognition of good joint construction by observation.

Almost equal use of core specimens and nuclear gauge readings were noted in responses to the questionnaire survey. It should be noted that the only sure method of obtaining tangible density test results is with cores or other properly cut specimens that are representative of the constructed mix. Acceptance of the project should be based on densities from core specimens.

SUGGESTIONS AND RECOMMENDATIONS.

Based on this study, these suggestions and recommendations are made:

1. Field hot-mix specifications, such as FAA Item P-401, should consider incorporating other quality control and assurance criteria than those in current use. Criteria such as the density uniformity index or the joint-to-mat average density ratio could be utilized along with laboratory compacted density values from plant produced mix specimens. If the

following quantities and scheme are used, a more complete picture of project hot-mix construction relative to design should develop.

a. A minimum of three different average density quantities is recommended; laboratory compacted density in pcf or similar units, joint core density, and either of the relative density ratios or density uniformity index.

b. True joint locations in the construction are sometimes elusive due to paver overlap and construction redistribution of mix at longitudinal joints; this was noted in reference 11. The surest way to obtain representative density at edge junctions of paving lanes is to sample the joint in at least three locations near the indicated joint (see recommendation 3 below for a similar alternative).

2. Revised pay incentive charts, based on the new or revised criteria, could be developed. The FAA should decide if contractor pay should remain based on constructed density of joints and mats. Other studies of jointing have recommended that inclusion of these charts in the contract specifications help motivate contractors to make special efforts at producing more dense construction joints. If the decision is to continue with this approach, pay should be based on density as determined from randomly stationed core specimens that have been carefully removed from the construction and tested according to accepted standards.

3. Seven randomly located stations per 1000 ft of runway length or one random location per 1000 linear ft of interior joint strip and interior paving lane is recommended for density verification testing. This can be done separately for joint sampling and mat interior sampling. A minimum of two cores should be cut from each joint and mat area. When the stationing has been determined (in a random manner), the two cores will be located, cut, and tested. It should be emphasized that with runway lengths, the seven locations are not located by dividing 1000 ft by 7 and sampling at regular intervals of 142.9 ft and selecting random offsets. To properly locate samples, the 1000 ft should be broken into seven randomly determined stations and random centerline offsets (generally irregular intervals). The total number of specimens per 1000 ft of runway in this example is 28:14 joint specimens and 14 mat interior specimens. These typical sampling rates are not very different from those that are currently used.

   Joint cores can be sampled by always taking one core from the apparent joint location and another core, alternating by stationing, four to six inches to the right and left of the joint. Mat specimens may be obtained in sets of two, if desired. This type of sampling scheme will help ensure that representative project joint density is determined. The average of each set of density specimens can be used to enter the appropriate specification payment schedule for joint and mat density. This should prove out as a fair and unbiased method for verifying airport pavement construction.

4. Several methods and techniques of joint construction should be evaluated to develop a definitive indication of each technique's relative effectiveness at producing higher density

and better long-term durability. A couple of techniques could be used at individual small airport construction projects or several techniques could be demonstrated at a single large construction project. Long-term durability of jointing techniques could be documented by follow-up inspections with photographs.

5. Existing FAA construction projects, such as those found in the literature and those analyzed for this study, should be intermittently monitored for joint durability. Over a period of time, this could develop into a valuable database of jointing technique versus durability. Future revisions of specifications and construction criteria would be easier to incorporate with a strong database.

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