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Road Bureau, Ministry of Construction, JAPAN
Public Works Research Institute, Ministry of Construction, JAPAN
Federal Highway Administration, Department of Transportation, U.S.A.

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Proceedings of the 7th U.S.-JAPAN Workshop on Advanced Technology in Highway Engineering

Synopsis:

This technical memorandum describes summaries of presentation and discussion on the 7th U.S.-Japan Workshop on Advanced Technology in Highway Engineering held in Tsukuba from October 23rd to 31st, 1998.

Key Words: U.S.-Japan Workshop on Advanced Technology in Highway Engineering, Pavement, Accelerated Loading Test, Suspension, Strategic Highway Research Program (SHRP), Non-Road By-Products

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第7回日米道路科学技術に関する
ワークショップ報告書

1998年10月23日～31日

つくば市他

平成11年4月

建設省道路局、建設省土木研究所
アメリカ合衆国運輸省連邦道路庁

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1 ワークショップの概要

1.1 背景と目的

日米道路科学技術に関するワークショップ(以下日米道路 WS)は、平成4年5月29日、当時の建設省技監三谷浩氏および米国連邦道路庁(以下 FHWA) 長官トーマス・ラーソン氏が「日米道路科学技術協力の実施取り決め」に署名したことによって始まった。

その後、毎年日米交互にワークショップが開催され、道路全般にわたる緊密な情報交換や専門家の交換等が実施された。平成9年、米国で行われた第6回日米道路 WS において、前建設省土木研究所長辻靖三氏と FHWA 研究局長ロバート・ベッツォールド氏との間で、道路全般にわたる会議は3年に1回行い、それ以外の年はテーマを限定し、より専門的な研究交流を行うこととした。また、平成10年3月、井上靖武土木研究所長とベッツォールド FHWA 研究局長は、第7回のテーマとして「舗装」を取り上げることに合意した。

今回の日米道路 WS は、舗装技術の現況および将来についてより専門的な研究交流を促進するため、「舗装」をメインテーマとし、その下の個別テーマとして「促進載荷試験」、「サスペンション（舗装と車両の関係）」、「新道路研究計画(以下 SHRP)」、「建設外副産物の利用」の4つのセッションを実施した。

1.2 スケジュール

10月24日(土) 米国側参加者来日

25日(日) 東京湾アクアライン視察

26日(月) 開会式

挨拶	建設省土木研究所	井上 靖武
	米国連邦道路庁	Paul Teng
	ネブラスカ州道路局	Allan Abbott

基調講演

「21世紀国土均衡交通法 (TEA21)」	FHWA 舗装課長	Paul Teng
	ネブラスカ州道路局技術部長	Allan Abbott
「新道路整備五箇年計画」	建設省道路局道路経済調査室長	奥平 型

セッション1 促進载荷試験

土木研究所施設見学

歓迎レセプション

27日(火) セッション2 サスペンション (舗装と車両の関係)

セッション3 新道路研究計画 (SHRP)

夕食会

28日(水) セッション4 建設外副産物の利用

閉会式

挨拶	建設省土木研究所	山本 晃一
	米国連邦道路庁	Paul Teng
記念品贈呈		

29 日(木) 視察旅行

明石海峡大橋

淡路ハイウェイオアシス

野島断層

30 日(金) 視察旅行

阪神・淡路大震災関連復興状況

31 日(土) 米国側参加者帰国

1.3 会議プログラム

10月26日(月)

- 9:30～10:00 開会式 (8 階会議室)
(司会 建設省土木研究所道路研究室 田宮 佳代子)
挨拶 建設省土木研究所長 井上 靖武
米国連邦道路庁(FHWA)舗装課長 Paul Teng
ネブラスカ州道路局技術部長 Allan Abbott
- 10:00～10:15 記念撮影
- 10:30～12:00 基調講演 (8 階会議室)
(司会 建設省土木研究所道路研究室 田宮 佳代子)
「21 世紀国土均衡交通法 (TBA21)」 FHWA 舗装課長 Paul Teng
ネブラスカ州道路局技術部長 Allan Abbott
「新道路整備五箇年計画」 建設省道路局道路経済調査室長 奥平 聖
- 12:00～13:00 昼食 (1 階会議室)
- 13:00～15:30 セッション1 促進載荷試験 (8 階会議室)
「土木研究所舗装走行実験場における試験結果」
建設省土木研究所舗装研究室長 池田 拓哉
「回転式舗装試験機による試験結果」
日本道路公団試験研究所舗装研究室長 七五三野 茂
- (14:15～14:30 休憩)
「リノ舗装走行試験場 (WesTrack) および FHWA の促進載荷試験機の現状」
ターナー・フェアバンク道路研究センター(TFHRC)
舗装供用性研究室長 Charles Churilla
「州における舗装促進試験計画」
FHWA ニューヨーク支所 Max Grogg
- 15:40～17:15 土木研究所施設見学
30MN 大型構造部材万能試験機～試験走路～舗装走行実験場～屋内標識実験施設
- 18:00～20:00 歓迎レセプション (ホテルグランド東雲)

10月27日(火)

9:30～10:45 セッション2 サスペンション（舗装と車両の関係）（8階会議室）
「軸重規制の現状と将来」

FHWA 舗装課長

Paul Teng

「エアサスペンションの評価と幅広シングルタイヤの影響」

FHWA 道路施設課長

Byron Lord

(10:45~11:00 休憩)

11:00～12:00 セッション3 SHRP (8階会議室)

「舗装の長期供用性(LTPP)の現状」

TFHRC 舗装供用性研究室長

Charles Churilla

12:00~13:00 昼食 (1 階会議室)

13:00～15:30 セッション3 SHRP（続き）

「ジャイレトリコンパクタの共通試験」

土木研究所舗装研究室

久保 和幸

「SUPERPAVE による日本のアスファルトの評価」

土木研究所化学研究室

佐々木 巖

(14:25~14:40 休憩)

「SUPERPAVE の現状」

FHWA 道路施設課長

Byron Lord

18:00~20:00 夕食会

10月28日(水)

9:30～11:30 セッション4 建設外副産物の利用 (8階会議室)

「副産物利用の基本方針」

土木研究所新材料開発研究官

猪熊 明

「建設外副産物の舗装への利用例」

建設省土木研究所舗装研究室長

池田 拓哉

(10:35～10:50 休憩)

「廃ゴムタイヤの利用」

FHWA 舗装課長

Paul Teng

「廃ゴムタイヤ以外の建設外副産物の利用」

FHWA ニューヨーク支所

Max Grogg

11:30～11:45 閉会式

(司会 建設省土木研究所道路研究室 田宮 佳代子)

挨拶 建設省土木研究所次長 山本 晃一

米国連邦道路庁舗装課長 Paul Teng

記念品贈呈

2 ワークショップの報告

2.1 開会式

井上靖武土木研究所長は、まず、今回の日米道路科学技術に関するワークショップ(以下日米道路 WS)が開催されるまでの経緯について述べ、今回の日米道路 WS からは包括的な意見交換を3年に1回とし、それ以外の年はテーマを絞り込んだより深い研究交流を行うことを強調した。また井上所長は、3月に渡米した際にベッツォールド米国連邦道路庁(FHWA)研究局長と会談し、テーマを「舗装」とすることで合意したことを付け加えた。さらに、今回の日米道路 WS は、日米両国における専門的研究成果を交換することにより、より高度な協力活動を行うために重要なワークショップであることを述べた。

Paul Teng 米国連邦道路庁(FHWA)舗装課長は、今回の日米道路 WS における技術情報の交換は、FHWA にとって大きな重要性をもつと述べた。また、過去6回のワークショップで大きな成果が上げられたことを述べた上で、テーマが舗装に絞られた今回のワークショップも、大きな成果を収められるであろうと述べた。最後に、他の4名の参加者を紹介した。

最後に Allan Abbott ネブラスカ州道路局技術部長が、ネブラスカ州は、人口は少ないが優れた交通システムを有していることにより商業および人々の往来が州内外を通じて実現できていることを例にとり、交通システムの重要性を説いた。また、本ワークショップにおいて貴重な情報を得て、舗装の耐久性向上に役立てたいと述べた。

2.2 基調講演

2.2.1 21 世紀国土均衡交通法(TEA21)

(1) 米国連邦道路庁(FHWA)の取り組み

①講演者

Paul Teng (FHWA 舗装課長)

②講演要旨

21 世紀国土均衡交通法 (Transportation Equity Act for the 21st Century; 以下 TEA21)は、1998 年 6 月 9 日、大統領により署名された。同法は 21 世紀に向けた交通を最適化するための法律であり、2003 年までの時限立法である。予算規模は約 2000 億ドルで、TEA21 の前身の法律である総合陸上輸送効率化法(ISTEA)の 1.4 倍である。そのうち、陸上輸送調査に 5 億 9 千万ドル、技術開発に 2 億 5 千万ドル、教育訓練プログラムに 1 億 2 千万ドル配分されている。

TEA21 に対応するため、FHWA は舗装技術プログラムを行っている。舗装技術プログラムは性能の向上、および資産管理の 2 つのカテゴリーに分類され、性能の向上は、耐久性、表面のなめらかさ、安全性、美観を指標として構造や混合物の仕様を決定するものであり、資産管理は、供用性、保全、費用対効果、利用者の評価を指標として分析および意思決定を行うものである。そして、これらの意思決定に関しては、ポルトランドセメント、アスファルト、舗装の管理、リサイクル材料、舗装の長期供用性といった 5 つの技術分野がサポートすることになっている。

TEA-21 は行政改革の意味あいがあり、同法の施行にともない、FHWA の 9 つの地方事務局が廃止され、4 つの支援センターに統合された。支援センターは、メリーランド、シカゴ、サンフランシスコ、アトランタに設置され、それぞれ、東部、中西部、西部、南部を管轄することとなった。

(2) 州政府の取り組み

①講演者

Allan Abbott (ネブラスカ州道路局技術部長)

②講演要旨

ネブラスカ州は、アメリカ合衆国の中央に位置しており、面積 20 万 km²、人口約 150 万人の州である。道路延長は 16 万 km であるが、半分は砂利道である。これらの道路の補修費用は TEA21 の予算によって賄われる。TEA21 の前身である ISTEA の時代には、設計および施工に関しては連邦道路庁の承認が必要であったが、TEA21 になってからは、州が設計および施工に関する権限を持つようになった。

TEA-21 施行以後、連邦道路庁の研究開発予算の半分が、州に研究開発費として配分されるようになった。しかし、全米レベルの研究開発を行う場合、各州が任意にお金を出し合うことになった。この資金の運営は、アメリカ州道路行政官協会(AASHTO)内の常任委員会によって行われている。また、調査プロジェクトは常任委員会が起案し、50 州およびワシントン DC、プエルトリコの代表者 52 名で構成される AASHTO の理事会が調査プロジェクトを承認する仕組みになっている。なお、調査プロジェクトの承認には 35 票が必要である。

2.2.2 新道路整備五箇年計画

①講演者

奥平 聖 (建設省道路局道路経済調査室長)

②講演要旨

日本の本格的な道路整備は 1954 年の道路整備五箇年計画に始まった。その後、経済成長とモータリゼーションの進展とともに、道路整備はこの五箇年計画をもとに計画的に整備が進められた。1965 年に名神高速道路が、1969 年に東名高速道路が全通した。1987 年に高速道路網 14,000km が計画され、現在、約 7,000km が供用されている。1988 年に瀬戸大橋児島－坂出ルート、1997 年に東京湾アクアライン、1998 年に明石海峡大橋が開通した。

1970 年の 1 人あたりの乗用車保有台数は、米国が 0.44 台／人に対し、日本は 0.07 台／人であった。この頃から、乗用車が普及し、1990 年には、日本は 3 人に 1 台（米国は約 0.6 台／人）になった。現在の日本の保有水準は米国の 30 年前の水準に達した。

新道路整備五箇年計画の策定に当たっては様々な難しい問題があった。道路上には、交通渋滞、交通事故の多発、騒音等の環境問題など、多くの課題が生じている。また、財政難、公共事業への批判（コスト高・行政のわかりにくさ等）、行政改革など道路を取り巻く社会・経済情勢も厳しくなっている。

新道路整備五箇年計画の予算は 78 兆円で前回の計画とほぼ同規模である。新道路整備五箇年計画の特徴は、施策の柱を、①新たな経済構造実現に向けた支援（経済構造改革）、②活力ある地域づくり・都市づくりの支援（地域・まち）、③よりよい生活環境の確保（くらし・環境）、④安心して住める国土の実現（国土保全）の 4 点に整理したことや、高規格幹線道路を 7,265km から 8,626km に整備するなど具体的な整備目標を示したことである。

道路政策を進める際には、道路事業の効率化を行うとともに事業の評価システムやパブリック・インボルブメント、パートナーシップの確立を実施する。事業の評価システムについては、事前評価や工事中の再評価を今年度より開始した。事後調査についても、近いうちに、費用効果分析を中心としたガイドラインを固めることにしている。パブリックインボルブメントは、新道路整備五箇年計画で初めて採用され、延べ 11 万人の意見をもとに新道路整備五箇年計画が策定された。また、10 月より意見・要望を聞くための窓口を、東京に試行的に開設した。パートナーシップの確立は、国民と行政、官と民、国と地方が適切に役割分担をした新しいパートナーシップを構築する。

技術開発にあたっては、新道路技術五箇年計画を策定中であり、これについては土木研究所が極めて重要な役割を果たす。

今後、少子化・高齢化、国際化が進む中で競争力を維持するためには、インフラの整備が必要であり、道路整備を進めていくためには日米の協力が益々必要になる。

2.3 セッション

2.3.1 促進載荷試験

(1)土木研究所舗装走行実験場

①発表者： 池田 拓哉（建設省土木研究所舗装研究室長）

②発表内容

まず、土木研究所舗装走行実験場の概要を述べ、次に舗装走行実験場の研究成果のうち、リフレクションクラック抑制方法とインターロッキングブロックについて発表した。

リフレクションクラックの抑制方法については、対策なし、リフレクションクラック抑制シート（以下シート）、誘導目地について比較した結果、誘導目地がリフレクションクラックの誘導効果があることが紹介された。また、インターロッキングブロック舗装の耐久性については、舗装走行実験場における供用性や破損状態の結果が紹介された。

③ディスカッション

・米側からもリフレクションクラック対策が紹介され、特にグラスファイバーメッシュというシートの一種が成果を上げていることが紹介された。

(2)日本道路公団試験研究所回転式舗装試験機

①発表者： 七五三野 茂（日本道路公団試験研究所舗装研究室長）

②発表内容

まず、日本道路公団試験研究所回転式舗装試験機の概要について述べ、試験結果の一例として、アスファルト種別を変えた排水性舗装の耐流動性試験を紹介した。また、回転式舗装試験機は、従来の現場における試験よりも短期間でアスファルト混合物の評価が可能であることが強調された。

③ディスカッション

・大型供試体の作製方法について質問があり、隣接する供試体作成室での作製状況について回答があった。

(3)リノ舗装走行試験場（WesTrack）および FHWA の促進載荷試験機の現状

①発表者： Charles Churilla（ターナーフェアバンク道路研究センター(TFHRC)舗装供用性研究室長）

②発表内容

まず、リノ舗装走行試験場（WesTrack）の概要について述べた。また、WesTrack で行われた「アスファルト舗装の供用性に基づく仕様に関する調査」の試験結果を紹介した。さらに、TFHRC が所有する促進載荷試験施設の概要や、FHWA が所有する可搬式促進載荷試験機である Heavy Vehicle Simulator (HVS)についても紹介した。

③ディスカッション

・屋外試験における温度制御について質問があり、HVS にビニール製のおおいをかぶせて路面温度を制御するとの回答があった。

(4)州の促進載荷試験計画

①発表者： Max Grogg（米国連邦道路庁ニューヨーク州支所）

②発表内容

実大規模の促進載荷試験は、ノースカロライナ州、ミネソタ州 (Mn/ROAD)、オハイオ州の試験道路で実施されている。これらの試験道路は舗装の長期供用性(LTPP)調査にも使用されている。直線型の促進載荷試験施設は、オハイオ州の促進舗装載荷施設、ルイジアナ州の舗装研究施設 (PRF)、カリフォルニア州の促進舗装試験機 (CAL-APT)、カンザス州の促進試験施設 (K-ATL)、テキサス州の牽引式載荷機 (TxMLS) があり、フロリダ州でも 1999 年より開始される。

③ディスカッション

- ・特に質疑なし

2.3.2 サスペンション (舗装と車両の関係)

(1)軸重規制の影響

①発表者： Paul Teng (FHWA 舗装課長)

②発表内容

現在の米国における車両重量規制は総重量で 36t、シングル軸で 9t、タンデム軸で 15t である。安全で効率的な貨物輸送を促進するためのトラックの大きさおよび重量に関する研究が行われている。

③ディスカッション

- ・「重量の規制緩和が運輸業界から強く要望されているのではないか」という質問に対し、「運輸業界にとって道路は金の卵を生むニワトリである。路面を悪化させると、輸送効率が悪化し、商業的損失も大きくなるので、そのような要望はありえない。」との回答があった。

(2)エアサスペンションの評価

①発表者： Byron Lord (FHWA 道路施設課長)

②発表内容

エアサスペンションの衝撃係数は良好な路面で 1.1~1.15、粗い路面でも 1.2 であり、スチールサスペンションに比べ小さい。また、エアサスペンションは舗装の摩耗を軽減するなど、道路に対しても非常に効果的である。

③ディスカッション

- ・エアサスペンションを推進する方向にあるのかどうかを確認したところ、方針の決定は運輸業界が行うとの回答があった。

(3)幅広シングルタイヤの影響

①発表者： Byron Lord (FHWA 道路施設課長)

②発表内容

TFHRC の促進載荷試験施設で実施された幅広シングルタイヤの影響に関する実験を行った。その結果、幅広シングルタイヤは従来のダブルタイヤに比べて、舗装に与えるダメージは大きいことがわかった。

③ディスカッション

- ・「幅広シングルタイヤを規制する方向にあるのか」という質問に対し、「幅広シングルタイヤの使用を許可

- するかどうかについての規制は州の権限であり、州ごとに異なる対応となっている」との回答があった。
- ・運輸業界は、幅広シングルタイヤを導入すると輸送コストが低下するので、導入の要望がある。

2.3.3 新道路研究計画 (SHRP)

(1) 舗装の長期供用性(LTPP)

①発表者： Charles Churilla (TFHRC 舗装供用性研究室長)

②発表内容

LTPP の概要とこれまでの経過を紹介した。また、LTPP の調査結果は“DataPave97”として CD-ROM に収録されていることや、2002 年版 AASHTO 舗装設計指針に反映されることが紹介された。

③ディスカッション

- ・「現状での具体的な成果」について質問したところ、「供用性に基づいたバインダおよび混合物の新しい仕様(SUPERPAVE)による配合が流動に強いことなど、SUPERPAVE が概ね正しい方向にあることがわかった」との回答があった。

(2) ジャイレトリコンパクタの共通試験

①発表者： 久保 和幸 (建設省土木研究所舗装研究室主任研究員)

②発表内容

建設省土木研究所および民間 16 社で構成されるつくば舗装技術交流会は、日本で保有するジャイレトリコンパクターについて共通試験を実施した。その結果、締固め状態についてはメーカー間に差異があることがわかった。

③ディスカッション

- ・米側からキャリブレーションについての質問があった。米国では、頻繁に使用するところでは毎日、そうでないところでは週に 1 回程度、しばらく使わなかったときにはその都度、ジャイレイションの角度と圧縮力についてキャリブレーションしてから使用している。米国でも導入当初は同様の問題について悩まされたが、キャリブレーションの徹底で問題がなくなった。

(3) SUPERPAVE による日本のアスファルトの評価

①発表者： 佐々木 徹 (建設省土木研究所化学研究室研究員)

②発表内容

日本で使用されているバインダについて、SUPERPAVE による評価を行った。その結果、ストレートアスファルトについては現行の評価基準とほぼ類似した序列であるが、改質アスファルトに関しては、高温域においてグレード間の差異はみられなかった。

③ディスカッション

- ・特に質疑なし

(4) SUPERPAVE の現状

①発表者： Byron Lord (FHWA 道路施設課長)

②発表内容

FHWA では、バインダに関する専門作業班(ETG)を作り、SUPERPAVE バインダ仕様に関する検討を行っている。また、現在は現場による確認を行っている。

③ディスカッション

・米国における SUPERPAVE セン断試験機(SST)については、5 年間の舗装の性能保証を求める場合が少なからずあり、そのときに将来の破損状況を予測するなどといった目的で実際に使われている。しかし、高価すぎるということで SUPERPAVE の見直しが行われている。

2.3.4 建設外副産物の利用

(1)副産物利用の基本方針

①発表者： 猪熊 明（建設省土木研究所新材料開発研究官）

②発表内容

副産物の分類やリサイクルの基本方針について発表した。建設省の建設副産物のリサイクル目標が全体で 80%、アスファルト・コンクリート塊やコンクリート塊で 90%であることが紹介された。

③質疑応答

・「アスファルト・コンクリート塊やコンクリート塊のリサイクル目標が 90%であるが達成できるのか」という質問に対し、「リサイクル率は年々向上しており、達成は可能と考える」との回答があった。

(2)建設外副産物の舗装への利用

①発表者： 池田 拓哉（建設省土木研究所舗装研究室長）

②発表内容

ガラスびんを破碎加工したカレットはアスファルト混合物の骨材として、ごみ焼却灰はアスファルト混合物、下層路盤材や透水性ブロックとしての利用が検討された。しかし、いずれの材料もガラス質の性状から、はく離が懸念されるため、アスファルト混合物の骨材としては望ましくない。

③ディスカッション

・「ガラスカレットはうまく行かないのではないか」という質問に対し、「アスファルトとの付着性に問題があり、混入率に限界があることがわかっている。実際に試験をして判断する。」との回答があった。

(3)廃ゴムタイヤの利用

①発表者： Paul Teng（FHWA 舗装課長）

②発表内容

1991 年の総合陸上交通輸送効率化法 (ISTEA) で、廃ゴムタイヤを原材料とした改質剤(Crumb Rubber Modifier; 以下 CRM)の研究が盛り込まれ以来、様々な研究がなされている。ワイオミング大学西部研究所(WRI)は、CRM とアスファルトの相互作用を研究した。米国道路共同研究プログラム(NCHRP)は、CRM 入り改質アスファルトの SUPERPAVE プロトコルを発表した。オレゴン州立大は CRM と舗装の設計、施工、リサイクルとの関係について調査した。さらに、国立労働安全研究所(NIOSH)は CRM の環境評価を行った。

③ディスカッション

- ・「多様なタイヤの廃ゴムを使うと品質が安定しないのでは」との質問に対し、「タイヤに含まれる異物をうまく除去すればほとんど問題はない」との回答があった。

(4)その他の建設外副産物の利用

①発表者： Max Grogg (米国連邦道路庁ニューヨーク州支所)

②発表内容

リサイクル材料の研究開発は、FHWA とニューハンプシャー大学内に設置されたリサイクル材料支援センターと共同で行われている。TEA21 により、年間 150 万ドルの予算が 6 年間計上されている。リサイクル材料支援センターは材料の性状や新材料・新技術の開発を行う。FHWA は研究開発とともに、リサイクルに関する施策を行う。

③ディスカッション

- ・特に質疑なし。

2.4 閉会式

はじめに、山本晃一土木研究所次長が、今回の日米道路 WS はテーマを絞り込んだより深い研究交流を行う最初の会議であったが、舗装技術をはじめ、実り多い成果が得られたことを述べた。また、このような日米間の研究情報の共有は非常に重要であることと強調した。

次に、Paul Teng 米国連邦道路庁舗装課長が、3 日間のワークショップで実り多い成果が得られたことを述べた。今後もこのような有益な会議を継続していきたいと述べ、次回の日米道路 WS は 1999 年に米国で開催することを述べた。

3 参加者一覧

米国連邦道路庁

Paul Teng	舗装課長
Byron Lord	道路施設課長
Max Grogg	ニューヨーク州支所

ターナーフェアバンク道路研究センター

Charles Churilla	舗装供用性研究室長
------------------	-----------

ネブラスカ州道路局

Allan Abbott	技術部長
--------------	------

建設省

奥平 聖	道路局道路経済調査室長
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関口 幹夫	技術部
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ガイアートクマガイ

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小島 逸平	技術研究所長
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武井 利公	技術研究所
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小松原 昭則	舗装研究室主任研究員

北海道工業大学

亀山 修一	講師
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飯田 健一	技術部
児玉 孝喜	技術部
山崎 泰生	技術部
金井 利浩	技術研究所
門澤 忠雄	技術研究所

アートエンジニアリング

川野 敏行	社長
-------	----

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	矢部 正宏	技術本部長	黒川 勲	技術研究所
	小林 信夫	技術研究所長		
ニチレキ			世紀東急工業	
	羽入 昭吉	技術研究所	松田 敏昭	技術部
	伊藤 達也	技術研究所	奥平 真誠	技術研究所
	田中 正義	技術研究所	鈴木 徹	技術研究所
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	遠藤 桂	技術研究所	大成ロテック	
	高田 祥子	技術研究所	福田 萬大	技術研究所
日新舗道			加納 孝志	技術研究所
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	東本 崇	技術研究所		
佐藤道路			渡辺組	
	松野 三朗	社長	藤田 大二	技術研究所

土木研究所

井上 靖武 所長
 山本 晃一 次長
 京才 俊則 研究調整官
 中村 亮 道路部長
 片脇 清 材料施工部長
 岡原 美知夫 構造橋梁部長
 常田 賢一 道路交通総括研究官
 小林 保 総合交通安全研究官
 猪熊 明 新材料開発研究官
 恒岡 伸幸 国際研究協力推進室長
 濱田 俊一 道路研究室長
 上田 敏 高度交通システム研究
 室長
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**Proceedings of
The 7th U.S.-JAPAN Workshop
on Advanced Technology
in Highway Engineering**

**October 23 - 31, 1998
Tsukuba, JAPAN**

APRIL, 1999

**Road Bureau, Ministry of Construction, JAPAN
Public Works Research Institute, Ministry of Construction, JAPAN
Federal Highway Administration, Department of Transportation, U.S.A**

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1. Outline of the Workshop

1.1 Background and Objectives

The U.S.-Japan Workshops on Advanced Technologies in Highway Engineering started on May 29, 1992, when the Vice-Minister of Construction for Engineering Affairs of Japan, Hiroshi Mitani, and the Secretary of the Federal Highway Agency of the United States, Thomas Larson, signed the agreement for scientific cooperation between Japan and the United States concerning road technologies.

Each year, a workshop has been held alternately in Japan and the United States to exchange general and technical information concerning roads. In the 6th Japan-US Road Workshop, which was held in the United States in 1997, Seizo Tsuji, the former Director-General of the Public Works Research Institute, and Robert Betsold, the Research Director of the Federal Highway Agency, decided to hold workshops for general road affairs every three years and to focus on specific and technical subjects in the other workshops. In March 1998, Yasutake Inoue, the present Director-General of the Public Works Research Institute, and Betsold selected "Pavement" as the topic for the 7th Workshop.

The 7th Japan-US Road Workshop was held in 1998 to exchange technical information concerning pavement and to promote future communication. Four sessions were held under the main theme "pavement" and discussed accelerated loading tests, suspension, Strategic Highway Research Project (SHRP), and utilization of non-road by-products.

1.2 Schedule

Oct. 24 (Sat.) Arrival of the participants from the United States

25 (Sun.) Study Tour (Tokyo-Bay Aqualine)

26 (Mon.) **Opening Ceremony**

Address Yasutake Inoue (Public Works Research Institute)

Paul Teng (Federal Highway Administration (FHWA))

Allan Abbott (Nebraska Department of Roads (DOR))

Keynote Speeches

"Transportation Equity Act for the 21st Century"

Paul Teng (FHWA)

Allan Abbott (Nebraska DOR)

" New 5-Year Road Improvement and Management Program "

Kiyoshi Okudaira (Road Bureau, MOC)

Session 1 Accelerated Loading Tests

Visit to Facilities in PWRI

Reception

27 (Tue.) **Session 2 Suspension (Interaction between pavement and vehicles)**

Session 3 Strategic Highway Research Program (SHRP)

Dinner

28 (Wed.) **Session 4 Utilization of Non-Road by-Products**

Closing Ceremony

Address

Koichi Yamamoto (PWRI)

Paul Teng (FHWA)

Presentations of the memorials

29 (Thu.) Study Tour

Akashi Kaikyo Bridge

Awaji Highway Oasis

Nojima Fault

30 (Fri.) Study Tour

Restoration from the Hyogo-ken Nambu Earthquake

31 (Sat) Departure of the US participants

1.3 Workshop program

October 26 (Monday)

9:30-10:00 Opening Ceremony (8F Conference Room)
(Mistress of Ceremonies: Kayoko Tamiya, Traffic Engineering Division, PWRI)
Address: Yasutake Inoue (Director-General of PWRI)
 Paul Teng (Chief of Pavement Division, FHWA)
 Allan Abbott (Director - State Engineer, Nebraska DOR)

10:00-10:15 Group Photo

10:30-12:00 Keynote Speeches (8F Conference Room)
(Mistress of Ceremonies: Kayoko Tamiya)
"Transportation Equity Act for the 21st Century"
 Paul Teng
 Allan Abbott
"New 5-Year Road Improvement and Management Program"
 Kiyoshi Okudaira (Director of Highway Economic Research Section of
 the Road Bureau)

12:00-13:00 Lunch

13:00-15:30 Session 1 Accelerated Loading Tests (8F Conference Room)
"Pavement Test Field of PWRI"
 Takuya Ikeda (Pavement Division, PWRI)
" Accelerated Loading and Environmental Simulator at Research Institute of the
Japan Highway Public Corporation (JHRI)"
 Shigeru Shimeno (Pavement Division, JHRI)

14:15-14:30 Break)

 "Current Status of the Reno Test Track & FHWA's Acceleratad Loading Facilities"
 Charles Churilla (Pavement Performance Division, Turner Fairbank
 Highway Research Center (TFHRC))
"States' Accelerated Pavement Testing Programs"
 Max Grogg (New York Division, FHWA)

5:40-17:50 Visit to Facilities in PWRI
 30MN Multi-Function Equipment for Testing Large Structural Members
 Test Track
 Pavement Test Field

Traffic Sign Laboratory

18:00-20:00 Reception (Hotel Grand Shinonome)

October 27 (Tuesday)

9:30-10:45 Session 2 Suspension (Interaction between Pavement and Vehicles)
(8F Conference Room)

"Regulation of Axle Load Now and Future"

Paul Teng (Pavement Division, FHWA)

"Evaluation of Air Suspension and Effect of Wide Base Single Tire"

Byron Lord (Highway Infrastructure Division, FHWA)

(10:45-11:00 Break)

11:00-12:00 Session 3 SHRP (8F Conference Room)

"Status of Long-Term Pavement Performance (LTPP)"

Charles Churilla (Pavement Performance Division, TFHRC)

12:00-13:00 Lunch (1F Conference Room)

13:00-15:00 Session 3 SHRP (cont.)

"Collaborative Study on Gyratory Testing Machine"

Kazuyuki Kubo (Pavement Division, PWRI)

"SUPERPAVE Evaluation of Asphalt Binders in Japan"

Iwao Sasaki (Chemistry Division, PWRI)

(14:25-14:40 Break)

" Status of SHRP Binder Specifications and Mix Design "

Byron Lord (Highway Infrastructure Division, FHWA)

18:00-20:00 Dinner

October 28 (Wednesday)

9:30-11:30 Session 4 Utilization of Non-Road By-Products (8F Conference Room)

"Basic Policies to Handle By-Products"

Akira Inokuma (Research Coordinator for Advanced Materials
Technology, PWRI)

"Example of Application of By-Products"

Takuya Ikeda (Pavement Division, PWRI)

(10:35-10:50 Break)

"Utilization of Used Rubber Tires"

Paul Teng (FHWA)

"Utilization of Other Non-Road By-Products"

Max Grogg (New York Division, FHWA)

11:30-11:45

Closing ceremony

(Mistress of Ceremonies: Kayoko Tamiya)

Address:

Koichi Yamamoto (Deputy Director of PWRI)

Paul Teng (Director of Pavement Section of FHWA)

Presentation of Memorials

2. Report of the Workshop

2.1 Opening ceremony

The Director-General of the Public Works Research Institute, Yasutake Inoue, described the backgrounds before holding the 7th Japan-US Road Workshop, and emphasized that each year the workshop would focus on one specific subject to enhance information exchange, except for the comprehensive meetings to be held every three years. Inoue added that he and Betsold, the research director of the U.S. Federal Highway Administration, had met in March in the United States and had decided the topic for the 7th workshop to be "pavement." He expressed his hope that the 7th workshop would help exchange technical information and enhance research cooperation between Japan and the United States.

The Director of Pavement Section of the US Federal Highway Administration, Paul Teng, stated that the 7th workshop was significant for FHWA in terms of technical information exchange. He explained that the six workshops in the past had produced excellent results, and that the 7th workshop for discussing "Pavement" would also be fruitful. He also introduced the other participants from the United States.

The Director - State Engineer of the Nebraska Department of Roads (Nebraska DOR), Allan Abbott, emphasized the importance of transportation systems and explained how the State of Nebraska keeps people and goods flowing smoothly within the state and with the neighboring states with its transportation system, which helps business flourish despite its small population. He expressed his intention to collect information during the workshop, to help improve the durability of pavement.

2.2 Keynote speeches

2.2.1 Transportation Equity Act for the 21st Century (TEA21)

(1) Measures taken by the US federal government

1) Speaker: Paul Teng (Chief of Pavement Division, FHWA)

2) Abstract

On June 9, 1998, the President signed the Transportation Equity Act for the 21st Century (TEA21), which is a law in force up to 2003 for optimizing transportation. The budget is approximately US\$200 billion, which is 1.4 times larger than the amount for ISTEA, the former act of TEA21. Of the budget, \$590 million is for land transportation survey, \$250 million for technical development, and \$120 million for training programs.

FHWA is conducting a pavement technology program to cope with TEA21. The program consists of two subprograms, 1) improvement of pavement performance and 2) resource control. The subprogram for improving pavement aims to determine the best structure and mixture specifications in terms of durability, smooth surface, safety, and aesthetics. The resource control program analyzes the serviceability, maintenance, cost performance, and users' evaluation to help make decisions. Five groups of specialists in the fields of portland cement, asphalt, maintenance of pavement, recycled materials, and long-term performance of pavement support the decision-making process.

TEA21 involves reforming the administrative structure. Nine regional FHWA offices were disbanded and integrated into four support centers, which are at Maryland, Chicago, San Francisco, and Atlanta and are in charge of the East, Middle West, West, and South, respectively.

(2) Measures taken by state governments

1) Speaker: Allan Abbott (Director - State Engineer, Nebraska DOR)

2) Abstract

The State of Nebraska is located in the middle of the United States, covers an area of 200,000 km², and has a population of approximately 15 million. Road length exceeds 160,000 km, half of which is gravel roads. Roads are repaired with the TEA21 budget. During ISTEA, the former act of TEA21, designs and construction had to be approved by the Federal Highway Agency. Under TEA21, state governments are responsible for design and construction.

After the enforcement of TEA21, one half of the research and development budget of the Federal Highway Agency is allotted to state governments. To conduct national-level research and development activities, states voluntarily share the expenses. A standing committee in American Association of State Highway and Transportation Officials (AASHTO) is in charge of managing the fund and planning research projects. The project plans are then approved by the board of directors of AASHTO, which consists of 52 representatives from 50 states, Washington DC, and Puerto Rico. Thirty-five votes are necessary for the approval of a project.

2.2.2 New 5-Year Road Improvement and Management Program

1) Speaker: Kiyoshi Okudaira (Director of Highway Economic Research Section of the Road Bureau)

2) Abstract

Full-scale road construction in Japan began in 1954, when the 5-Year Road Improvement and Management Program started. As the economy grew and motorization advanced, roads were systematically constructed under the 5-year project. In 1965, *the Meishin Expressway* was completed. *The Tomei Expressway* opened in 1969. In 1987, plans were drawn up for an expressway network of 14,000 km, of which 7,000 km is now open to the public. In 1988, *the Kojima-Sakaide section of the Seto Bridge* was completed. *The Tokyo-Bay Aqualine* was completed in 1997, and *the Akashi Kaikyo Bridge* was finished in 1998.

In 1970, the number of passenger cars per person was 0.44 in the United States and 0.07 in Japan. Passenger cars spread rapidly thereafter in Japan, and in 1990 one out of every three persons owned a car in Japan (0.6 vehicles/person in the US), which is a level equivalent to that of the US 30 years ago.

Various issues were considered when drawing up the New 5-Year Road Improvement and Management Program, such as traffic congestion, increasing accidents, noise, and other environmental issues. There were financial difficulties, criticism against public construction works (high cost and administrative structures that are difficult to understand), administrative reform, and other social and economic problems concerning roads.

The budget for the New 5-Year Road Improvement and Management Program is 78 trillion yen, which is almost the same as the budget of the former project. The new project is characterized by four policies: 1) support for constructing new economic structure (reformation of economic structure), 2) support for activating regions and cities (regions and cities), 3) creation of better living environments (life and environment), and 4) construction of safe land for living (protection of national land). Another characteristic of the project is that it sets specific goals, such as to increase the

existing 7,265 km of high-quality road to 8,626 km.

The road policies aim to efficiently construct roads and to establish systems for evaluating construction works, public involvement, and partnership. The system for evaluating construction works in advance or during construction started this year. A guideline will soon be created for the system for analyzing the cost performance of existing roads. The New 5-Year Road Project is the first to adopt public involvement, and was designed based on the opinions of 110,000 people in total. In October, a center for collecting public opinions and demands was provisionally established. Partnerships between citizens and administrative bodies, private companies and the government, and the national government and regional administrative bodies will be developed, to each of which the work will be appropriately allotted.

A 5-year plan for technological development is now being drafted, in which the Public Works Research Institute is playing the central role.

In order to maintain international competitiveness in the aging society, Japan needs to construct infrastructure and to cooperate further with the United States concerning road construction.

2.3 Technical Sessions

2.3.1 Accelerated Loading Tests

(1) Pavement Test Field of PWRI

1) Speaker: Takuya Ikeda (Pavement Division, PWRI)

2) Contents of the presentation

Ikeda explained briefly the test course of the PWRI. He described their studies on the prevention of reflective cracks and the inter-locking blocks.

They investigated reflective cracking on road sections in which prevention sheets against reflective cracking, crack inducing joints, and no special measures were installed. Ikeda reported that crack inducing joints showed good results. He also showed the results of the durability and performance tests on inter-locking block pavement at the PWRI test course and pictures of breakage.

3) Questions and answers

A U.S. participant outlined the measures against reflective cracking in the United States, among which sheets of glass fiber mesh are effective.

(2) Accelerated Loading and Environmental Simulator at the Research Institute of the Japan Highway Public Corporation (JHRI)

1) Speaker: Shigeru Shimeno (Pavement Division, JHRI)

2) Contents of the presentation

Shimeno explained briefly that the tests conducted at the Research Institute of the Japan Highway Corporation with a rotary tester. As an example, he described the plastic flow property of drainage pavement by changing type of asphalt binder. He emphasized that the Accelerated Loading and Environmental Simulator is faster than the conventional testers used at construction sites for evaluating asphalt mixtures.

3) Questions and answers

There was a question about the method of preparing large specimens. Shimeno explained

the process used in the specimen preparation room installed adjacent to the tester.

(3) Current Status of the Reno Test Track & FHWA's Accelerated Loading Facilities

1) Speaker: Charles Churilla (Pavement Performance Division, Turner Fairbank Highway Research Center (TFHRC))

2) Contents of the presentation

Churilla explained briefly the test course (WesTrack) in Reno, Nevada, and reported the results of their studies on asphalt pavement specification and performance conducted on the WesTrack. He also described their facilities for accelerated loading tests and a heavy vehicle simulator (HVS), which is a movable accelerated loading tester that FHWA owns.

3) Questions and answers

There was a question concerning temperature control of HVS during out-door tests. Churilla explained that they control the temperature of the road surface by covering the HVS with a plastic sheet.

(4) States' Accelerated Pavement Testing Programs

1) Speaker: Max Grogg (New York Division, FHWA)

2) Contents of the presentation

Full-size accelerated loading tests are conducted on test courses in North Carolina, Minnesota (Mn/ROAD), and Ohio. These courses are also used for investigating the long-term performance of pavement. There are straight courses for accelerated loading tests in the accelerated pavement loading facility in Ohio, the pavement research facility in Louisiana (PRF), the accelerated pavement tester of California (ACL-APT), the accelerated testing line in Kansas (K-ATL), and the traction loader in Texas (TxMLS). A facility in Florida will start operation in 1999.

3) Questions and answers

There were no questions.

2.3.2 Suspension (Interaction between Pavement and Vehicles)

(1) Regulation of Axle Load Now and Future

1) Speaker: Paul Teng (Pavement Section, FHWA)

2) Contents of the presentation

In the United States, the vehicle weight limit is now 36t total weight, 9t single axle weight, and 15t tandem axle weight. Studies are being conducted on the size and weight of trucks to promote safe and efficient goods transportation.

3) Questions and answers

There was a question asking whether the transportation industry is requesting less strict weight regulation. Teng replied that roads are the hen that lays gold eggs for the transportation industry, that deteriorated road surfaces cause inefficient traffic and business losses, and that there had never been such a request.

(2) Evaluation of Air Suspension

1) Speaker: Byron Lord (Highway Infrastructure Division, FHWA)

2) Contents of the presentation

The impact coefficient of an air suspension was 1.1 - 1.15 for a smooth surface and 1.2 for a rough surface, both of which are smaller than the coefficient of a steel suspension. Air suspensions also cause less wearing of pavement and less damage to roads than steel suspensions.

3) Questions and answers

There was a question asking whether the use of air suspensions would be promoted in the United States. Lord replied that the transportation industry would make the decision.

(3) Effect of Wide Base Single Tire

1) Speaker: Byron Lord (Highway Infrastructure Division, FHWA)

2) Contents of the presentation

The effect of wide single tires on road surface was investigated at the accelerated loading test facility of TFHRC. Wide single tires damaged pavement more severely than the conventional dual tires.

3) Questions and answers

There was a question concerning the regulation of wide single tires. The reply was "each state is responsible for regulating or permitting wide single tires; the action varied by state." The transportation industry wants to use wide single tires, which reduce the transportation cost.

2.3.3 Strategic Highway Research Program (SHRP)

(1) Status of Long-Term Pavement Performance (LTPP)

1) Speaker: Charles Churilla (Pavement Performance Division, TFHRC)

2) Contents of the presentation

Churilla gave a brief outline of LTPP and the results. He described that the results of LTPP had been compiled in a CD-ROM "DataPave97" and will be reflected in the 2002 AASHTO pavement design guideline.

3) Questions and answers

There was a question concerning examples of the results. Churilla mentioned that new mixes of binders and asphalt mixtures, which SUPERPAVE specifies based on performance tests, showed high resistance against flow, suggesting that SUPERPAVE heading in the right direction.

(2) Collaborative Study on Gyratory Testing Machine

1) Speaker: Kazuyuki Kubo (Pavement Division, PWRI)

2) Contents of the presentation

The Tsukuba Pavement Technology Exchange Group, which consists of the PWRI and 16 private companies, conducted a uniform test on gyratory compactors deployed in Japan. The state of

compaction differed by manufacturer.

3) Questions and answers

There was a question about calibration from a US participant. In the United States, the gyration angles and compaction forces of compactors are calibrated every day if the machines are frequently used, once every week if the machines are used not so frequently, and every time before use if the machines are not used for a long time. There were similar problems in the United States, which were solved by conducting calibration.

(3) SUPERPAVE Evaluation of Asphalt Binders in Japan

1) Speaker: Iwao Sasaki (Chemistry Division, PWRI)

2) Contents of the presentation

The binders used in Japan were evaluated with SUPERPAVE specifications. The SUPERPAVE evaluation of straight asphalt showed results similar to the conventional evaluation method. However, modified asphalts of different SUPERPAVE grades showed no difference at high temperatures.

3) Questions and answers

There were no questions.

(4) Present States of SUPERPAVE

1) Speaker: Byron Lord (Highway Infrastructure Division, FHWA)

2) Contents of the presentation

FHWA has an expert task group (ETG) for studying SUPERPAVE specifications for binders. The specifications are now being checked at construction sites.

3) Questions and answers

There was a question on utilization SUPERPAVE Shear Tester (SST). In the United States, a 5-year performance guarantee is often required for pavement. The SST is actually used in such cases for predicting breakage in the future, but is too expensive and is now being revised.

2.3.4 Utilization of Non-Road By-Products

(1) Basic Policies to Handle By-Products

1) Speaker: Akira Inokuma (Research Coordinator for Advanced Materials Technology, PWRI)

2) Contents of the presentation

Inokuma described the basic policies for classifying and recycling by-products. The Ministry of Construction aims to recycle 80% of all construction by-products and 90% of asphalt-concrete and concrete masses.

3) Questions and answers

There was a question asking whether the goal of recycling 90% is attainable. Inokuma answered that the percentage of recycled products is increasing each year and the goal will be reached.

(2) Example of Application of By-Products

1) Speaker: Takuya Ikeda (Pavement Division, PWRI)

2) Contents of the presentation

PWRI is investigating the use of cullets prepared by crushing glass bottles for aggregates of asphalt mixture, melt slag made from burned residue in incinerators for asphalt mixtures, base course, and water-permeable blocks. However, all materials contain glass and may cause separation of aggregates and mixtures.

3) Questions and answers

There was a suggestion mentioning the difficulty of using glass cullets. Ikeda replied that glass cullets are not adhesive to asphalt, that there is a limit for introducing glass cullets in asphalt, and that the use of glass cullets will be decided after examining test results.

(3) Utilization of waste tires

1) Speaker: Paul Teng (Pavement Division, FHWA)

2) Contents of the presentation

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 led to studies on the use of crumb rubber modifier (CRM), which is produced from waste tires. The West Research Institute of Wyoming University (WRI) studied the interactions between CRM and asphalt. The National Cooperative Highway Research Program (NCHRP) announced the SUPERPAVE protocol for asphalt modified with CRM. Oregon University investigated the relationships between CRM and the design, application, and recycling of pavement. The National Institute for Occupational Safety and Health (NIOSH) evaluated the environmental impact of CRM.

3) Questions and answers

There was a question asking whether waste tires, whose materials may not be uniform, produce products of unstable quality. Teng replied that the problem is overcome by removing foreign materials from waste tires.

(4) Utilization of Other Non-Road By-Products

1) Speaker: Max Grogg (New York Division, FHWA)

2) Contents of the presentation:

FHWA and a support center for recycling materials established in the University of New Hampshire are conducting a joint study on the utilization of recycling materials. Under TEA21, US\$1,500,000 per year is appropriated in the budget. The center investigates the properties of recycling materials and develops new technologies. The FHWA conducts research and development and formulates policies concerning recycling.

3) Questions and answers

There were no questions.

2.4 Closing ceremony

Koichi Yamamoto, the Deputy Director-General of the Public Works Research Institute, noted that the 7th workshop was the first meeting to have addressed a specific topic and had produced good results. He emphasized that information exchanges between Japan and the United States are very important.

Paul Teng, the Director of Pavement Section of the US Federal Highway Agency, stated that the 3-day workshop had been fruitful and expressed his hope to continue such significant meetings. The next Japan-US workshop will be held in the United States in 1999.

3. List of participants

US Federal Highway Agency

Paul Teng	Chief of Pavement Division
Byron Lord	Chief of Highway Infrastructure Division
Max Grogg	New York Division

Turner Fairbank Highway Research Center

Charles Churilla	Chief of Pavement Performance Division
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Nebraska Highway Agency

Allan Abbott	Director - State Engineer
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Ministry of Construction

Kiyoshi Okudaira	Director of Highway Economic Research Section of the Road Bureau
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Civil Engineering Research Institute, Hokkaido Development Agency

Morito Takahashi	Head of Maintenance and Management Section
Kimio Maruyama	Maintenance and Management Section

Institute of Civil Engineering, Tokyo Metropolitan Government

Mikio Sekiguchi	Technology Division
-----------------	---------------------

Research Institute of the Japan Highway Public Corporation

Shigeru Shimeno	Director of Pavement Section
Keizo Kamiya	Pavement Section
Akinori Komatsubara	Pavement Section

Hokkaido Institute of Technology

Shuichi Kameyama	Instructor
------------------	------------

Art Engineering Co., Ltd.

Toshiyuki Kawano	President
------------------	-----------

Fukuda Road Construction Co., Ltd.

Masatoshi Kobayashi	Technical Research Institute
Takuya Mizuno	ditto
Hitoshi Taguchi	ditto

Gaeart Kumagai Co., Ltd.

Sadao Nagumo	Executive Director of Technology
Ippei Kojima	Director of Technical Research Institute
Hideo Suzuki	Technical Research Institute
Toshihiro Takei	ditto
Hironari Yamawaki	ditto

Kashima Road Construction Co., Ltd.

Manabu Fuchigami	Technology Division
Ken-ichi Iida	ditto
Takayoshi Kodama	ditto
Yasuo Yamazaki	ditto
Toshihiro Kanai	Technical Research Institute
Tadao Monzawa	ditto

Maeda Road Construction Co., Ltd.

Masahiro Yabe	Executive Director of Technology
Nobuo Kobayashi	Director of Technical Research Institute

Nichireki Co., Ltd.

Akiyoshi Hanyu	Technical Research Institute
Tatsuya Ito	ditto
Masayoshi Tanaka	ditto

Nippon Hodo Co., Ltd.

Takemi Inoue	Director of Technical Research Institute
Masaru Mizobuchi	Director of Northern Research Institute

The Nippon Road Co., Ltd.

Fumio Tai	Technical Headquarters
Katsura Endo	Technical Research Institute
Sachiko Takada	Technical Research Institute

Nisshin Hodo Kensetsu Co., Ltd.

Akira Takahashi	Director of Technical Center
Nobuo Handa	Technical Center

Obayashi Road Corporation	
Shuichi Kokubun	Director of Technical Research Institute
Yukinori Inaba	Technical Research Institute
Yoshifumi Kitaoka	ditto
Koseki Hiroji	ditto
Takashi Tomoto	ditto
 Sato Road Co., Ltd.	
Saburo Matsuno	President
Kitaro Uchida	Director of Technical Research Institute
Tsutomu Kurokawa	Technical Research Institute
 Seikitokyu Kogyo Co., Ltd.	
Toshiaki Matsuda	Technology Division
Makoto Okudaira	Technical Research Institute
Toru Suzuki	ditto
 Shimizu Jushi Corporation	
Takashi Ijima	Executive Director of Technology
 Showa Shell Sekiyu k.k.	
Atsushi Fujitani	Central Research Institute
Yasuhiko Sato	ditto
 Taise Rotec Corporation	
Takatomo Fukuda	Technical Research Institute
Takashi Kano	ditto
Akinori Kobayashi	ditto
 Taiyu Kensetsu Co., Ltd.	
Hiromitsu Nakanishi	Director of Central Research Institute
 Toa Doro Kogyo Co., Ltd.	
Susumu Kanno	Technical Research Institute
 Tokyo Hosokawa Kogyo Corporation	
Masami Sasaki	Director of Technical Research Institute

Watanabe-gumi Co., Ltd.

Daiji Fujita

Technical Research Institute

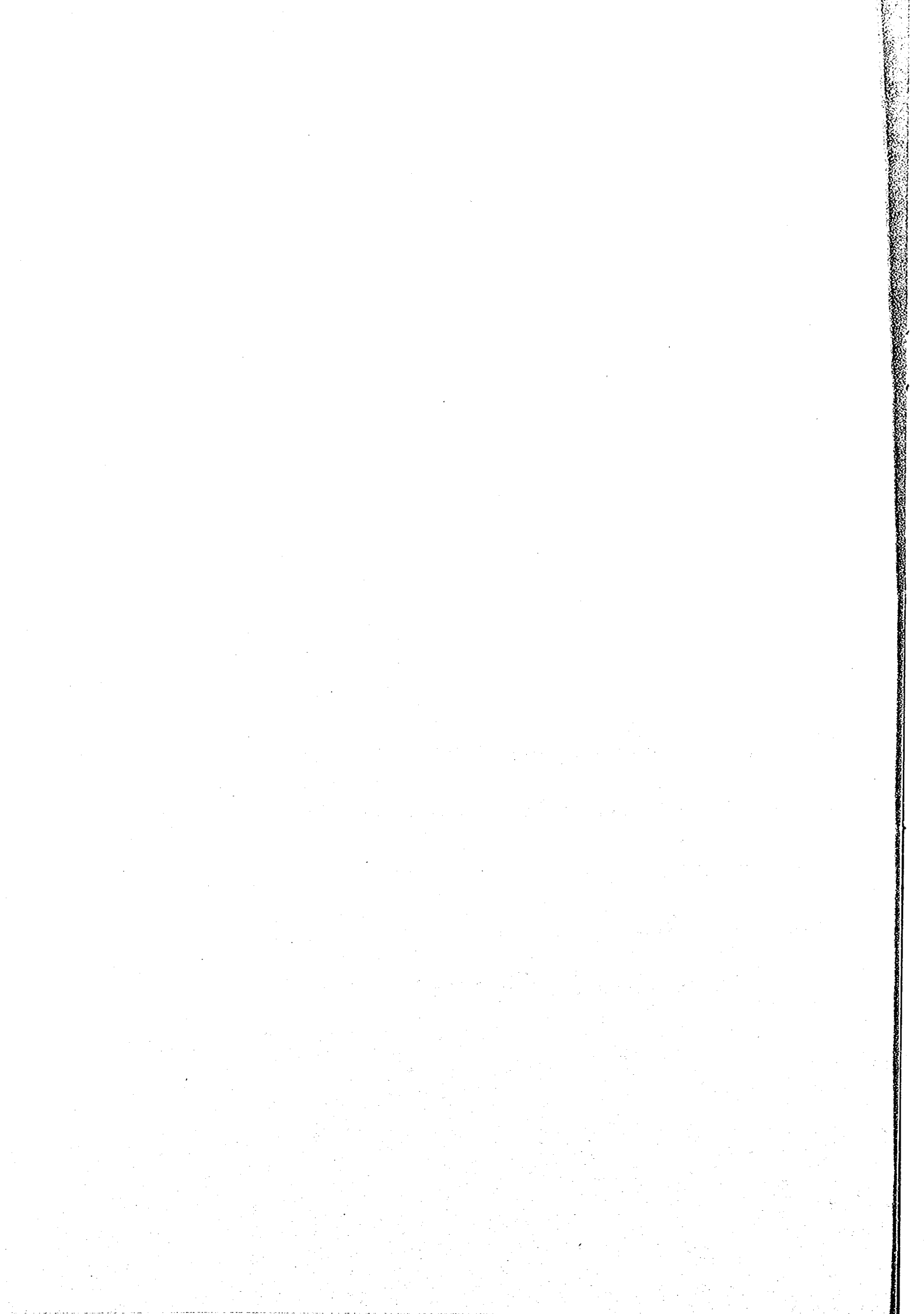
Public Works Research Institute

Yasutake Inoue	Director General
Koichi Yamamoto	Deputy Director General
Shunsoku Kyosai	Assistant Director General
Makoto Nakamura	Director of Road Department
Kiyoshi Katawaki	Director of Material and Construction Method Department
Michio Okahara	Director of Structure and Bridge Department
Ken-ichi Tokida	Research Coordinator for Road Traffic
Tamotsu Kobayashi	Research Coordinator for Traffic Safety
Akira Inokuma	Research Coordinator for Advanced Materials Technology
Nobuyuki Tsuneoka	Head of International Cooperation Division
Shun-ichi Hamada	Head of Traffic Engineering Division
Satoshi Ueda	Head of Advanced Transportation Division
Katsuhiko Mitsuhashi	Head of Traffic Safety Division
Takuya Ikeda	Head of Pavement Division
Seishi Meiarashi	Head of Chemistry Division
Shinri Sone	Traffic Engineering Division
Kayoko Tamiya	ditto
Satoru Yamamoto	Exchange Researcher of the Traffic Engineering Division
Kazuhiko Ando	Traffic Safety Division
Kazuyuki Kubo	Pavement Division
Satoshi Taniguchi	ditto
Kazushi Komoriya	ditto
Yuichi Ikeda	ditto
Ken Kijima	Chemistry Division
Masaru Terada	ditto
Iwao Sasaki	ditto

付録 / Appendix (会議資料 / Resume)

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1. Transportation Equity Act for the 21st Century

TEA-21

Transportation Equity Act for the 21st Century

Paul Teng, P.E.
Chief, Pavement Division
Federal Highway Administration

TEA-21

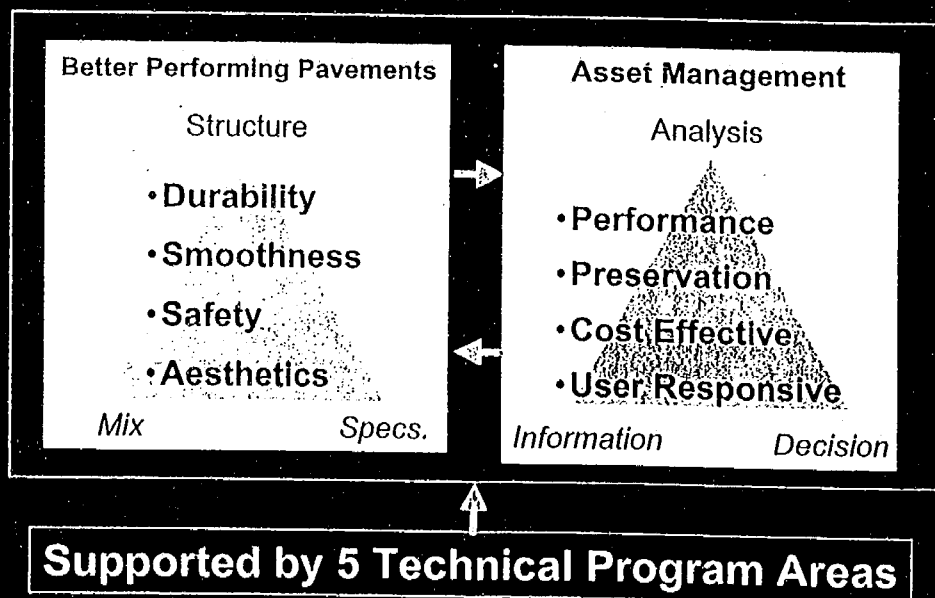
- Highways, Highway Safety, Transit
- 6 - year legislation - 1998 - 2003
- Signed into law June 9, 1998
- \$ 218 billion authorized
(40% increase over ISTEA)

TEA-21, RESEARCH AND TECHNOLOGY

◆ Highways

- Surface Transportation Research
- Technology Deployment Initiative and Partnerships
- Training and Education Programs

FHWA's Pavement Technology Program Focus Areas



PAVEMENT RTCG (PMCG)

PAVEMENT TECHNOLOGY PROGRAM FOCUS AREAS

Better Performing Pavements

The goal of Better Performing Pavements is to provide the operating characteristics that the highway users demand: pavement durability, ride smoothness, safe wet weather operations, minimized surface noise characteristics, and surface appearance. This goal will be accomplished through the identification, research, development, delivery and deployment of enhanced pavement technologies for pavement design, construction, maintenance and rehabilitation to improve pavement operating characteristics.

This focus area will address a broad, coordinated suites of technology and training activities associated with new and recycled materials, the design system and selection of design features, and the construction process. It will build on the results of the SHRP research, the findings of the LTPP program, the current AASHTO mechanistic design initiative, ongoing performance-related specifications' development, and construction experience to advance the state-of-the-practice used by State and local governments, consultants, and the paving and materials supply industries.

Asset Management

Asset management is the systematic process of maintaining, upgrading, and operating physical assets cost effectively and efficiently. It combines engineering principles with sound business practices and economic theory, and it provides tools to facilitate a better organized, logical approach to decision-making. The goal of Asset Management in the pavement focus area is to provide the tools that agency managers and decision makers can use to make better management decisions regarding their pavements' performance and costs.

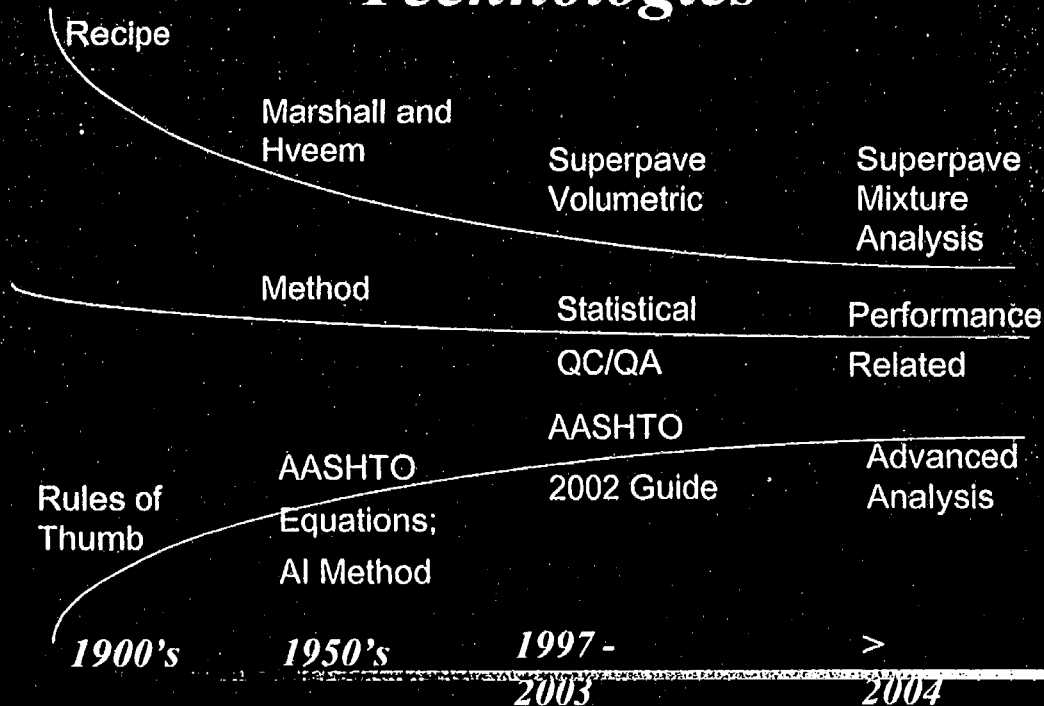
This goal will be accomplished in a partnership with the American Association of State Highway and Transportation Officials (AASHTO) who is providing national leadership through the development of an Asset Management strategic plan. This plan will serve as a broad blueprint for coordinating activities on needed tools and procedures and provide guidance for the Asset Management deployment strategies. This focus area builds upon the longstanding experience, expertise, and accomplishments of the Pavement Management Systems that FHWA has established with all States since the 1970's. However, additional work is needed to research, develop, deliver and deploy tools and methods to: forecast condition and costs, assign value to assets, measure return on investment, measure resource capacity and user costs, quantify benefits and opportunity costs, and evaluate investment tradeoffs. Performance-based measures and knowledge of associated economic implications are needed to support better strategic decision making.

FHWA's Pavement Technology Program

◆ Program Areas

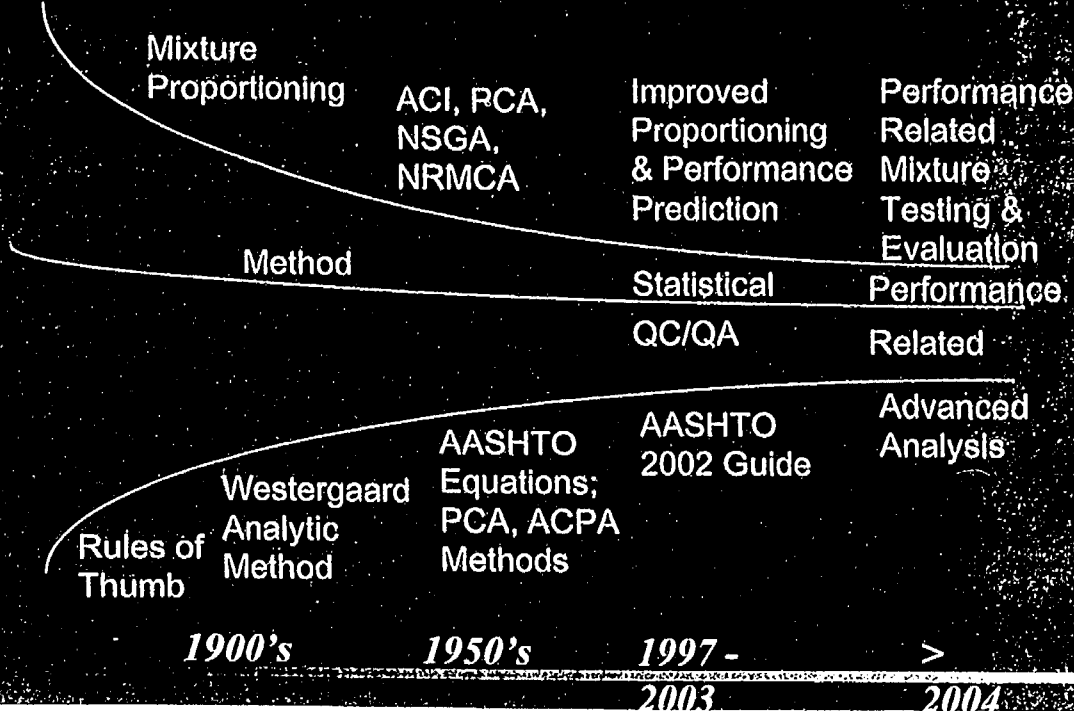
- Portland Cement
- Asphalt
- Pavement Management
- Advanced Research, Secondary Materials
- Long-Term Pavement Performance

Evolution--Asphalt Technologies

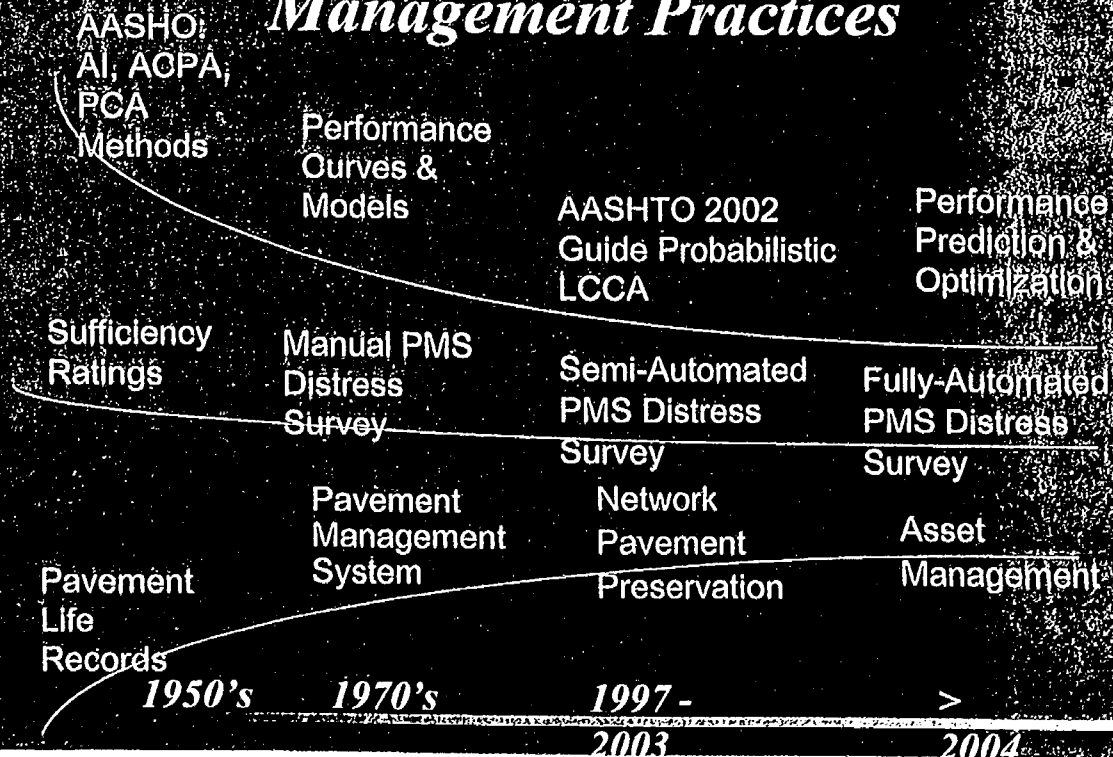


Evolution--PCCP Technologies

Recipe



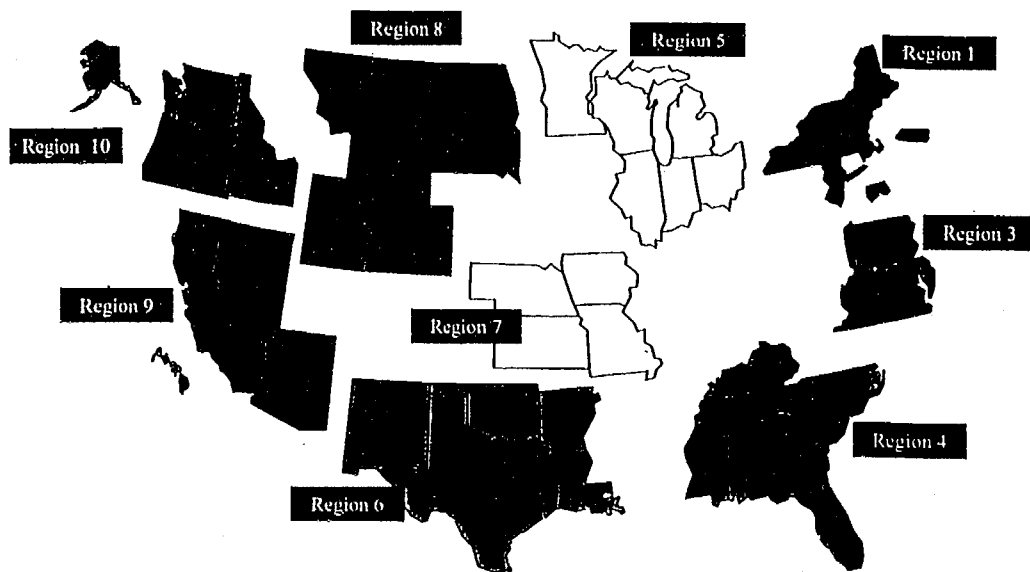
Evolution- Asset (Pavement) Management Practices



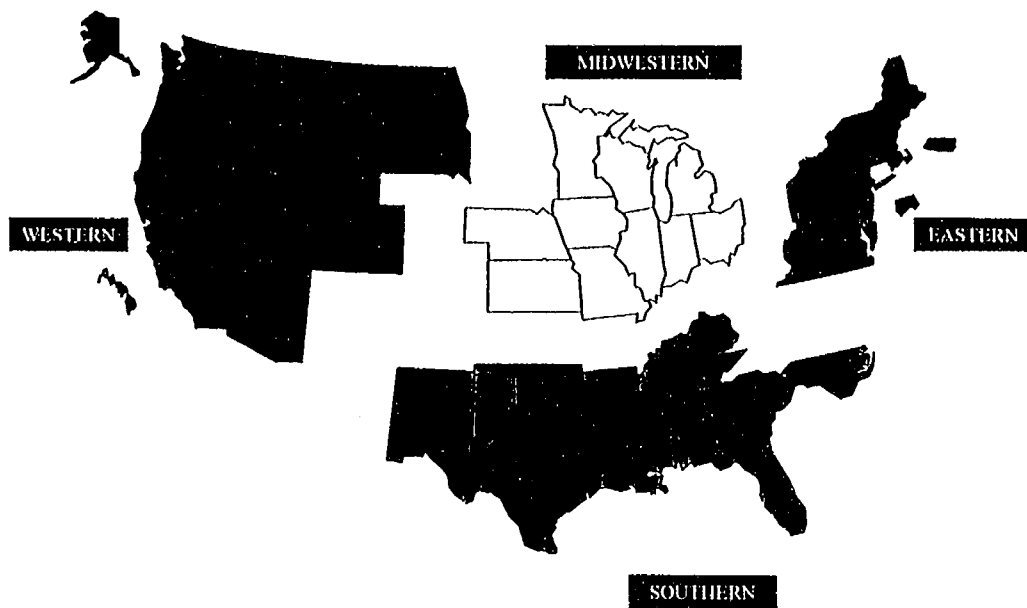
TEA-21, OTHER FHWA ACTIVITIES

- Restructuring to Eliminate 9 Regional Offices
- Division Offices to be serviced by 4 Resource Centers

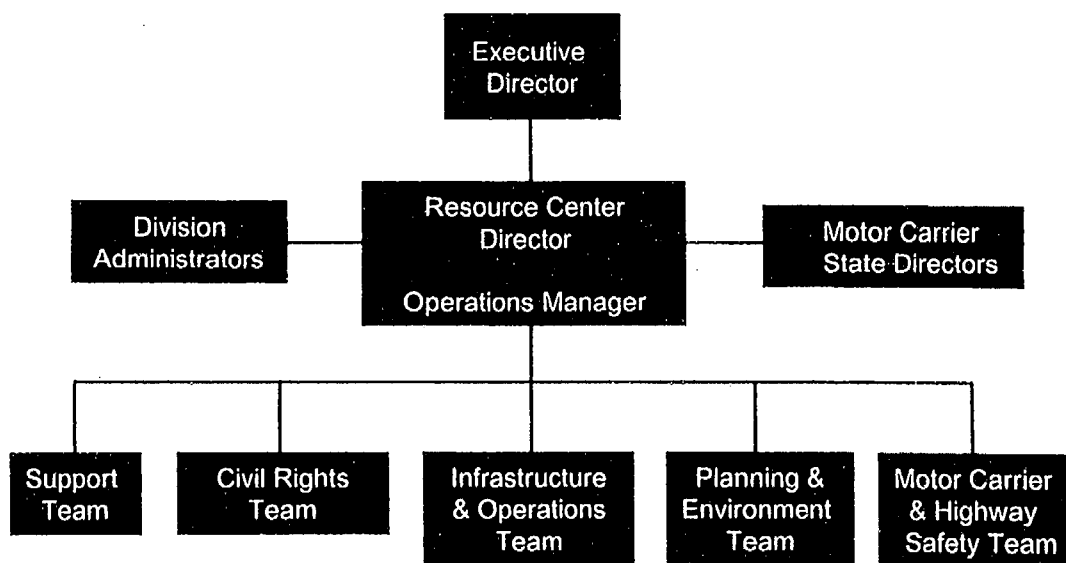
Existing Nine Regions



Resource Center Areas
(Four Resource Centers - Standard Boundaries)

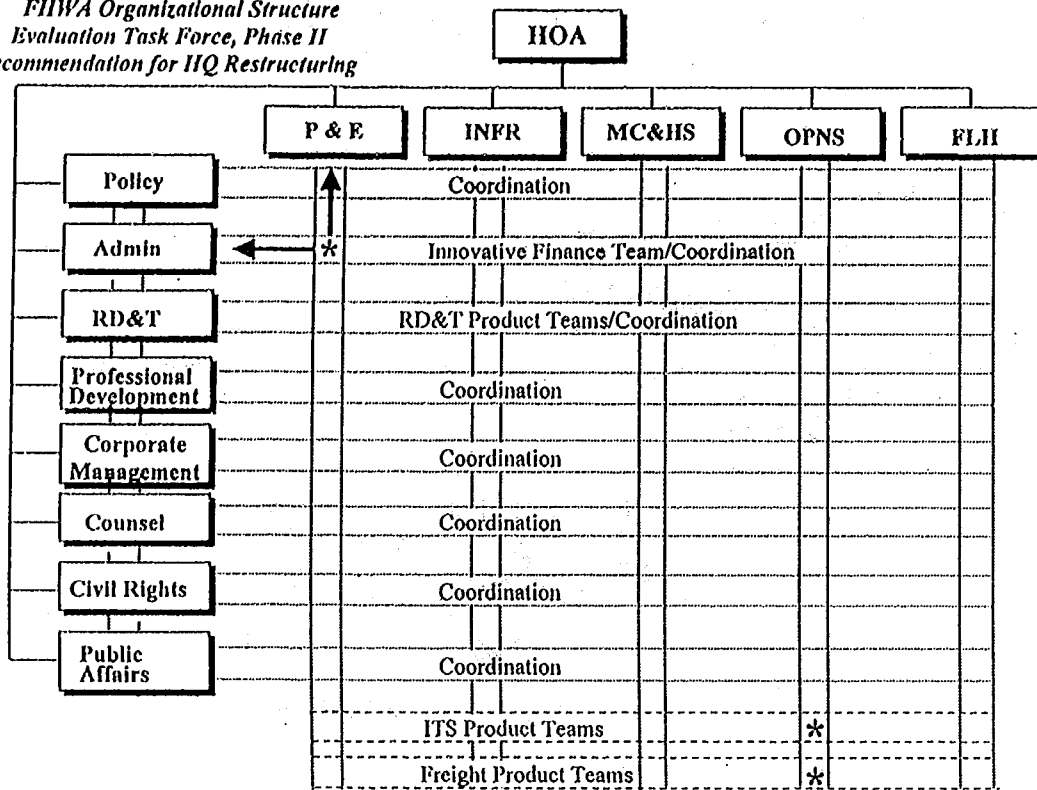


RESOURCE CENTER STRUCTURE



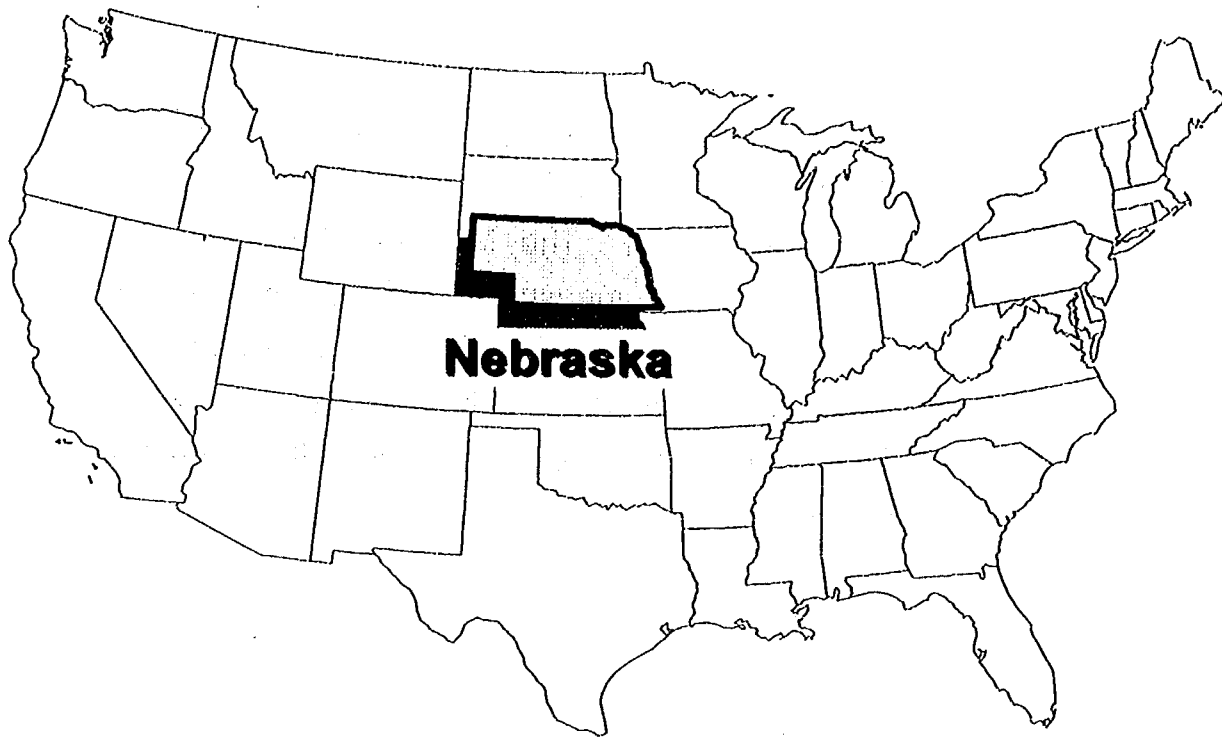
August 25, 1998

*FIIWA Organizational Structure
Evaluation Task Force, Phase II
Recommendation for IIQ Restructuring*



* Centralized management element

United States of America



Nebraska

Population: 1,578,385

Land Area: 200,000 square kilometers

Counties: 93

Elevation: 256 meters in the East to 1,654 meters in the West

Capital: Lincoln

State Motto: "Equality before the Law"

Nickname: Cornhusker State, the Tree Planters' State

State Bird: Western Meadowlark

State Flower: Goldenrod

State Tree: Cottonwood

Location and Size

Nebraska is situated in the east-central area of the Great Plains about midway between New York and San Francisco. It is generally rectangular in shape. The Missouri River bounds the eastern border. The state measures 638 kilometers across including the western panhandle. The diagonal from northwest to southwest measures 738 kilometers. The State's area is almost 200,000 square kilometers. This land area places the state 15th in the nation according to size

Transportation

- Nebraska is Strategically located near the center of the continental United States. Its central location, combined with a fully integrated transportation system, provides quick, easy access to anywhere in the country.
- Interstate 80, which runs the entire length of the state, is the most traveled transcontinental highway in the U. S. Nebraska Communities are connected by a good highway system of more than 35,000 kilometers of hard surfaced roads including 16,000 kilometers of state highways 775 kilometers of which are Interstate 80.
- Nebraska has two interstate and several intra-state bus lines.
- Rail Service is provided by the Burlington Northern, Chicago and Northwestern, and Union Pacific Railroads. The Union Pacific is the nation's largest railroad system. Passenger service to five Nebraska communities is provided by Amtrack.

G e n u i n e
Nebraska

There is still a place in America with room to room and space to Space

It's a place to explore, a place to lose yourself.

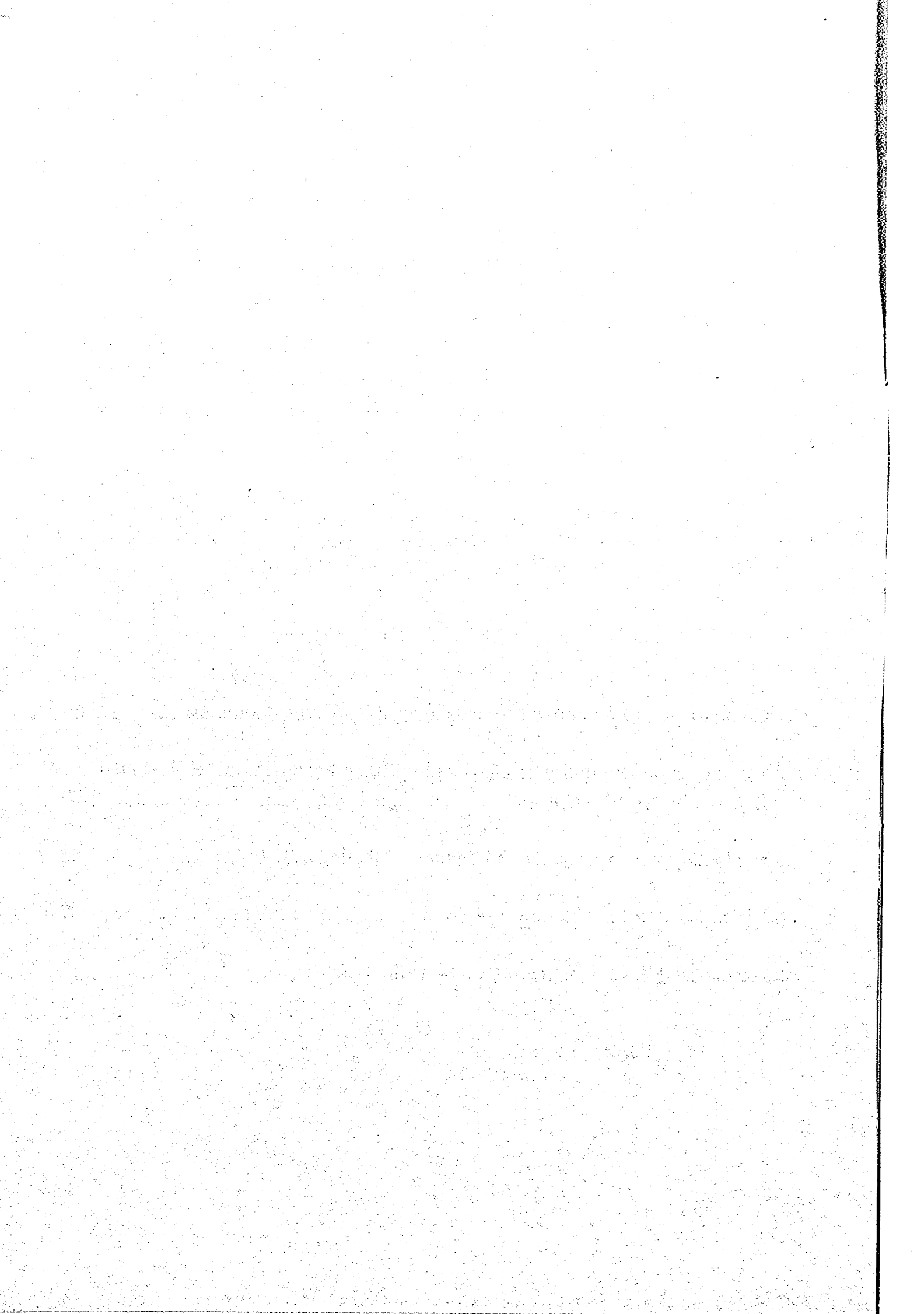
And find yourself.

Nebraska is what America was and too little of it still is.

We're still as free and accepting and willing to share as those who first
lived on this land.

2. Accelerated Loading Test

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2.1 Comparison of Preventive Methods against Reflective Cracking

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Summary

This paper presents results of study on preventing reflective cracking by crack prevention sheets and crack inducing joints. In 1990, test pavement was constructed at the Pavement Test Field of the Public Works Research Institute. The test pavement consisted of a 50mm asphalt concrete layer on 150mm cement concrete slabs, which had 11 joints with 60mm depth at 5m intervals. Crack prevention sheets between the asphalt layer and the concrete slabs were installed on 4 joints. Crack inducing joints were cut in the asphalt layer with 15mm deep, just above 3 joints of the concrete slabs. No special measures were taken for other 4 joints. The test pavement received 390,000 times of loading for six years by Loading Vehicles with 98kN rear axle load. In order to study effects of sheets and inducing joints, cracking on the pavement surface was surveyed at every 20,000 times of loading. In 1996, detailed survey was conducted including core boring. Reflective cracking on the joints with no measures grew immediately after its occurrence. Cracking on the joints with crack prevention sheets grew slowly. However, the crack prevention sheets did not completely prevent occurrence of reflective cracking. Since the shape of cracking is jagged and branched, it lead to further defects such as spalling and faulting. On the contrary crack inducing joints properly lead reflective cracking from joints on cement concrete slabs. Crack inducing joints did not cause spalling and other fatal deterioration. Therefore, it is effective to construct crack inducing joints where reflective cracking is expected.

1. Introduction

Composite pavement, consisting of an asphalt layer on cement concrete slabs, is a durable pavement structure with good riding comfortability in comparison with ordinary asphalt pavement and cement concrete pavement. However, except when the asphalt layer is constructed on continuously reinforced cement concrete slabs or semi-flexible pavement, the cement concrete slabs have joints at constant intervals in order to absorb expansion and contraction by change of temperature. Therefore, reflective cracking in the asphalt layers is a crucial problem for composite pavement structures.

In order to study the effect of crack prevention sheets and crack inducing joints, test composite pavement was constructed at the Pavement Test Field in the Public Works Research Institute. The test section received repeated loading by real-sized large vehicles. This paper presents the result of the survey for six years.

2. Survey Procedure

(1) Structure and Joints

Figure-1 shows the pavement structure of the test pavement. In 1990, the test pavement was constructed

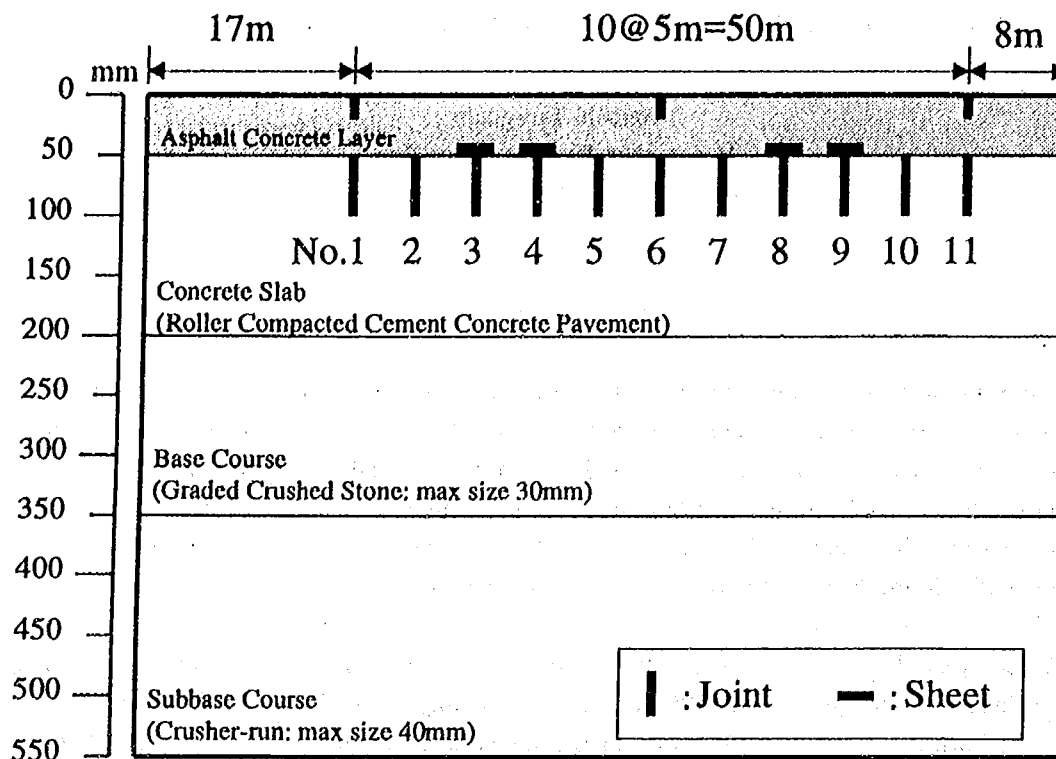


Figure-1 Pavement Structure

at a part of a circular test track (628 meter long in total), consisting of a 50mm asphalt layer on 150mm cement concrete slabs. The cement concrete slabs were roller compacted cement concrete pavement, which had 11 joints with 4mm width and 60mm depth at 5m intervals. Crack prevention sheets were installed between the asphalt layer and the concrete slabs to cover 4 joints on the slabs. Crack inducing joints were cut in the asphalt layer with 4mm width and 15mm depth, just above 3 joints of the slabs. No measures were taken for other 4 joints.

(2) Loading Test by 'Loading Vehicles'

The test pavement received 390,000 times of loading by 'Loading Vehicles' with 44.1kN front axle load and 98kN rear axle load. Loading by the heavy vehicles began in 1990 and ended in 1996. Table-1 shows the loading times of each year. At every 20,000 times of loading, location of surface cracking on the test pavement was sketched. Through this survey, occurrence and progress of each cracking were identified.

Table-1 Loading times of each year

Year	Loading Times
1990	70,000
1991	70,000
1992	80,000
1994	80,000
1995	80,000
1996	10,000
TOTAL	390,000

(3) Core Boring

After loading by Loading Vehicles finished, detailed crack survey and core boring were conducted. Cores were cut out in 150mm diameter and 200mm depth to observe the cracking occurrence in the asphalt layer and the concrete slabs.

(4) Adhesive Strength Test

Adhesive strength between the asphalt layer, the crack prevention sheets and the cement concrete slabs was measured using adhesive strength tester shown on Figure-2. After cutting the pavement by core cutter to cement concrete slabs with 100mm diameter, a plate is glued by epoxy resin. Pulling the cramp by oil pressure, the adhesive is measured.

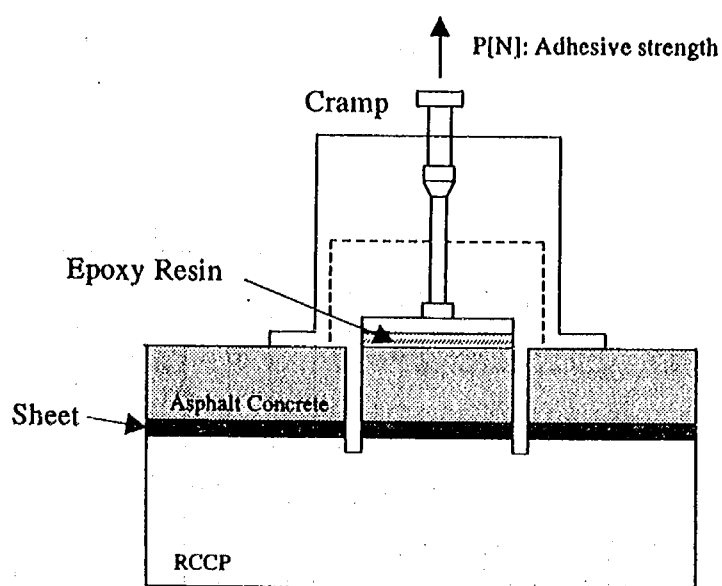


Figure-2 Adhesive Strength Tester

3. Result of the Survey

3.1 Crack Occurrences

Figure-3 shows crack occurrence on the test pavement at 40,000 times of loading in 1991. This figure indicates that a crack expanded continuously on No.10 joint with no special measures. On the contrary, a crack appeared discontinuously on No.9 joint with a crack prevention sheet and no crack appeared at No.11 crack inducing joint.

Figure-4 shows cracking after 390,000 time of loading and location of core boring. This figure indicates that cracking finally expanded continuously on entire joints with crack prevention sheets. Besides this, longitudinal cracks appeared on the inner tread. These longitudinal cracks are considered as fatigue cracks. However, no cracking appeared at all crack inducing joints.

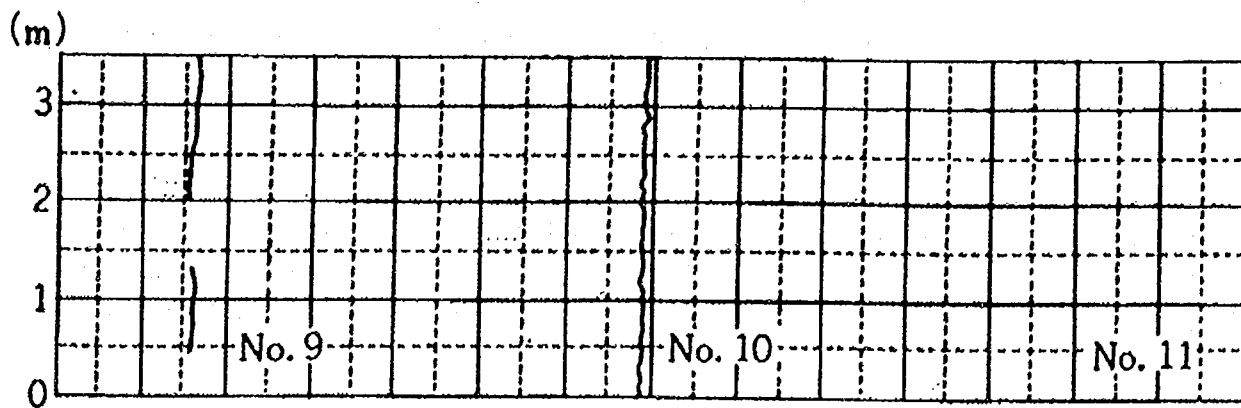


Figure-3 Cracking at 40,000 times of loading in 1991

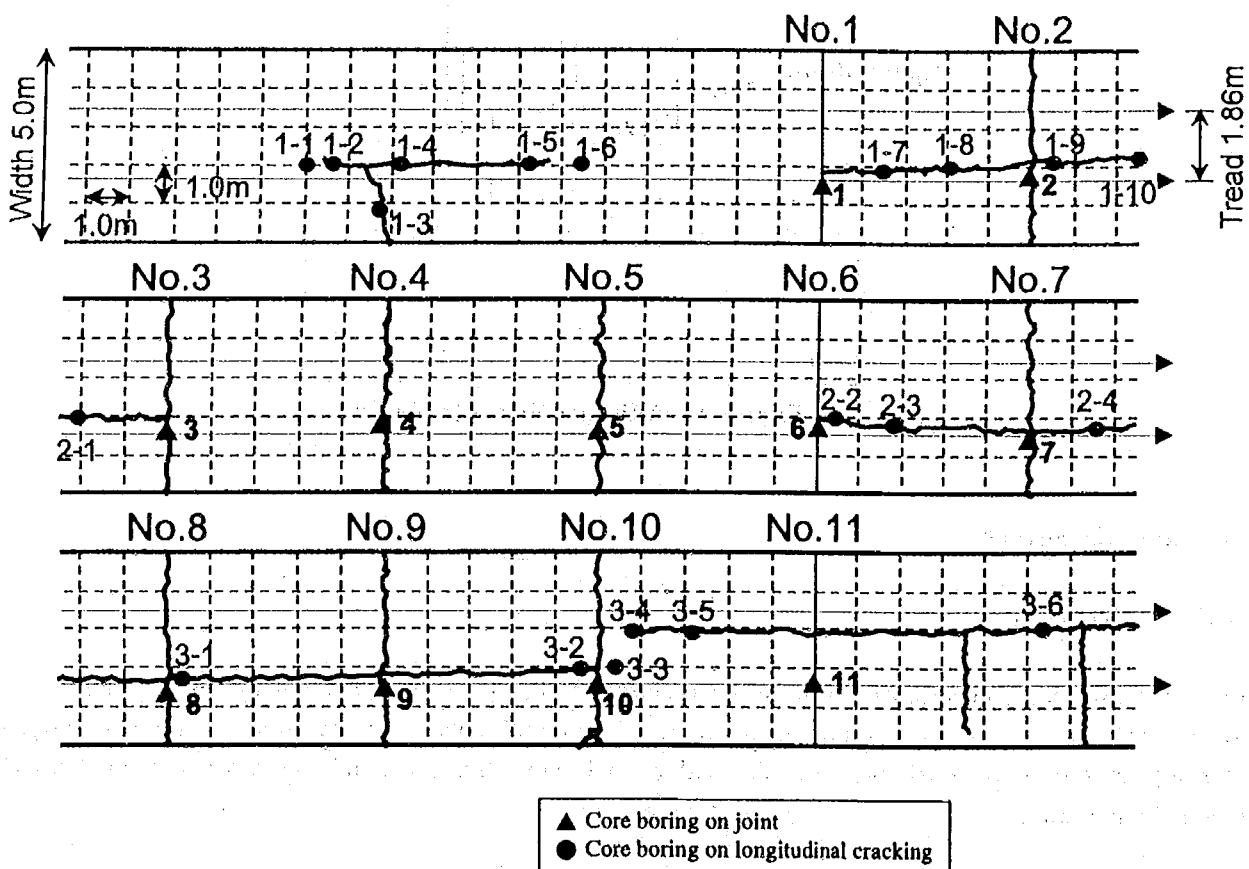


Figure-4 Cracking After Entire Loading Test and Location of Core Boring

In order to identify the cause of the longitudinal cracking, the asphalt layer was cut partially on longitudinal cracks. It was confirmed that cracking on the surface course occurred above the longitudinal cracking in cement concrete slabs. The surface cracking, therefore, was a reflective cracking.

It was also confirmed that reflective cracks on joints with no special measures and crack prevention sheet occur earlier than the longitudinal fatigue cracking

3.2 Core Boring

Figure-5 shows examples of cores obtained from the test pavement.

Cracks on joints with crack inducing joints, as shown on the core No.6, connected from contraction joints to crack inducing joints. And cores had no branches or spallings. However, cracks on joints with crack prevention sheets, as shown on the core No.9, and no special measures, as shown on the core No.10, occurred from the contraction joints to the surface. And cores had branches in the layer and spallings on the surface.

Cracking on longitudinal cracking, as shown on the core No.2-3, occurred in asphalt and cement concrete layer and they connected at the boundary. The cause of longitudinal cracking at the inner tread of the surface cause was cracking in the cement concrete slabs.

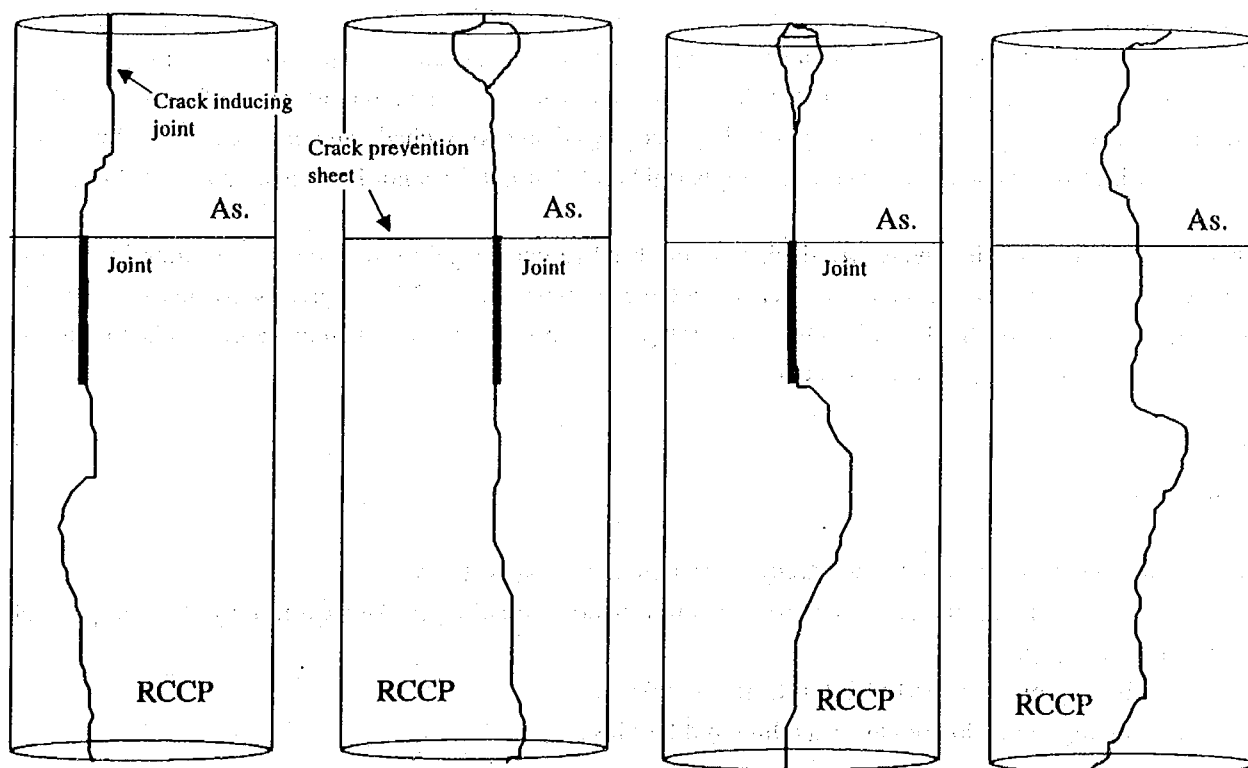


Figure-5 Cracking on Cores

3.3 Adhesive Strength

The test pieces were detached between the sheets and the cement concrete slabs. Adhesive strength between the sheets and the asphalt layer was higher than that between the sheets and concrete slabs. However, cracks occurred on joints with crack prevention sheets.

4. Analysis

4.1 Effects of Crack Prevention Sheet

Since cracking on crack prevention sheets expanded slowly, effect of crack prevention sheets was confirmed. However, the sheets did not prevent occurrence of reflective cracking. Cracking on joints with no special measures appeared earlier than cracking on joints with crack prevention sheets. In addition, cracking expanded immediately at the entire width on the joint with no special measures, while cracking expanded slowly on the joint with crack prevention sheets. Furthermore, cracking in cores on joints with sheets appeared on the whole thickness and had branches. Since the shape of cracking was jagged and branched, the cracking caused spalling as well as cracking on joints with no special measures.

4.2 Effects of Crack Inducing Joint

Since crack inducing joints lead progress of cracking properly, no spalling and faulting was observed on the surface course. Reflective cracking is considered to grow from bottom to surface on cracking or joints of cement concrete slabs. When it grows, cracking traces weak points of the layer. When crack inducing joints are installed, the position is thinner and weaker than other positions. Therefore, cracking connects to the crack inducing joints. The crack inducing joint can be considered as an artificially installed cracking. In case of natural cracking, its shape is jagged and branched, and may cause spalling and faulting. Since the shape of artificial cracking is rigid and sharp, it does not lead spalling and faulting.

When crack inducing joints were installed, workers tried to cut the joints just above the joints in cement concrete slabs. However, construction errors were not inevitable. When cores were observed, crack inducing joints were installed within 5 to 10mm range on joints in cement concrete slabs. This amount of errors does not affect proper crack induction.

5. Conclusion

The results of the test paving and the survey were summarized as follows.

- 1) Crack prevention sheets delay occurrence on reflective cracking. However, they do not prevent reflective cracking.
- 2) Crack inducing joints properly lead reflective cracking.
- 3) Crack inducing joints do not cause spalling and faulting.

In this study, the depth of crack inducing joints was constant at 15mm. In order to introduce this technique to actual site, standard depth and width of the joints should be decided. The range of construction errors is also to be identified. Furthermore, proper treatment such as joint sealing after installation of crack inducing joints should be studied. Consequently, surface cracking was caused by

fatigue cracking in cement concrete slabs and it was also a reflective cracking.

6. Application to actual site

To confirm effects of crack inducing joints in actual sites, crack inducing joints are tested by test pavement on the national highway 52. Cross section of the test pavement is shown on Figure-6. The pavement consists of 50 mm asphalt concrete layer on 250mm roller compacted cement concrete slabs. Depth of crack inducing joints was 15mm, 25mm, 50mm. These pre-cut joints are expected to prevent occurrence of random reflective cracking.

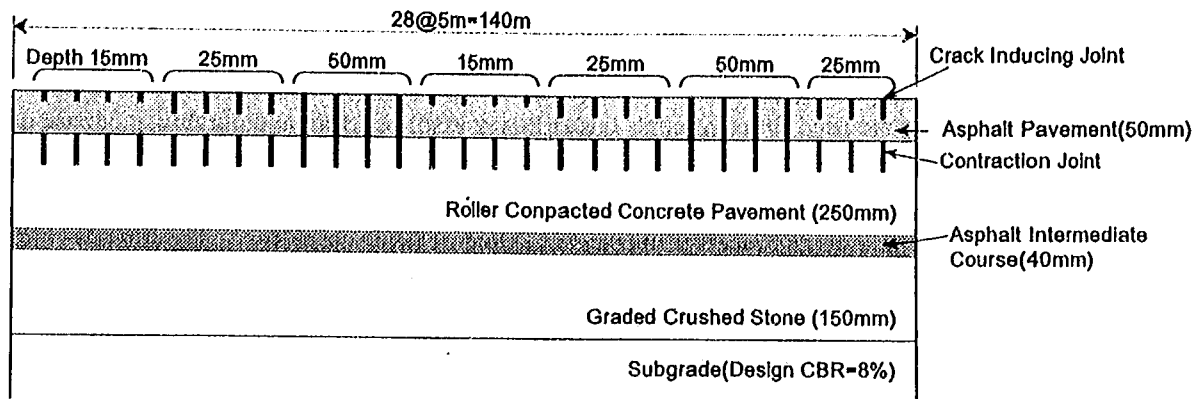


Figure-6 Cross Section of Test Pavement

REFERENCE

- 1) S. Taniguchi, T. Ikeda (1998): "Study in Reflective Cracking on Composite Pavement", Proceedings of Fifth International Conference on Bearing Capacity of Roads and Airfields, Vol.2, pp.867-874

2.2 Evaluation on Durability of Interlocking Block Pavement under Repeated Loading by Heavy Vehicles

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Summary

When interlocking blocks are used for pavements under heavy load, structure and durability of base courses should be carefully examined. Test pavements with two types of base courses with high bearing capacity, namely asphalt stabilization and cement stabilization, were constructed at the Pavement Test Field in the Public Works Research Institute and received repeated loading of heavy vehicles. The interlocking block pavement with asphalt stabilized base performed better than that with cement stabilized base. Therefore, it is recommended that the base course of interlocking block pavements for heavy traffic roads should be stabilized with asphalt in order to prevent damages on interlocking blocks.

Damages on interlocking blocks and layers under blocks were examined after repeated loading. When blocks were removed, it was found that the laying course deformed by repeated loading and joint sand disappeared. The deformation was caused by pulverization of sand into smaller particles. The change of particle size caused deformation of pavement surface and lead to fatal deterioration on each piece of blocks under wheel paths.

Another problem was hardening of bedding sand on both asphalt and cement stabilized bases, since hardened sand has no function as a laying course. It was anticipated that cement in the stabilized base affected the bedding sand, since hydration of cement continues in a long term. However, analysis on samples of hardened sand proved that the sand did not contain any ingredient of hydration. Therefore, change on particle size of bedding sand also the cause of hardening. It was concluded through the study that quality of bedding sand and joint filling sand is crucial to maintain good surface condition.

1. Introduction

It was in 1970's that interlocking blocks (hereinafter referred as IL blocks) was introduced in Japan. When IL block pavement is designed, two approaches are known: theoretical methods and empirical methods. When a conventional method, i.e. an empirical method, is used for design, equivalent layer coefficient of IL blocks is needed¹⁾. In 1987, the Public Works Research Institute, the Ministry of Construction (hereinafter referred as PWRI) and Interlocking Block Pavement Engineering Association (hereinafter referred as IBPEA) constructed test pavements at the Pavement Test Field in PWRI in order to

¹ The coefficient is the same concept as the AASHTO Structural Index. However, the coefficient for hot mixed asphalt is not 0.44 but 1.0 in the Japanese design specification.

evaluate durability of IL block pavement under repeated load of large-sized vehicles and to establish a design method for IL block pavement for highways.

In 1992, a part of the result available by 1990 was presented at the 4th International Pavement Conference held in New Zealand [1]. The major outputs are:

- (1) Upper base courses with high bearing capacity such as asphalt or cement stabilization are required for heavy vehicle traffic.
- (2) Spacer ribs work effectively to reduce chip-off.
- (3) Herringbone bond is suitable as the laying pattern for heavy traffic roads.

This paper reports on the results since 1991.

2. Repeated Loading Test

The Pavement Test Field consists of a large loop with the length of 870m and a circular medium loop with the length of 628m as shown in Figure 1. The IL block test pavements were constructed in 50m long on a part of the middle loop. Driverless radio-controlled vehicles with axle load of 98kN or 137kN ran repeatedly on the test pavements to examine performance of the IL block pavements. The number of both 98kN and 137kN axle load was automatically counted separately so that exact number of 98kN (10ton) equivalent axle load (hereinafter referred as EAL) is obtained, which is essential to evaluate performance of test pavements. The lateral running position of the loading vehicles are automatically controlled so that their running position follows the normal distribution, within 25cm right and left range to the center line.

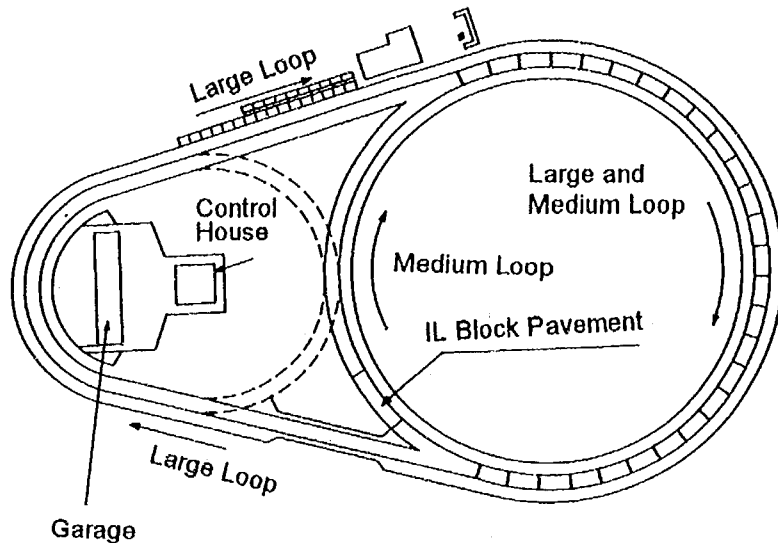


Figure 1 Plane View of Pavement Test Field

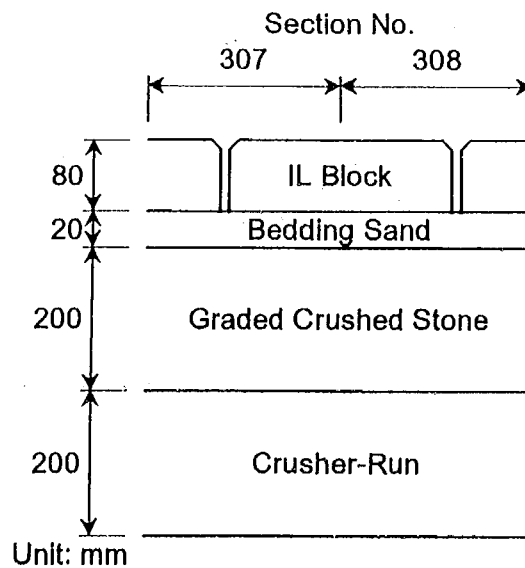


Figure 2 Cross Section of IL Block Test pavement in 1987

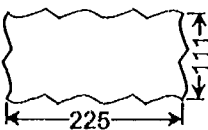
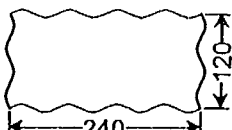
3. Test Sections and Measurements

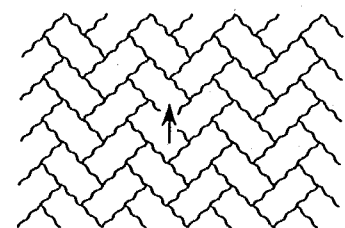
The loading test in 1987, which was conducted to the structure shown in Figure 2, concluded that upper base courses with high bearing capacity were required in order to prevent rutting on the pavement surface through deformation of the upper base course [1]. Loading tests after 1988 were conducted to study layer coefficient of IL blocks by adjusting

the converted thickness (hereinafter referred T_A^2) of cement and asphalt stabilized base courses to the same thickness.

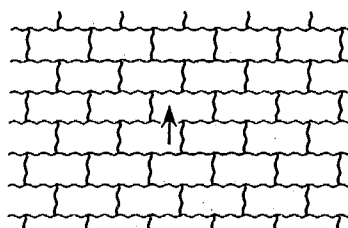
Table 1 shows structure and size of test pavements since 1988. Construction cost of the 40cm base courses with asphalt stabilized base is higher than that with cement stabilized base by 27%. During the loading test, rutting, deflection, breakage and movement of blocks were periodically measured and observed.

Table 1 Outline of Test Pavements

Test Section	307	308	309
Year of Construction	1988	1991	1991
Width (m)	7.0	7.0	7.0
Length (m)	24.5	12.25	12.25
Shape of IL Block(mm)			
Laying Pattern	Herringbone Bond	Herringbone Bond	Stretcher Bond
Pavement Structure (mm)			
T_A of Base Course (mm)	165	160	



Herringbone Bond Pattern



Stretch Bond Pattern

←: Direction of Vehicle Running

3.1 Rutting

Rutting was measured by deformation recorded on the paper of a transverse profilometer. Measurement was carried out on the fixed lines of the test sections between marking points on both sides of the track. Number of measuring lines were three for section 307, and two for section 308 and 309. Rutting depth of the sections evaluated by the average of all obtained data on right and left wheel paths.

² T_A is the value corresponding to the Structural Number of the AASHTO Design Manual.

3.2 Deflection by FWD

Deflection was measured by Falling Weight Deflectometer. Deflections caused by a 49kN (5ton) of dynamic load on the pavement surface were measured by seven deflectometers. The measurements were carried out three time on the same point. The first measurement was abandoned, since the values were not stable. The average of the second and third measurements was recorded as the deflection of the point. The measurements were conducted at 4 points for section 307 and 2 points for section 308 and 309. Finally the average of 2 or 4 points was used for the evaluation.

3.3 Breakage of IL Blocks

Breakage of the block was classified into three categories such as chip-off, light cracking in a block and serious cracking through the block. All IL blocks in the test sections was surveyed. The result was summarized as rate of broken blocks, i.e. number of broken blocks of each breakage category to total number of blocks on the test sections, expressed in %.

3.4 Movement of IL Blocks

Movement of blocks was evaluated by the movement of the center of each block. Using the same marking points for rut depth, a string was extended between the points. The distance from the string to the center of the block was measured periodically. The movements were defined plus when the center is in vehicle running direction from the string and vice versa. For evaluation, the average of movement on each string was used.

4. Result of Survey

Measurements of the pavement surface condition and FWD deflection were carried out when number of loading reached set amount. Table 2 shows surface condition and deflection. Number of loading reached 540,000 times for the section 307, and 380,000 times for the section 308 and 309. Number of 98kN EAL was 801,976 for section 307, and 513,282 for section 308 and 309. The reason of the difference on EAL between test sections is that section 308 and 309 were reconstructed two time from sand cushion layers.

4.1 Durability of Base Course Materials

As shown in Table 2, the section 307 had less rutting and breakage of blocks than section 308 and 309. When regression analysis was carried out on the rate of block breakage, rutting, movement and deflection, rate of breakage and rutting showed good correlation. The result of analysis of variance also showed that two factors were highly significant as shown in Table 3.

Then analysis of performance was conducted. Maintenance Control Index (hereinafter referred as MCI) was developed to evaluate surface condition of asphalt and cement pavement. MCI formula is shown as formula (1).

Table 2 Pavement Surface Condition of Test Sections

Section	Year	98kN EAL	Rutting (mm)	Deflection (mm)	Breakage (%)	Movement (mm)	MCI ₀
307	1988	0	3.3	0.90	0	0	9.31
	1988	125,191	10.4	0.98	0.6	1.90	7.16
	1989	288,694	9.1	0.89	1.8	-0.70	6.79
	1990	478,641	7.7	0.84	4.0	0	6.46
	1991	552,136	8.7	1.11	5.3	0.30	6.15
	1992	635,416	10.0	0.89	7.7	-4.53	5.71
	1994	718,696	11.1	1.02	8.6	-0.37	5.50
	1995	801,976	14.5	0.89	13.6	-1.53	4.75
308	1990	0	1.3	—	0	4.0	10.00
	1990	189,947	0.5	1.24	1.8	6.5	8.01
	1991	263,442	4.8	1.42	5.4	-1.0	6.60
	1992	346,722	7.7	1.18	11.9	4.6	5.57
	1994	430,002	15.5	1.41	14.8	-1.6	4.57
	1995	513,282	19.7	1.18	26.6	0.1	3.54
309	1990	0	2.5	—	0	3.0	9.43
	1990	189,947	4.8	1.07	1.4	8.0	7.43
	1991	263,442	5.9	1.26	3.9	0.5	6.69
	1992	346,722	6.9	1.05	7.0	9.8	6.13
	1994	430,002	11.5	1.06	10.6	1.6	5.28
	1995	513,282	18.8	1.04	17.5	1.1	4.10

Table 3 Analysis of Variance

Factor	Deviation sum of squares	Freeness	Unviassed Variance	Variance Rate	Verification
Regression	796.98	31	796.98	53.34	※※
Residual	448.21	1	14.94		
Total	1245.19	32			

※※Significant with 1% point ---7.56
5% point ---4.17

$$MCI_0 = 10 - 1.51C^{0.3} - 0.30D^{0.7}$$

(1)

Where C: Cracking Ration (%)

D: Rutting (mm)

Though C and D are terms for asphalt pavement usually, breakage rate of blocks was input to C in the analysis. The result is shown in Table 2. Figure 3 shows the relationship between cumulative 98kN EAL and MCI₀. MCI₀ decreases as 98kN EAL increases. The final value of MCI₀ was 4.75 for section 307, 3.54 for section 308 and 4.10 for section 309. In addition to the performance analysis, survey on the surface of upper base courses was conducted, of which details are in chapter 5.3, and cracking on the surface of the cement stabilized base was found. Considering these results, asphalt stabilized upper base course is preferable for IL block pavement for heavy traffic roads.

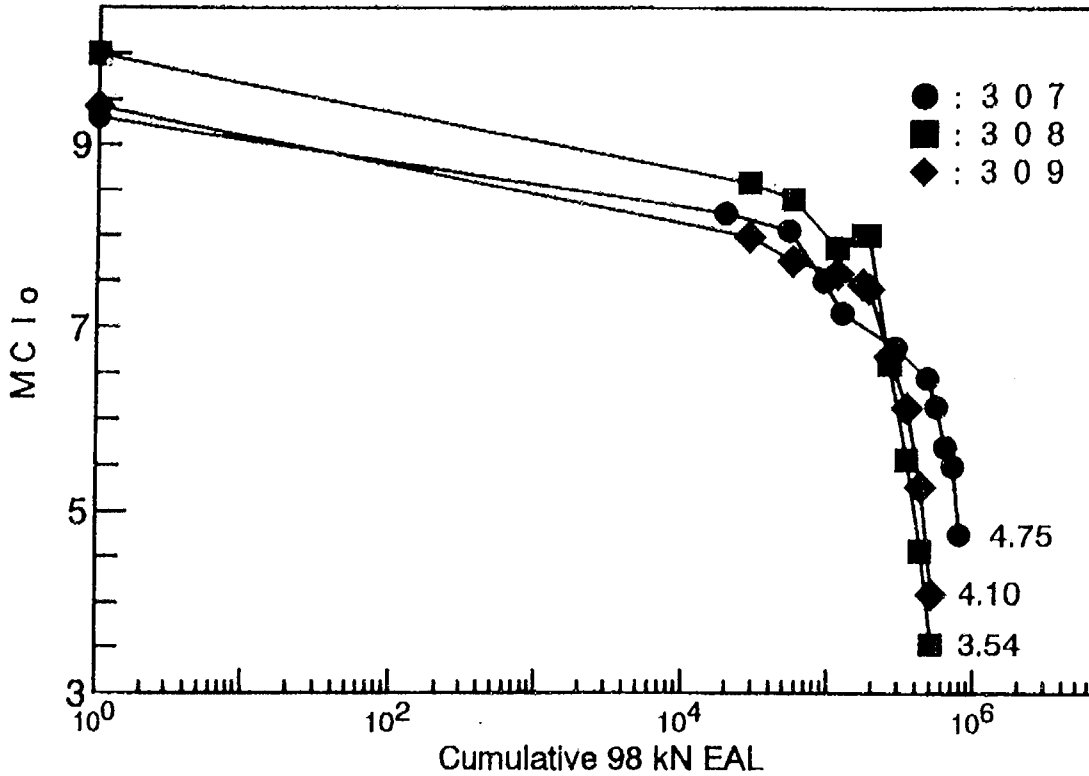


Figure 3 Relationship Between 98kN EAL and MCI₀

4.2 Equivalent Layer Coefficient of IL Blocks

Following formulas is known based on nationwide survey.

$$MCI = 9 - 65 \times (\log N - 5)^4 \times (2 - \log T_A)^8 \times (2 - \log CBR)^5 \quad (2)$$

When $MCI = MCI_0^3$, the formula is rewritten as

$$T_A = 10^Z \quad (3)$$

$$Z = 2 - \{ (9 - MCI_0) / 65 (\log N - 5)^4 / (2 - \log CBR)^5 \}^{1/8} \quad (4)$$

Since the converted thickness of upper and lower base courses is known, the converted thickness of IL block layer is also calculated. The result is shown in Table 4. Average coefficient of three test sections is 0.89 and equivalent layer coefficient for section 307, where bearing capacity of upper base course made of asphalt stabilization is high, gives value of 1.26. Considering these data, it was concluded that equivalent layer coefficient of IL blocks including laying course is almost equal to that of hot mixed asphalt, namely 1.0.

³ In order to calculate MCI, rutting, roughness and cracking should be known numerically. When data on roughness is not available, MCI₀ is used instead of MCI.

Table 4 Equivalent Layer Coefficient of IL Blocks

Section	307	308	309	Average
Equivalent Layer Coefficient	1.26	0.68	0.74	0.89

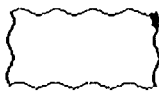
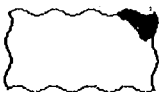
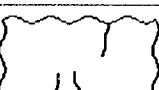
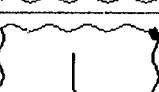
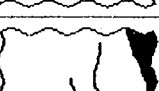
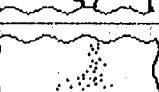
5. Damages on IL Blocks and Base Courses after Loading Test

The damages on IL blocks and base course layers were examined after the loading test. Block breakage, disappearance of joint sand and profile of cross sections of each pavement layers were examined for each test sections.

5.1 Breakage of the Blocks

Breakage of the blocks was classified into 9 categories, as shown in Table 5, according to the damage level. The distribution of 9 types of breakage was closely examined on all test sections. More than 80% of damages was slight, which needed no replacement of blocks and more than 70% of damages were chip-off on some of the four corners of IL blocks.

Table 5 Classification of Damage

Classification	Situation	Level	307	308	309
A-1		Chip-off (light and no need for replacement)	358 (87.5)	277 (83.2)	235 (91.1)
A-2		Chip-off (heavy and need to be replaced)	47 (11.5)	43 (12.9)	4 (1.6)
B-1		Cracking (light)	1	3 (0.9)	9 (3.4)
B-2		Cracking (heavy)	1	4 (1.2)	3 (1.2)
C-1		Chip-off and Cracking Complex (light)		2 (0.6)	
C-2		Chip-off and Cracking Complex (heavy)		3 (0.9)	1 (0.4)
D-1		Compressive Failure (light)	1		
D-2		Compressive Failure (heavy)	1		
E		Others (stripping etc.)		1 (0.3)	6 (2.3)
Total			409 (100)	333 (100)	258 (100)

Chip-off on the corners of IL blocks was intensively examined. The layout of IL blocks and running direction of the loading vehicles were classified into pattern 1 to pattern 3 as shown in Figure 4. Then location of IL blocks were classified into inner wheel path (hereinafter referred as IWP), outer wheel path (hereinafter referred as OWP) and between wheel paths (hereinafter referred as BWP). The summary is shown on Table 6.

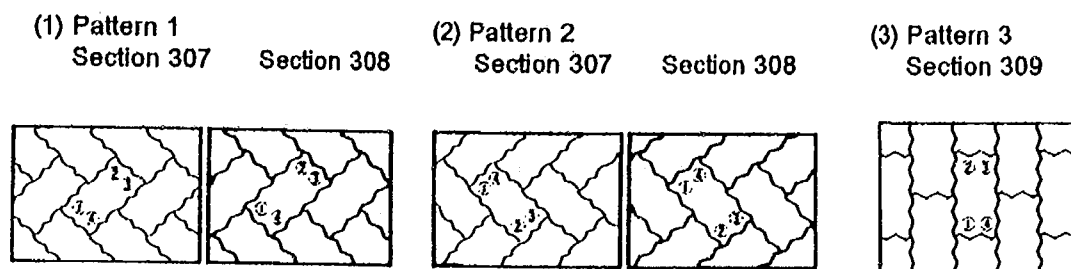


Figure 4 Laying Patterns of IL Blocks

Table 6 Result of Chip-off Re-analysis

Pattern	Number of Blocks with Chip-off	Chip-off Position											
		IWP				BWP				OWP			
		①	②	③	④	①	②	③	④	①	②	③	④
1	82	4	3	21	7	2	4	7	9	2	7	11	5
		35 (42.7)				22 (26.8)				25 (30.5)			
2	219	0	73	16	8	2	15	14	3	2	59	12	15
		97 (44.3)				34 (15.5)				88 (40.2)			
1	125	1	15	5	6	15	6	5	16	6	41	4	5
		27 (21.6)				42 (33.6)				56 (44.8)			
2	88	6	12	12	6	1	2	6	14	4	5	13	7
		36 (40.9)				23 (26.1)				29 (33.0)			
3	210	17	13	16	10	14	16	17	15	27	15	21	29
		56 (26.7)				62 (29.5)				92 (43.8)			

At section 307, chip-off of pattern 2 occurred 2.5 times as much as pattern 1. Chip-off mainly occurred at corners marked No. 2 on IWP and OWP. At section 308, more chip-off occurred at corners marked No.2 for pattern 1 on OWP. At section 309, more chip-off was observed on OWP. However, the damage equally occurred at each corner.

The survey is summarized that, in the case of stretcher bond, chip-off evenly occurs at four corners of IL blocks and that, in the case of herringbone bond, chip-off concentrates at a specific corner. In order to reduce the damage of IL blocks, it is necessary not only to investigate the mechanism of chip-off but also to establish a specification of hardness of the block surface.

5.2 Disappearance of Joint Sand

Disappearance of joint sand was identified using a scale specially made for the survey. If 2 cm or more joint sand disappeared from the surface of IL blocks, the joint was marked on survey sheets. The rate of disappearance was calculated by formula (5).

$$\text{Disappearance rate of joint sand (\%)} = \frac{\text{Total length of joint without enough joint sand (m)}}{\text{Total length of joints (m)}} \quad (5)$$

As a result shown on Table 7, the disappearance rate increased in the order of the section 307, 309 and 308 showing the same tendency as block breakage and rutting depths. Especially on the section 308, block breakage tends to concentrate at the place where joint sand disappeared.

Disappearance of joint sand causes not only a malfunction as a continuous layer consisting of small blocks interlocking together but negative effect laying course and base courses as more water permeates from the joint. Therefore, it is necessary to refill joints immediately when joint sand disappears. Furthermore, quality on joint sand should carefully examined in order to prevent the disappearance.

Table 7 Disappearance Rate of Joint Sand

Section	307	308	309
Disappearance Rate	10.5	25.6	21.2

5.3 Survey on Cross Section of Each Pavement Layers

In order to survey the deformation of layers, IL blocks were removed in 1 m width along 4 to 5 transverse lines in each test sections. A string was extended and fixed along the trench to measure depth to each layer. Result of the survey is shown in Figure 5.

As the figures show, deformation on the IL block surface is corresponding to that of laying courses. The cause of deformation on the bedding sand was considered that sand for the layers broke into smaller particles. Another cause was hardening of the sand. The hardening, which was observed on all test sections, especially occurred along wheel paths and more hardening occurred on cement stabilized base, i.e. section 308 and 309. The hardened sand no longer functions as a laying course anymore.

Since hydration of cement stabilized base continues in a long term, cement in the stabilized base might affect the sand for the laying course. Samples of sand were taken from the location of wheel paths, where hardening was observed, and non-wheel paths, where no hardening was observed. The samples have undergone compaction tests and X-ray analysis.

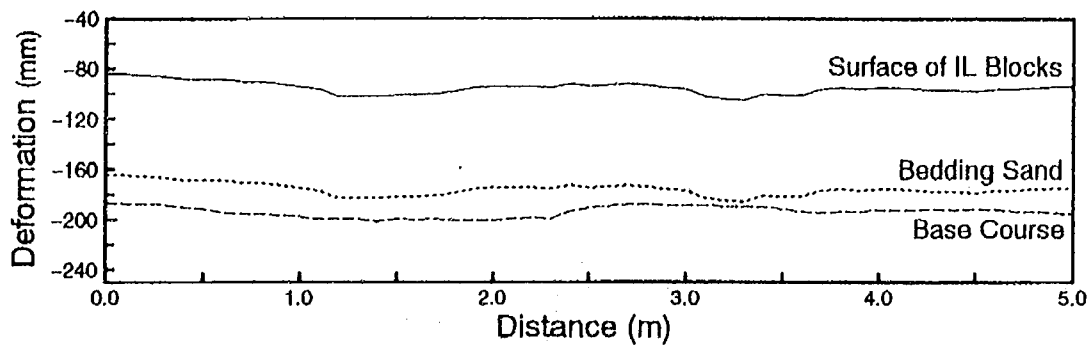
5.4 Result of Laboratory Tests

The results of passage rate of sieves and washing test of bedding sand under the wheel path and the non wheel path are shown in Table 8. Amount of loss by washing test shows that sand under the wheel passes,

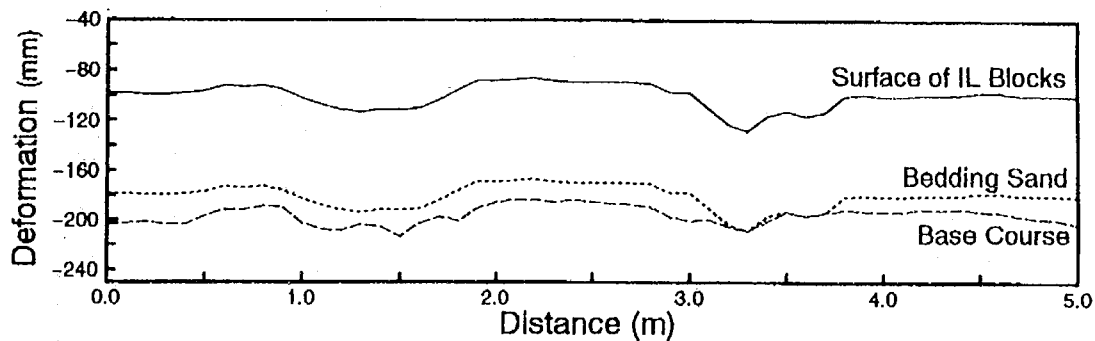
of which rate of loss was 9.0% in average, became finer than that under non wheel paths, of which rate of loss was 2.5% in average. In X-ray analysis, as shown in the analysis charts of Figure 6, quarts, muscovite, magnetite, feldspar, amphibole and cristobalite were detected. However, no hydrate of cement was detected.

As a result of the analysis, it was concluded that the deformation and hardening of the bedding sand was caused by pulverization of sand. This pulverization caused deformation of the IL block surface and brought fatal damage to the IL blocks under wheel paths. It became clear that quality of bedding sand is quite important for keeping the pavement surface in good condition.

(1) Section 307



(2) Section 308



(3) Section 309

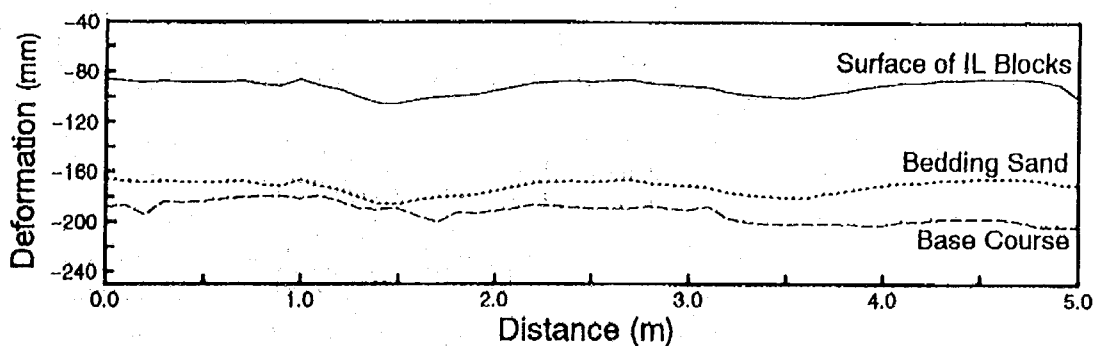
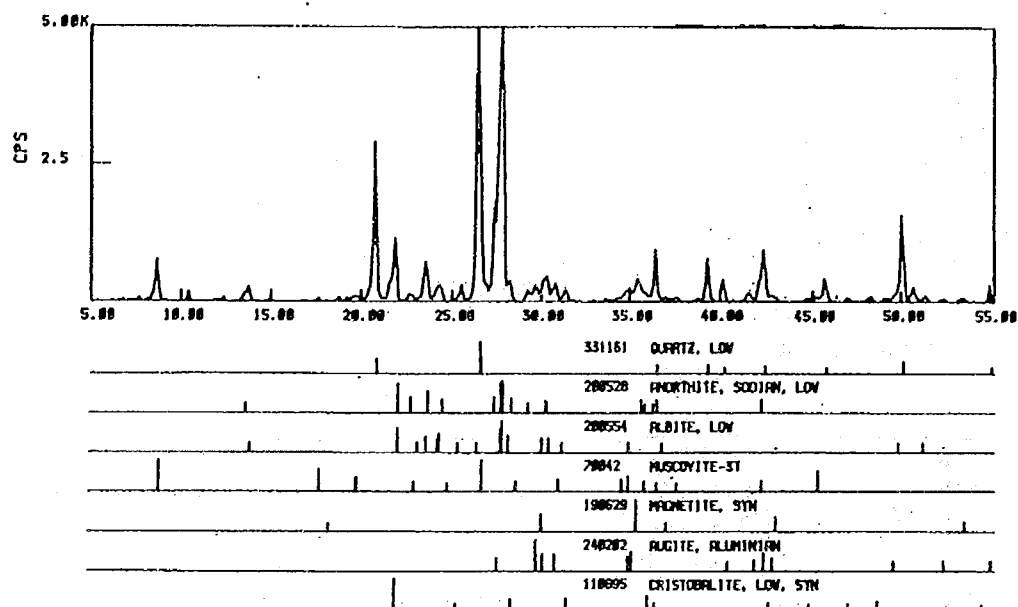


Figure 5 Profile of Cross Section

Table 8 Result of Sieve Analysis and Washing Test

Position	Section	Passing (%)						Washing Test (%)
		5.0	2.5	1.2	0.6	0.3	0.15	
Wheel Path	307	97	88	80	60	24	5	7.2
	308	97	91	84	66	24	5	10.2
	309	97	91	82	64	24	5	9.8
	Average	97	90	82	63	24	5	9.0
Non Wheel Path	307	98	89	80	63	27	5	2.1
	308	98	93	85	68	28	6	2.5
	309	94	88	80	65	27	6	2.9
	Average	97	90	82	65	27	6	2.5

(1) Section 309 (Wheel Path)



(2) Section 309 (Non Wheel Path)

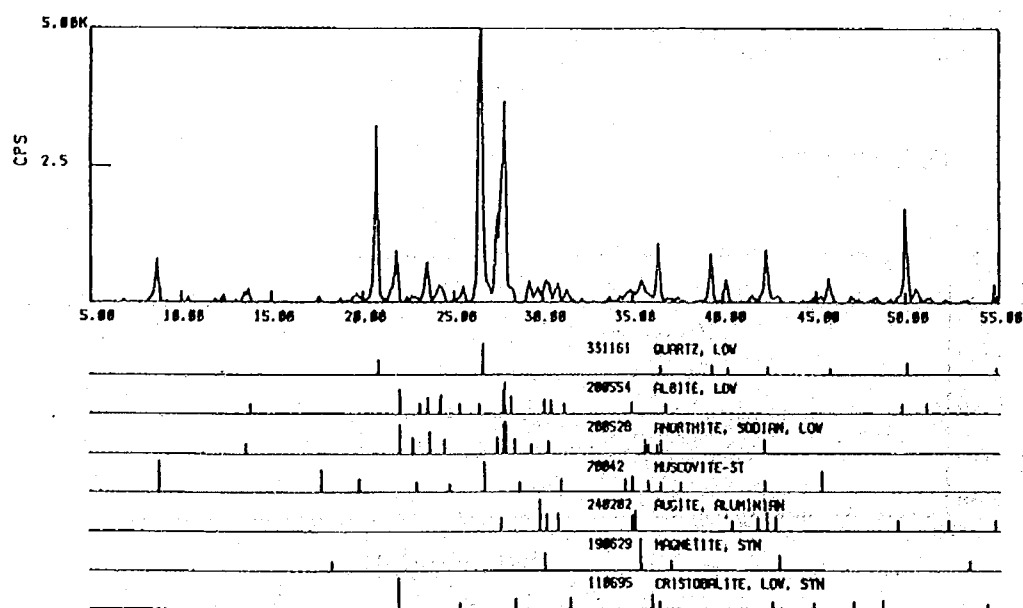


Figure 6 Result of X-ray Analysis Pattern

6. Conclusion

- (1) The equivalent layer coefficient of IL blocks is almost equal to that of hot mixed asphalt.
- (2) When repeated load is given to test sections, the test section with an asphalt stabilized base course performs better than that with a cement stabilized base course. Therefore, asphalt stabilized base is recommended for IL block pavement for heavy traffic roads.
- (3) The detailed survey on the damage level of IL blocks indicated that more than 80% of the chip-off damage does not require any replacement and that 70% of the damage occurred on corners of the IL blocks. When chip-off is concerned, it occurred evenly on each corner of IL blocks in case of stretcher bond type laying pattern. When IL blocks were laid in herringbone bond pattern, however, chip-off tends to occur at a specific corner of blocks.
- (4) Loss of joint sand and deformation of laying course cause fatal damage on the IL blocks. Hardening of sand was also observed. Since no hydrate was found by X-ray analysis, the hardening was also caused by pulverization of sand.
- (5) In order to maintain good surface condition of IL block pavement, quality of sand should be carefully examined before construction.

7. Current Issues on IL Blocks

The repeated loading test in PWRI provided various data, which had not been available by test paving on actual highways. In order to establish design specifications of IL block pavement for heavy traffic roads, following issues should be clarified.

- (1) Cause of chip-off on IL blocks
- (2) Specification of hardness of IL block surface
- (3) Performance evaluation formulas for IL block pavement
- (4) Specification of quality of bedding sand and joint sand

The last issue, specification of bedding sand and joint sand, is recognized most important. PWRI and ILBEA collaboratively started repeated loading test on test sections using four types of materials for laying course from 1997.

8. Acknowledgement

This study was completed collaboratively between PWRI and member companies of ILBEA. The authors deeply acknowledge devotion of the technical committee of ILBEA, which consists of central, and local government authorities, road contractors and technical staff of member companies.

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2.3 Implementation of Accelerated Pavement Testing at JHPC

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1. Introduction

Japan Highway Public Corporation (JHPC) has operated the Accelerated Loading and Environmental Simulator (ALES) since 1970 to evaluate deformation and ravelling property of asphalt mixtures, structural evaluation of pavement, and so on in a short period of time by simulating traffic and environment condition on expressways.

ALES is mainly used to evaluate deformation and ravelling property of asphalt mixtures by conducting 6 series of tests annually.

2. Feature of ALES

Current ALES (Figure 1) is the second generation which has been operated since 1993. A set of round test track (about 25 m long) is consisted of 16 trapezoid shape specimen (2m width) and the feature is as follows,

- ① Four wheels are laid down cross wise and the diameter of axle is 8 meters(Inner test track) and 10 meters(Outer test track).
- ② Maximum load on each wheel is 7 tons.
- ③ Maximum rotation speed is 100km/hour.
- ④ The machine is inside building and the temperature of pavement surface can be controlled in the range from - 20 °C to + 60 °C.
- ⑤ Wet road surface is simulated by water sprayer system.
- ⑥ Structural evaluation of pavement is also possible using part of test track.
- ⑦ Whole equipment is supported by 34 air cushion springs to prevent transmission of vibration around the facility.

3. Simulation of traffic and environmental condition

The most important thing for testing by ALES is to simulate traffic and environment condition as it is on real expressways.

For example, main reason of plastic flow rutting on asphalt pavement is attributed to the number of heavy commercial vehicles and high temperature on pavement surface; therefore, plastic flow rutting is increased during summer time mainly. The highest temperature on pavement surface in summer is 55°C~60°C and it was found that both

surface temperature and vertical temperature change from surface to subbase course affect degree of plastic flow rutting.

Based on basic trial tests, temperature at starting point and heat caused by friction between tire and pavement were main factors to affect surface and vertical change of temperature of specimen. Finally it was almost achieved to simulate daily temperature change on expressways from morning to evening. (Figure 2, Figure 3)

Sliding movement of tire along the axle to prevent passing same position was also studied since sliding amount affects shape of deformation due to the uncertain extra amount of asphalt mortar to prevent accurate measurement of rutting depth.

3. Example of evaluation test for plastic flow resistance of asphalt mixtures

Based on study of basic test condition, a series of evaluation tests for plastic flow resistance of asphalt mixtures was conducted. Standard test condition is as follows, surface temperature: around 55 °C, load: 2.5 tons, rotation speed: 80 km/h.

In case of dense-graded asphalt mixture, about 200,000 passing wheels which takes about 5 days leads to the rutting depth of more than 25 mm, the maximum target rutting depth for maintenance. Regarding change of rutting depth, the result of simulation showed almost same tendency on expressways and that our simulation method is accurate.

Drainage pavement is getting popular to improve safety and noise problem. It is necessary to evaluate the plastic flow property of drainage pavement by changing type of asphalt binder and gradation for both durability and economy.

Figure 4 shows the result of plastic flow property test of drainage pavement under standard test condition described above.

Compared to the mixture with High Viscosity Modified Asphalt(HVMA), the rutting depth of mixture with Modified Asphalt Type II (MAT II) is a little bit large but it seems to have enough durability in practical use. The cost of MAT II is cheaper than that of HVMA and it is expected that use of MAT II will contribute cost reduction of pavement construction in some case based on the result of testing by ALES.

4. Conclusion

Before implementation of testing by ALES, the result of laboratory test was realized in construction field directly and sometimes the new mixtures were failed to be durable and safe. ALES can achieve the evaluation of asphalt mixtures in a short period of time before pavement construction and it has played important role to get high durability of pavement and safety on expressways.

Table 1 Loading capacity of ALES

Tire	Inner track			Outer Track
	Large Vehicle Single	Large Vehicle Dual	Passenger Vehicle single	Large Vehicle Single
	20 inches	14 inches	20 inches	
Test speed	0- 100 km/h			0- 80 km/h
Load	Max 3t/wheel	Max 7t/wheel	Max 0.4t/wheel	Max 2.5t/wheel
Torque	Equivalent $\pm 6\%$			Equivalent $\pm 3\%$
Shifting	$\pm 200\text{mm}$ from track center			$\pm 100\text{mm}$

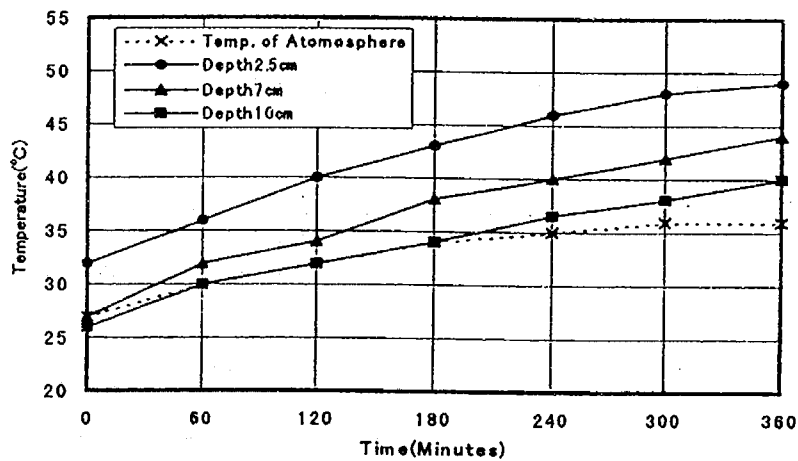


Figure2 Temperature of Pavement on Expressway

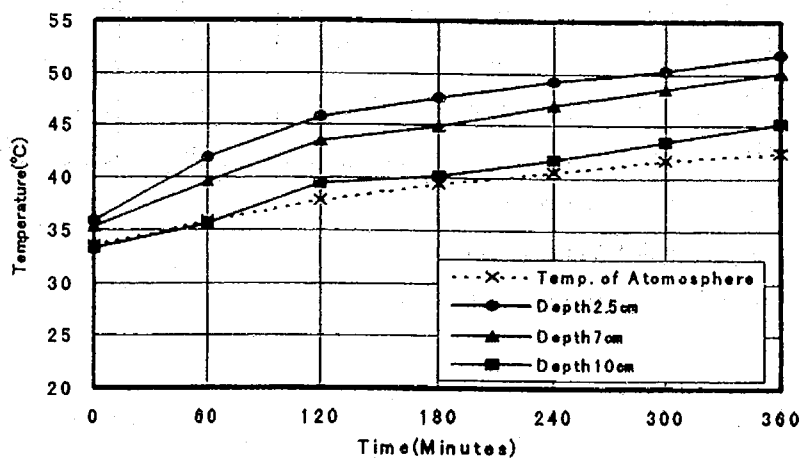


Figure3 Temperature of Pavement on ALES

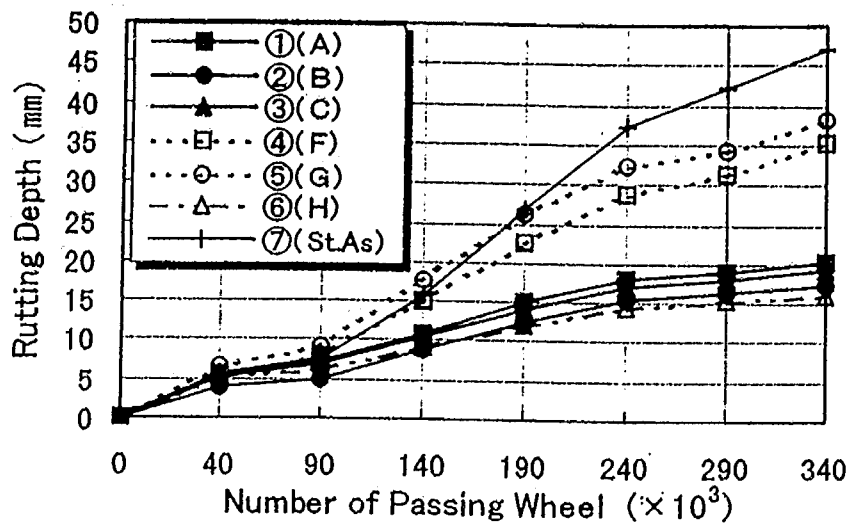


Figure 4 Result of Flow Rutting Test

Table 2 Property of Binder

Binder	Type	Penetration	Softening Point	Toughness	Tenacity	Viscosity at 60°C
		1/10cm	°C	kgf·cm	kgf·cm	poise
A	MAT II	48	59.1	229	180	20,000
B	MAT II	48	61.2	253	216	31,400
C	MAT II	67	78.7	196	175	9,500
D	MAT II	51	61.6	254	214	13,600
E	MAT II	53	63.6	224	189	15,800
F	MAT I	59	54.5	270	224	12,500
G	MAT I	50	55.9	61	20	6,470
H	HVMA	43	96.3	214	155	748,000

MAT II : Modified Asphalt Type II

MAT I : Modified Asphalt Type I

HVMA : High Viscosity Modified Asphalt

2.4 Westrack Performance - Interim Findings

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Abstract. A federally-funded multi-million dollar hot-mix asphalt (HMA) pavement research project is currently underway to further the development of performance-related specifications (PRS) technology and to provide early field verification for the Superpave asphalt mixture design procedure. WestTrack refers to a full-scale road test experiment in which various asphalt mixes are loaded in an accelerated fashion to determine the effect on field performance of "off-target" mix properties. The track is located near Reno, Nevada, and the WestTrack team includes consulting firms, universities, and road contractors.

This paper provides background information on the project including the nature of the experiment, the experimental factors, structural and mix design, track construction, vehicle loading, driverless vehicle technology, performance monitoring, and laboratory testing. It also presents information on the interim performance of the test sections and summarizes the planned approach to developing the pavement performance prediction models.

Keywords. Hot-mix asphalt, Superpave, performance-related specifications, accelerated pavement test, autonomous vehicles.

INTRODUCTION

WestTrack is a multi-million dollar accelerated pavement test facility located in the state of Nevada approximately 100 km (60 mi) southeast of Reno. The pavement test facility was designed and constructed by a team of private companies and universities (the WestTrack Team) under contract to the U.S. Department of Transportation's Federal Highway Administration. The project was awarded to the WestTrack Team by the Federal Highway Administration in September of 1994. The track, which includes 26 HMA pavement test sections, was designed and constructed between October 1994 and October 1995 and has been subjected to traffic since March 1996. The initial 26 sections included fine- and coarse-graded Superpave mixtures with a Dayton, Nevada, crushed gravel aggregate; asphalt and air void contents and aggregate gradation (minus 0.075-mm sieve material) were systematically varied among the sections to represent typical construction variations.

Approximately 4.5 million 80-kN (18,000-lb) equivalent single axle loads (ESALs) have been applied to the test sections as of March 1, 1998. By May of 1997 (after 2.8 million ESALs), excessive rutting or fatigue cracking required replacement of a number of the original HMA sections. Eight of the replacement sections contained a coarse-graded

Superpave mixture with a Lockwood, Nevada, crushed andesite aggregate; sections again were constructed with systematic variations in asphalt and air void contents.

OBJECTIVES

The project has two primary objectives, as given below:

- Continue the development of performance-related specifications (PRS) for HMA pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt content, aggregate gradation, in-place air void content, etc.) from design target values.
- Provide early field verification of the Strategic Highway Research Program (SHRP) Superpave HMA mixture design method.

These objectives are addressed in the WestTrack experiment by designing, constructing, operating, monitoring performance, and developing performance prediction models from 34 different HMA test sections placed on a 3-km (1.8-mile) oval track.(1)

WESTRACK OVERVIEW

The WestTrack Team consists of the sponsoring agency (Federal Highway Administration) and seven private and university groups. Each of the groups has specific responsibilities within the framework of the project. Team members and their primary responsibilities are as follows:

- Nevada Automotive Test Center (prime contractor, driverless vehicle development, track loading).
- Nichols Consulting Engineers (experiment design, performance monitoring, PRS development).
- University of Nevada, Reno (pavement research, conventional HMA testing, construction coordination).
- University of California at Berkeley (SHRP-related HMA accelerated performance testing and performance modeling).
- Oregon State University (SHRP-related HMA testing, data analysis).
- Granite Construction Co. (track construction, rehabilitation, and maintenance).
- Harding Lawson Associates (track geometric design, construction inspection, quality control/quality assurance testing).

Principal Investigators for the WestTrack Team are Jon Epps (University of Nevada, Reno), Stephen Seeds, and Sirous Alavi (Nichols Consulting Engineers). The Co-Program Managers are Henry C. Hodges Jr. and Colin Ashmore (Nevada Automotive Test Center). Principal participants are as follows: at Granite Construction, Mike Robinson and Kevin Robertson; at Harding Lawson Associates, Stuart Dykins; at the University of Nevada, Adam Hand; at Oregon State University, Rita Leahy; and at the University of California at Berkeley, Carl Monismith. Technical oversight on the project has been provided by Terry Mitchell, Ray Bonaquist, and Chris Williams of FHWA's Turner-Fairbank Highway Research Center in McLean, Virginia.

BACKGROUND

Location and Climate. WestTrack is located in the Carson River valley in the high desert of northwest Nevada approximately 100 km (60 miles) from Reno and 60 km (35 miles) from Carson City, Nevada. The track is located on the proving grounds of the Nevada Automotive Test Center. The climate at the test site is typical of high desert climates in the intermountain western portion of the United States. A few summer temperatures approach 40°C (104°F) and some winter temperatures may fall to -25°C (-13°F). Annual precipitation, in the form of both rain and snow, is approximately 100-mm (4-in.). Frost penetration into the fill and subgrade materials is unlikely at this site.

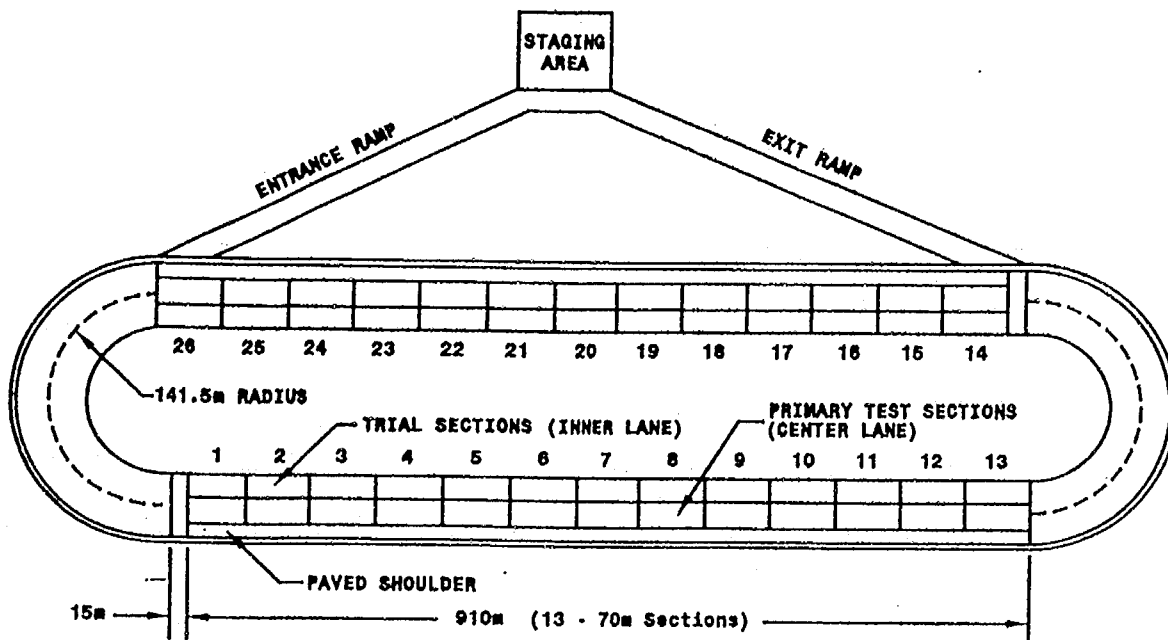


Figure 1. Layout of test track (not to scale)

Track Configuration. The track is an oval, consisting of two tangent sections connected by two spiral curves, as shown in Figure 1. All test sections are constructed on the tangents between the turnarounds. The tangent sections are 10.4-m (34-ft) wide and consist of two 3.7-m (12-ft) lanes with a 1.2-m (4-ft) HMA shoulder outside and a 1.8-m (6-ft) gravel shoulder inside. The outside lane serves as the actual "test" lane while the inside lane serves as both a paved shoulder and a "trial" HMA placement lane. Each of the 34 experimental section sites (26 original sections and 8 replacements) is 70-m (230-ft) in length with 25 meters (82-ft) set aside for transition, 40 meters (13-ft) for performance monitoring, and 5 meters (16-ft) for destruction sampling.

Vehicle Loading. Pavement loading is accomplished using four (driverless) tractor/triple-trailer combinations. A typical 3-axle tractor/single-axle semi-trailer (3S1) is followed by two trailers, each with two single axles. Weights on each load axle are 89 kN (20,000 lb), contributing to a total of 10.48 ESALs per truck pass. To aid in the electronic control of the trucks through the driverless vehicle system, each is equipped with a turbo-charged, electronically controlled engine. The automatic transmission in each truck allows electronic control of the transmission function. The trucks and trailers are equipped with anti-lock brake systems (ABS) and electronic brake valves for electronic control of the braking system. The trucks are equipped with 700 kPa (100 psi), 295/75R22.5 radial tires. The test speed is 64 km/h (40 mi/h).(2)

Performance Monitoring. The methods and frequency of performance monitoring are shown in Table 1. Visual distress surveys and 35-mm pictures are taken to record the type, severity, and extent of distress on the test sections. Transverse profiles at the surface of the pavement have been measured by the "Dipstick" (a commercially available profile instrument), an Arizona DOT transverse profile device, and a newly developed laser device. Transverse profile at the interface of the HMA and the base course is measured using the U.S. Forest Service liquid level gauge.

Deflection measurements are made with a falling weight deflectometer (FWD), while longitudinal profile and surface friction are measured, respectively, using the K.J. Law Profilometer and modified ASTM Skid Trailer.

TABLE 1
WESTRACK PAVEMENT PERFORMANCE MONITORING
PROCEDURES AND FREQUENCIES

Performance Data Type	Method or Protocol	Device	Collection Interval
Visual Distress Survey	SHRP P-338	Manual	2-week
Transverse Profile-Surface	SHRP P-338	FACE Technologies Dipstick*	2-week
Transverse Profile-Subsurface	-----	USFS Liquid Level Gauge	2-week
Deflection Measurements	LTPP Manual	Dynatest FWD	4-week
Longitudinal Profile	SHRP P-378	K.J. Law Profilometer	2-week
Surface Friction	ASTM Skid (E274)	DFMV Traction Truck	4-week

*Note: An Arizona DOT transverse profiler and a project-built laser transverse profile device were also used.

An accelerometer and load cells are mounted on one of the trucks to monitor vehicle dynamics. Strain gages have been installed at the bottom of the hot-mix asphalt in each section.

A Long-Term Pavement Performance (LTPP) weather station is located at the track, along with two LTPP seasonal monitoring devices for measuring temperature variations and possibility of frost penetration with depth, and for measuring moisture contents in the base, engineered fill, and subgrade soil. Additional thermocouples were installed in the HMA at a single location to provide temperature readings at five different depths in the pavement layer.

EXPERIMENT DESIGN

Seven experimental factors were considered in developing the experimental plan for the initial 26 sections: asphalt binder type, asphalt binder content, aggregate type, aggregate gradation, aggregate shape and surface texture, in-place air void content, and thickness of the hot-mix asphalt layer. A complete factorial was not feasible due to of economic constraints. Three experimental factors were ultimately chosen based on their potential impact on performance and/or the perception of how thoroughly they had been investigated in the past. All factors are discussed below.

Asphalt Binder. A single performance-graded asphalt binder was chosen, a PG 64-22. This asphalt binder meets the high temperature requirement at the 98 percentile level for the Superpave specification. The asphalt binder meets the low temperature Superpave requirement at the 50 percentile level. Since the life of the test track was not expected to exceed three years, the use of a somewhat higher than desired "low temperature grade" for this climate was considered adequate. In addition, it was not possible to obtain a non-modified PG 64-28 from domestic crude sources at a reasonable cost for use in the experiment.

Aggregate Type, Surface Texture, Shape and Gradation. A single primary aggregate source was selected for use in the original construction. Three gradations were utilized as shown in Figure 2.(3) A gradation on the fine side of the Superpave 19-mm nominal maximum size gradation curve was one of the selections. This gradation was designated as the "fine" gradation, because a relatively large portion of the aggregate passes the 4.75-mm sieve. To meet this gradation, a natural sand (from Wadsworth, NV) was blended with the primary aggregate (approximately 25 percent by total weight of aggregate). The primary aggregate was a partially crushed, fluvial deposited aggregate from a quarry near Dayton, Nevada.

A second gradation was obtained by adding approximately two percent "bag house" fines to the first selection, the fine-graded aggregate. This gradation was designated "fine plus," as it is the "fine" gradation "plus" extra bag house fines. A third gradation was developed on the coarse side of the Superpave 19-mm nominal maximum size gradation band.

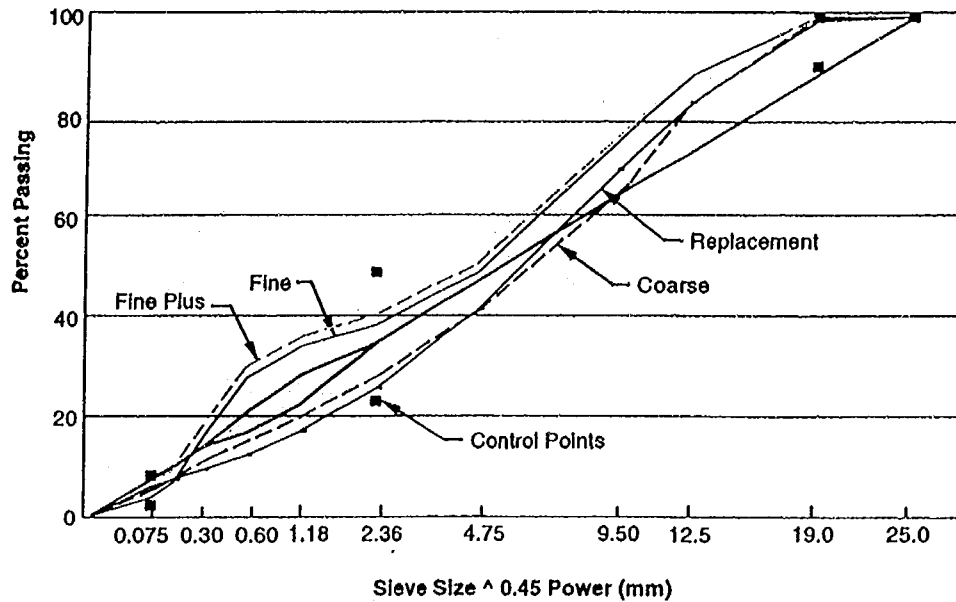


Figure 2. Mixture target gradations

This gradation was designated "coarse" because a relatively large portion of the aggregate was retained on the 4.75-mm sieve. This aggregate blend was prepared with only the primary aggregate (no natural sand).

Asphalt Binder Content. Optimum asphalt binder contents were determined for the "fine" and "coarse" gradations by the Superpave volumetric mix design procedure. (The target for the "fine plus" gradation was set at the target value for the "fine" gradation). The asphalt binder content was then varied plus and minus 0.7 percent from the optimum asphalt binder content for each of the gradations selected for evaluation. The target asphalt binder content for each mixture was designated as the "optimum," target or medium level while the asphalt binder contents 0.7 percent below and 0.7 percent above the target were designated "low" and "high," respectively.

In-Place Air Voids. Three levels of in-place air voids were selected for study in the project. Eight percent air voids were considered to be typical of hot-mix asphalt construction in the United States. This level of in-place air voids was designated as the "medium" level. The other target air voids selected were 4 and 12 percent and were designated as "low" and "high," respectively.

Thickness of Hot-Mix Asphalt. A single thickness of hot-mix asphalt was selected. The structural section for the track was designed to provide fatigue failure for a typical hot-mix asphalt at about 3.3 million ESALs. The structural section consisted of the following: 150-mm (6-in.) of scarified and mixed subgrade soil; 300-mm (12-in.) of engineered fill (obtained from the natural subgrade materials); 300-mm (12-in.) of dense-graded crushed aggregate base course; and 150-mm (6-in.) of hot-mix asphalt, constructed in two 75-mm (3-in.) lifts.

Selected Experimental Design. The experimental design is shown in Table 2. Three aggregate gradations, three asphalt binder contents and three in-place air void contents were selected. Since it is unlikely that hot-mix asphalt pavements will be placed at low asphalt binder contents and low air voids or at high asphalt binder contents and high

TABLE 2
EXPERIMENT DESIGN FOR ORIGINAL 26 WESTRACK SECTIONS

Design Air Void Content	Aggregate Gradation Designation								
	Fine			Fine Plus			Coarse		
	Design Asphalt Contents (%)								
(%)	Low	Opt.	High	Low	Opt.	High	Low	Opt.	High
Low		04	18		12	09, 21		23 (39)	25 (55)
Medium	02	01/15	14	22	11/19	13	08 (38)	05/24 (35, 54)	07 (37)
High	03/16	17		10	20		26 (56)	06 (36)	

*Numbers shown in each cell represent WesTrack original construction section numbers, with replacement section numbers shown in parentheses.

air voids, these cells in the factorial were not filled. Five replicate sections were included in the experimental design. (This is reflected by the cells which have two numbers in Table 2.)

Replacement Sections. Eight replacement sections were placed in June of 1997. These sections contained a "coarse" gradation of a 100 percent crushed andesite aggregate from the Lockwood quarry near Reno, Nevada and a PG 64-22 asphalt binder. The gradation (shown in Figure 2) and optimum binder content for the coarse graded mixture were established using the Superpave volumetric design procedure. Sections were placed at optimum binder content and plus and minus 0.7 percent from the optimum. Target in-place air void contents of 4, 8, and 12 percent were used. Section designations are shown in Table 2 in parentheses.

MATERIALS AND MIXTURE DESIGNS

Asphalt Binders. Two non-modified asphalt binders were selected for use at WesTrack. A PG 64-22 refined at a West Coast refinery from a blend of U.S. domestic crudes was used for original construction. The PG 64-22 binder used for the replacement sections was obtained from Idaho. Table 3 contains results of Superpave tests performed on samples of the binder obtained during construction. Table 4 shows results obtained from the more traditional viscosity and penetration tests. In both the original and replacement sections, the binders are appropriately classified as PG 64-22 (or as AC-20).

Aggregate. Tables 5 and 6 contain the aggregate test results available to date. The Dayton partially crushed gravel, the Wadsworth natural sand, and the Lockwood crushed rock meet all Superpave requirements for the design traffic level. Additional aggregate testing is in progress to verify angularity and specific gravity test results previously obtained.

TABLE 3
REPRESENTATIVE ASPHALT BINDER PROPERTIES - SUPERPAVE TESTS

Sample Identification	Property								
	Flash Point (C)	Rotational Viscosity (Pa*s) @ 135°C	Mass Loss (%)	Original DSR @ 64°C (kPa)	RTFOT DSR @ 64°C (kPa)	PAV DSR @ 25°C (MPa)	BBR Stiffness S(t) @ - 12°C (MPa)	BBR Slope (m) @ - 12°C	PG Grade
Original Construction Sampled 9-20-95	268	0.306	0.25	1.244	2.406	3.308	215.5	0.335	64-22
Replacement Section Sampled 6-23-97	304	0.360	0.23	1.524	3.995	3.988	196	0.314	64-22

TABLE 4
REPRESENTATIVE ASPHALT BINDER PROPERTIES - CONVENTIONAL TESTS

Sample Identification	Property							
	Original						RTFOT	
	Vis@60°C in Poises	Vis@135°C in cSt	Pen@25°C in 1/10-mm	Pen@4°C in 1/10-mm	Flash-Point C	Solubility %	Vis@60°C in Poise	Duct.@25°C
Original Construction Sampled 9-20-95	1877	364	.54	18	268	99.9	4584	>50
Replacement Section Sampled 6-09-97	2521*	440*	65*		288		6275*	

*Performed by Utah DOT

Mixture Design. Mixture designs for the "fine" and "coarse" graded aggregate systems were established according to Superpave volumetric design methods. Optimum or target asphalt binder contents were established for these two mixtures. The asphalt optimum binder content for the "fine plus" gradation was identical to that used for the "fine" gradation. Mixture design details can be found in reference 3.

PERFORMANCE

The test track was designed to evaluate the rutting and fatigue performance of hot-mix asphalt. Low temperature or thermal cracking and water sensitivity problems were eliminated or minimized in the design process by binder selection and the use of hydrated lime. Performance information with respect to rutting and fatigue or alligator cracking is reported below. Performance to date suggests that thermal cracking and moisture sensitivity are not a concern.

Construction of the track was completed in early October, 1995, and traffic loading began in March of 1996. Since May of 1996, the track has experienced rutting and fatigue cracking. Some of the sections have been replaced and/or maintained as shown in Table 7. After approximately 1.5 million ESALs (November 1996), five sections were milled to a 50-mm depth and filled with 50-mm of new HMA. These "milled and filled" sections carried traffic through the winter months until June of 1997. After 2.8 million ESALs (June 1997), all of the HMA (150-mm) in these five sections and another five sections was removed and replaced with eight new coarse graded, experimental sections containing the Lockwood aggregate, and two sections containing Nevada DOT mixes. Fatigue cracking, rutting, and roughness were the reasons for the removal and replacement of these sections.

After 3.4 million ESALs (October 1997), six sections were milled and diamond ground to a depth of approximately 25-mm to remove ruts in the wheelpaths. One original construction section (3.4 million ESALs) and five replacement sections (0.58 million ESALs) were rehabilitated. Finally, after 4.1 million ESALs (January 1998), a mill and fill operation in the wheelpaths (50-mm in depth) was performed on sections 1, 3, and 10 and a patching operation was performed on Section 2.

TABLE 5
PRECONSTRUCTION AGGREGATE PROPERTIES - ORIGINAL CONSTRUCTION
1994 DAYTON AGGREGATE PRODUCTION

Stockpile/ Mixture Designation	Coarse Aggr. Angularity*, %		Fine Aggr. Angularity*, %	Flat or Elong.*, %	Sand Equi.*, %	LA Abrs.** , %	Deleterious Materials**, %
	1 Face	2 Face					
Dayton 3/4-inch	98.9	95.4		0.2		18.9	0.5
Dayton 1/2-inch	99.7	98.9		2.0		20.2	0.4
Dayton 3/8-inch	98.2	96.4				21.3	0.3
Dayton Rock Dust			47.6		49		0.5
Dayton Sand			44.5		31		
Wadsworth Sand			44.0		74		0.2
Fine	98.1	96.5	44.9***	0.6	65	20.3	0.2
Fine Plus	98.1	96.5	44.9***	0.6	65	20.3	0.2
Coarse	98.8	96.7	45.0	1.3	70	20.8	0.3

* Performed by FHWA

** Performed by University of Nevada

*** Based on Fine Aggregate Bulk Specific Gravity of 2.595 from field blend of July 8, 1995

TABLE 6
PRECONSTRUCTION AGGREGATE PROPERTIES - REPLACEMENT SECTIONS
1997 LOCKWOOD AGGREGATE PRODUCTION*

Stockpile/Mixture Designation	Coarse Aggr. Angularity, %		Fine Aggr. Angularity, %	Flat or Elong., %	Sand Equi., %	LA Abrs., %	Deleterious Materials, %
	1 Face	2 Face					
Lockwood 3/4-inch	92.9	90.9		0.0			
Lockwood 1/2-inch	94.5	92.9		0.2			
Lockwood 3/8-inch	99.1	98.8		0.0			
Lockwood Rock Dust			45.5		66		
Coarse Gradation	99.2**	98.4*	46.2	0.1	73		

* Sampled at Patrick hot-mix plant on 6-7-97

** Average of nine different laboratories

TABLE 7
TRACK REHABILITATION AND MAINTENANCE ACTIVITIES

Date	Accumulated ESALs X 10 ⁶	Number of Monitoring Sessions Prior to Activity	Activity	Section Number
March 1996	0	0	Initiation of traffic	1 through 26
November 1996	1.46	17	Mill 50-mm and replace with 50-mm of hot-mix asphalt (Replace badly rutted sections).	7, 9, 13, 21, and 25
June 1997	2.77	29	Remove hot-mix asphalt from ten sections and replace with eight sections of coarse graded (Lockwood) aggregate and two sections of Nevada DOT mixture. (Replace sections with rutting, fatigue cracking, and roughness).	Remove: 5, 6, 7, 8, 9, 13, 21, 24, 25, and 26 Replace with: 35, 36, 37, 38, 39, 43, 51, 54, 55, and 56
October 1997	3.4 (original) 0.58 (replacement)	34	Remove 25-mm in wheelpaths. (Replace sections with rutting and roughness).	23, 36, 37, 54, 55, and 56
January 1998	4.1 (original) 1.28 (replacement)	39	Mill 50-mm in wheelpath and replace with 50-mm of hot-mix asphalt or patch with special cold mix (section 2). (Replace sections with fatigue cracking).	1, 2, 3, and 10

The primary distresses developing at WesTrack have been rutting and fatigue cracking. Surface raveling has also occurred on some of the fine graded mixtures at the lower asphalt binder contents. The performance to date of the various mixtures relative to rutting and fatigue are discussed below.

Rutting. Rutting is defined as the maximum rut depth (peak-to-valley). Rut depth comparisons are shown in Figures 3-10 after 1.5 million ESALs for the original construction (Dayton aggregate) sections and in Figures 11-12 after 0.58 million ESALs for the replacement (Lockwood aggregate) sections. This information is discussed below.

"Fine" Gradation Mixtures. Figure 3 shows the relationship between rut depth and initial in-place air void content at the optimum asphalt binder content. In general, an increase in rut depth has been observed with an increase in initial in-place air voids, regardless of the asphalt binder content. At the optimum asphalt binder content, the variation in initial air void content resulted in ruts ranging from 7-mm to 12-mm. The two bars shown on Figure 3 at the medium air void level indicate that replicate test sections exist for this gradation, asphalt binder content, and air void content.

The relationship between rut depth and asphalt binder content for the "fine" graded mixture at the medium initial air void content (8 percent) is shown in Figure 4. An increase in rut depth is noted with increase in asphalt content.

"Fine Plus" Gradation Mixtures. Figure 5 shows the relationship between rut depth and initial in-place air void content at the optimum asphalt binder content. Again, increase in rut depth is evident as the initial in-place air voids are increased.

The relationship between the rut depth and asphalt binder content for the "fine plus" graded mixture at the medium initial air void content is shown in Figure 6. A large increase in rut depth is noted (8-mm to 10-mm) as the asphalt binder content increases from optimum to high. The high binder content mixtures at both the medium and low air void contents were removed after 1.5 million ESALs. The rutting behavior of the "fine plus" graded mixture is sensitive to changes in asphalt binder content at levels above the optimum asphalt binder content.

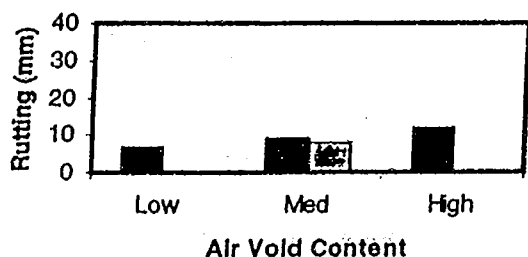


Figure 3. Fine gradation at optimum asphalt binder content - Dayton aggregate - ESALs ≈ 1.5 Million

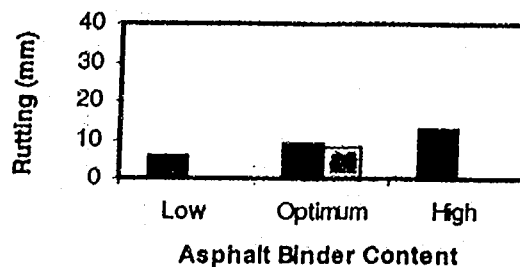


Figure 4. Fine gradation at 8 percent air void content - Dayton aggregate - ESALs ≈ 1.5 Million

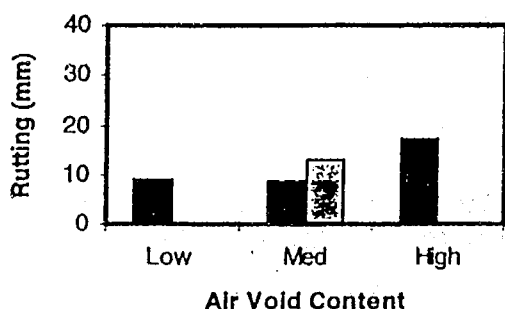


Figure 5. Fine plus gradation at optimum asphalt binder content - Dayton aggregate - ESALs ≈ 1.5 Million

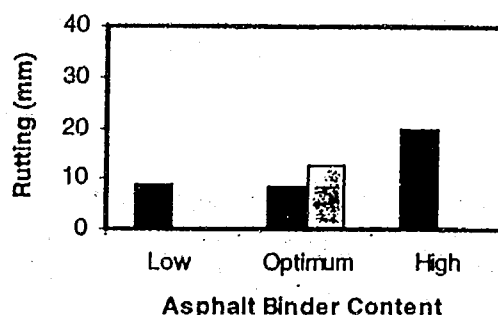


Figure 6. Fine plus gradation at 8 percent air void content - Dayton aggregate - ESALs ≈ 1.5 Million

“Coarse” Gradation Mixtures. Figure 7 shows the relationship between rut depth and initial in-place air void content at the optimum asphalt binder content. Rut depth increases from 13-mm to 21-mm as the initial in-place air voids are increased.

The relationship between the rut depth and asphalt binder content for the “coarse” graded mixture at the medium initial air void content is shown in Figure 8. An increase in rut depth with asphalt binder content is noted. The rut depths of these mixtures are greater than expected (17-mm to 36-mm) at all asphalt binder contents. The high binder content mixtures at both the medium and low air void contents were removed after 1.5 million ESALs.

Comparison of Gradations. The next figures show the relationship between rut depth and gradation at the optimum (Figure 9) and low (Figure 10) asphalt binder contents and medium air void content. The “coarse” graded mixtures have the largest rut depth under these conditions. In general, larger rut depths were observed for the “coarse” graded mixtures as compared to the “fine” graded mixtures under all conditions available for comparisons. The rutting of the “fine plus” gradation mixture was between the “fine” and “coarse” graded mixtures for all combinations of asphalt binder content and air void content.

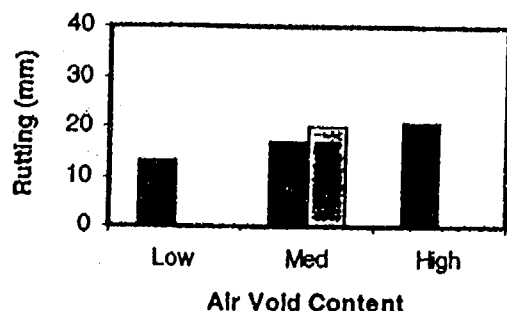


Figure 7. Coarse gradation at optimum asphalt binder content - Dayton aggregate
ESALs=1.5 Million

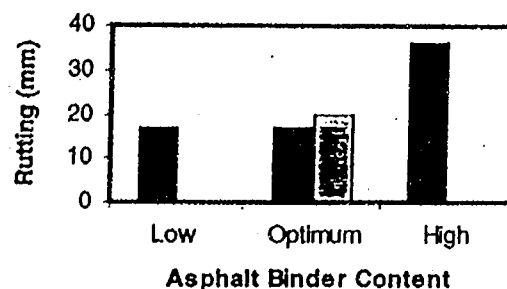


Figure 8. Coarse gradation at 8 percent air void content - Dayton aggregate
ESALs=1.5 Million

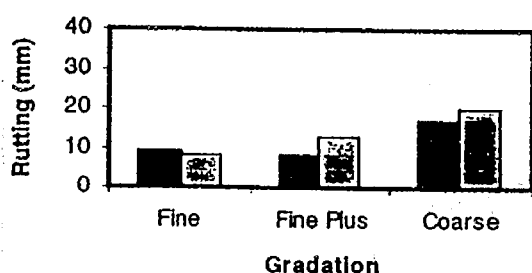


Figure 9. Optimum asphalt binder content at 8 percent air void content - Dayton aggregate
ESALs=1.5 Million

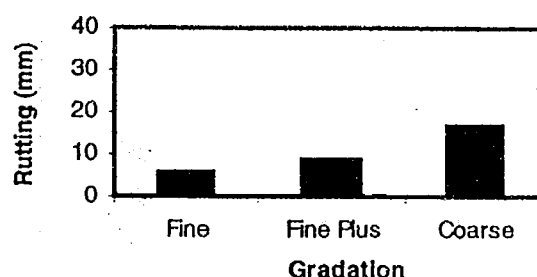


Figure 10. Low asphalt binder content at 8 percent air void content - Dayton aggregate
ESALs=1.5 Million

Figure 11 shows the relationship between rut depth and initial in-place air void content at the optimum asphalt binder content for the coarse graded replacement sections using Lockwood aggregate. Rut depth increases from 11-mm to 36-mm as the initial in-place air voids are increased.

The relationship between the rut depth and asphalt binder content for the coarse graded mixtures (replacement sections using Lockwood aggregate) at the medium initial air void content is shown in Figure 12. An increase in rut depth with asphalt binder content (from 13-mm to 26-mm) is noted.

Fatigue Cracking. Fatigue cracking is reported as the percent of the wheelpath area with fatigue cracking and is shown in Table 8 for the original sections after 2.8 million ESALs. The table indicates that in general the fatigue cracking initiates and is most severe in the left wheelpath.

"Fine" Gradation Mixtures. Figure 13 shows the relationship between fatigue cracking and initial in-place air voids for mixtures at the optimum asphalt binder content (this and succeeding figures show fatigue cracking across the entire test lane). A small amount of fatigue cracking is evident in the section that was placed at the initial high air void content. Fatigue cracking percentages less than five percent are considered insignificant, at this level the cracking could be the initiation of fatigue cracking or a flawed construction area. Once fatigue cracking exceeded five percent, it generally progressed rapidly.

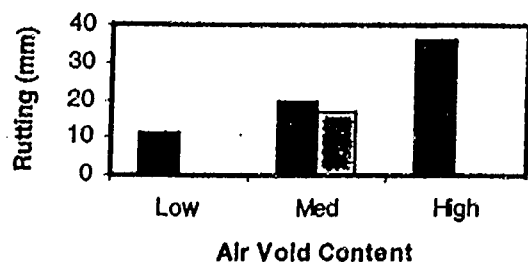


Figure 11. Coarse gradation at optimum asphalt binder content-Lockwood aggregate
ESALs= 582,000

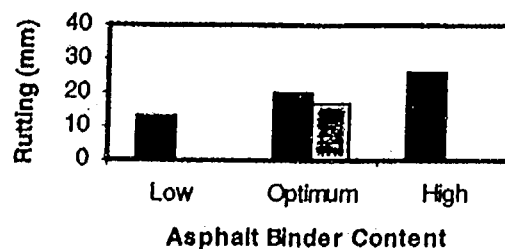


Figure 12. Coarse gradation at 8 percent air void content-Lockwood aggregate
ESALs= 582,000

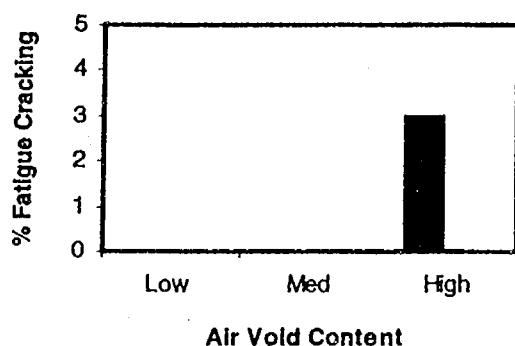


Figure 13. Fine gradation at optimum asphalt binder content- Dayton Aggregate
ESALs=2.8 Million

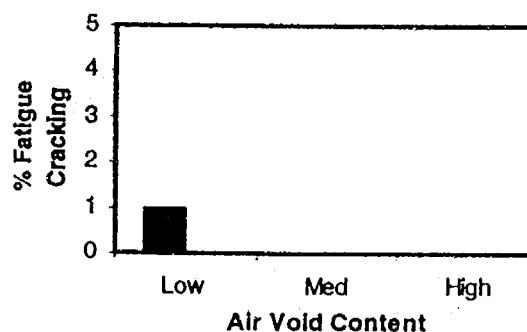


Figure 14. Fine plus gradation at optimum asphalt binder content- Dayton Aggregate
ESALs=2.8 Million

The only fatigue cracking at 2.8 million ESALs in the "fine" gradation sections was at the five percent or less level and occurred in the sections with either high air void contents and/or low asphalt binder contents. At 4.2 million ESALs at the low asphalt content, high air void sections showed fatigue cracking of 20 to 50 percent of the wheelpaths.

"Fine Plus" Gradation Mixtures. Figure 14 shows the relationship between fatigue cracking and initial in-place air voids for mixtures at the optimum asphalt binder content. An insignificant amount of fatigue cracking is evident in two of the sections at 2.8 million ESALs. The "fine plus" gradation section (section 10) with significant fatigue cracking is at high initial air void content and low asphalt binder content.

"Coarse" Gradation Mixtures. Figure 15 shows the relationship between fatigue cracking and initial in-place air voids for mixtures at the optimum asphalt binder content. Fatigue cracking increases significantly as air void content go from low to high at this binder content. The relationship between fatigue cracking and asphalt binder content at medium air void content is shown on Figure 16. An increase in the amount of fatigue cracking is evident as binder content decreases.

TABLE 8
FATIGUE CRACKING OF ORIGINAL SECTIONS FOR
MONITORING SESSION 29 (ESAL LOADING = 2.8 MILLION)

Test Section Number	Entire Test Lane % Fatigue Cracking	Left Wheelpath % of Wheelpath Fatigue Cracking	Right Wheelpath % of Wheelpath Fatigue Cracking
1	0	0	0
2	7	14	0
3	5	5	5
4	0	0	0
5	51	82	20
6	100	100	100
7	0	0	0
8	96	100	92
9	0	0	0
10	34	67	0
11	1	1	0
12	1	2	0
13	0	0	0
14	0	0	0
15	0	0	0
16	1	1	0
17	3	5	0
18	0	0	0
19	0	0	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
24	0	0	0
25	0	0	0
26	68	100	36

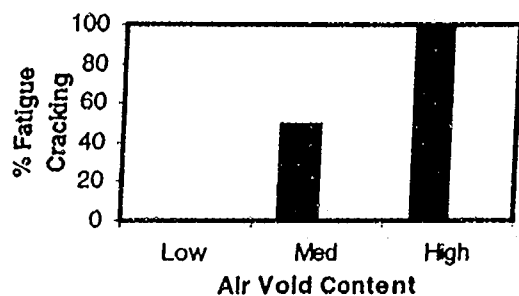


Figure 15. Coarse gradation at optimum asphalt binder content- Dayton Aggregate ESALs=2.8 Million

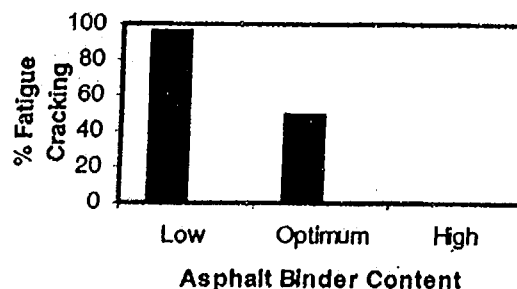


Figure 16. Coarse gradation at 8 percent air voids- Dayton Aggregate ESALs=2.8 Million

Comparison of Gradations. Figure 17 shows the relationship between fatigue cracking and gradation at the optimum asphalt binder content and medium initial in-place air voids; Figure 18 shows the same relationship at low asphalt binder contents. As shown in both figures, the "coarse" gradation section had the largest amount of fatigue cracking.

In general, the relative performance of all of the sections was as one would expect, e.g., low asphalt content, high air void mixes were the first to show fatigue cracking, and high asphalt content mixes tended to rut first. Unexpectedly, however, the "fine" gradation mixes performed better in terms of both rutting and fatigue than did the "coarse" gradation mixes. The very early rutting failures of the replacement sections were also very surprising, and the investigation into the causes is continuing.

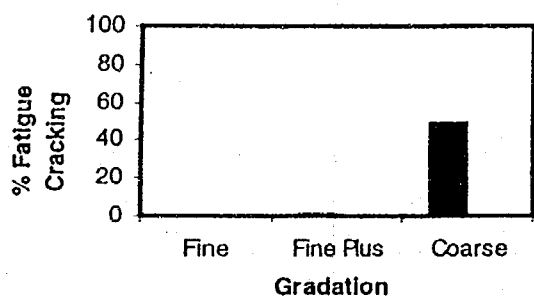


Figure 17. Optimum asphalt binder content at 8 percent air voids- Dayton Aggregate ESALs=2.8 Million

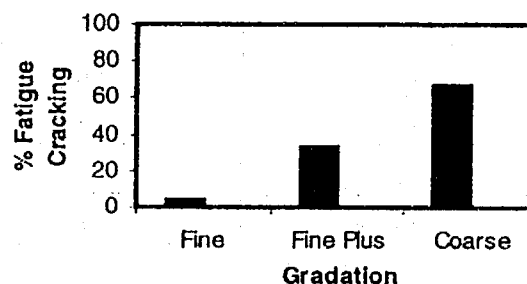


Figure 18. Low asphalt content at 12 percent air voids- Dayton Aggregate ESALs=2.8 Million

MATERIALS SAMPLING AND TESTING

Table 9 presents an overview of the extensive materials sampling and testing program associated with the WesTrack project. Sampling and testing associated with preconstruction, construction, and postconstruction phases of the project are identified.

Preconstruction Sampling and Testing. Preconstruction testing included determination of asphalt binder and aggregate properties as well as mixture design and performance prediction testing. Both Superpave and conventional asphalt binder properties were determined as previously discussed.

**TABLE 9
OVERVIEW OF MATERIALS AND SAMPLING
AND TESTING**

Project Phase	Purpose	Type of Test
Preconstruction	Asphalt Binder Properties	Superpave; Conventional
	Aggregate Properties	Superpave; Conventional
	Mixture Design	Superpave Volumetric; Hveem; Marshall
	Performance Prediction	Permanent Deformation; Fatigue; Thermal Cracking; Moisture Sensitivity
Construction	Material Properties	Superpave; Conventional
	Process Control and Quality Assurance	Asphalt Content; Aggregate Gradation; Volumetrics; In-place Air Voids
	Performance Prediction	Permanent Deformation; Fatigue; Thermal Cracking; Moisture Sensitivity
Postconstruction	Performance Prediction	Permanent Deformation; Fatigue; Thermal Cracking; Moisture Sensitivity

The Superpave volumetric design method was used for establishing the optimum asphalt binder content and aggregate gradation. Limited Hveem and Marshall mix design tests were also performed during the mixture design process.

Performance prediction testing is scheduled on the laboratory mixed-laboratory compacted samples. SHRP-developed test methods will be used. The repeated shear at constant height test performed using the Superpave Shear Tester (SST) will be the primary prediction test for permanent deformation or rutting. Beam fatigue tests will be used for fatigue or alligator cracking prediction. The modified Lottman test (AASHTO T 283) will be performed on gyratory compacted samples to determine moisture sensitivity.

Construction Sampling and Testing. The major purposes of construction sampling and testing were to control the construction process, to ensure that the mixtures produced were near their target values (quality assurance) and to determine material properties that could be used for performance prediction. Field mixed-laboratory compacted samples will also be used for performance prediction testing.

Postconstruction Sampling and Testing. The primary purpose of postconstruction sampling and testing is to characterize the field mixed-field compacted samples for performance prediction purposes. Materials have been or will be sampled at the following intervals: immediately after construction (within one or two weeks); after approximately 12 months of trafficking; and at the end of the service life of each failed pavement section.

PERFORMANCE PREDICTION

Mechanical characterization and performance prediction of the hot-mix asphalt are being performed at Oregon State University (OSU) and the University of California, Berkeley (UCB). Developments at UCB in the area of prediction of permanent deformation and fatigue are discussed in this section.

General Approach. Predicted responses of the WesTrack pavements to traffic loading are established using multilayer elastic analyses incorporating seasonal variations in the stiffness characteristics of the unbound layers and temperature

variations in the HMA sections, all of the variations are incorporated in the analysis by backcalculation from falling weight deflectometer (FWD) measurements.

The critical response for fatigue is the maximum principal tensile strain on the underside of the asphalt concrete layer. For rutting in the HMA, both maximum shear stress and the corresponding shear strain at a 50-mm (2-in) depth below the edge of a tire are utilized. The portion of the rutting contributed by the untreated pavement components is determined using computed vertical compressive strains at the subgrade surface.

Accumulations of damage are computed using the linear sum of cycle ratios for fatigue (extent of cracking) and the time-hardening hypothesis for rutting (rut depth).

Permanent Deformation. Permanent deformation characteristics of the mixes in the test pavements are being evaluated using the repeated load simple shear test at constant height (RSST-CH). The majority of tests have been performed on cores taken at the time of construction for both original 26 sections and the sections placed in June 1997. The shear tests have been performed at a temperature of 50°C [the critical temperature for WesTrack (4)] using a shear stress of 69 kPa (10 psi) applied in a haversine wave form with a time of loading of 0.1 sec and a time interval between loading of 0.6 seconds. A series of tests have also been performed on laboratory-compacted mixes representative of Sections 5 and 24 at 40°C, 50°C, and 60°C over a range in shear stresses from 42 kPa (6 psi) to 60 kPa (10 psi).

For each of the tests, a curve of the form:

$$\gamma^l = a n^b \quad (1)$$

where:

- γ^l = permanent shear strain
- n = stress repetitions
- a, b = experimentally determined coefficients

is to fit to the data for $n=100$ onwards as shown in Figure 19. In addition, the shear modulus is determined from the recoverable strain at $n=100$ repetitions.

From the test program using laboratory-compacted specimens representative of the mix in Sections 5 and 24, a curve of the following form was determined to be representative of the test data over the range in stresses and temperatures investigated.

$$\gamma^l = 1.262 \exp(0.0487\tau) \gamma^e n^{0.36} \quad (2)$$

where:

- τ = applied shear stress
- γ^e = elastic or resilient strain

The purpose of these tests is to provide input to a performance prediction model for permanent deformation estimation. The results of such an effort will serve as the basis for the development of pay factors which can be used in performance-related specifications for HMA construction.

Three alternative approaches to permanent deformation modeling have been utilized thus far: 1) regression modeling; 2) mechanistic-empirical modeling with correlation to laboratory (RSST-CH) data; and 3) mechanistic-empirical modeling based on laboratory data.

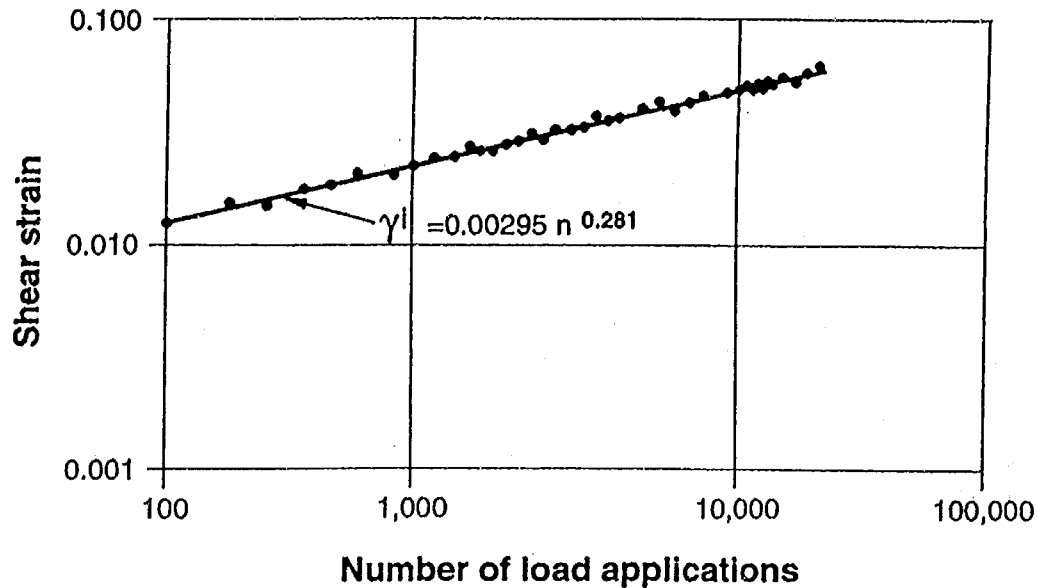


Figure 19. Permanent shear strain vs. load repetitions at 50°C and 69 kPa shear stress; test specimen from Section 18

The regression modeling provides a direct approach in that the ESALs to a specific rut depth, e.g., 19-mm (0.75-in.), can be estimated from an equation of the form:

$$\ln(\text{ESAL}_{0.75}) = a_0 + a_1 \cdot ac + a_2 \cdot av + a_3 \cdot ac^2 + a_4 \cdot av^2 + a_5 \cdot ac \cdot av + a_6 \cdot \text{fines} + a_7 \cdot \text{fines plus} + a_8 \cdot \text{coarse} \quad (3)$$

where:

ac	=	asphalt content, percent
av	=	air void content, percent
a_0 - a_8	=	regression coefficients
coarse	=	{ 1 for the coarse gradation; 0 for the fine gradation; 0 for the fine plus gradation }
fines	=	{ 1 for the fine gradation; 0 for the fine plus gradation; 0 for coarse gradation }
fines plus	=	{ 1 for the fines plus gradation, 0 for the fine gradation; 0 for the coarse gradation }

This approach has the advantage that it permits a direct development of pay factors for rutting. It has the disadvantage that it does not make use of laboratory determined mix parameters or of analysis methodology to predict the development of rutting with load applications.

The second and third procedures involve mechanistic-empirical modeling, which does permit a determination of rutting development as a function of traffic. This method will be briefly described herein and some comparisons of predictions using this procedure and actual rutting measurements are presented.

In the mechanistic-empirical procedures, rutting in the HMA is assumed to be controlled primarily by shear deformations. Computed elastic shear stress and strain at a depth of 50-mm (2-in.) beneath the edge of the tire are used as rutting determinants. Densification within the asphalt concrete is excluded since it has a minor effect on surface rutting.

In simple loading, permanent strain in the asphalt concrete is assumed to accumulate according to the following:

$$\gamma^I = a \cdot \exp(b\tau) \gamma^e n^c \quad (4)$$

where:

- γ^I = permanent (inelastic) shear strain at a 50-mm (2-in.) depth
- τ = shear stress determined at this depth using elastic analysis
- γ^e = corresponding elastic shear strain
- n = number of axle load repetitions
- a, b, c = regression coefficients

The time-hardening principle was used to estimate the accumulation of inelastic strains in the asphalt concrete under in-situ conditions. The resulting equations are as follows:

$$a_j = a \cdot \exp(b\tau) \gamma_j^e \quad (5)$$

$$\gamma_j^I = a_j [\Delta n_j]^c \quad (6)$$

$$\gamma_j^I = a_j [(\gamma_{j-1}^I / a_j)^{(1/c)} + \Delta n_j]^c \quad (7)$$

where:

- j is the j^{th} hour of trafficking
- γ_j^e is the elastic shear strain at the j^{th} hour, and
- Δn is the number of axle load repetitions applied during the j hour.

To simplify the calibration process, b was assumed to equal 0.0487, a value determined earlier from laboratory testing.

The Asphalt Institute subgrade strain criterion was the basis for simulating permanent deformation within the unbound layers. The subgrade strain criterion for 13-mm (0.5-in) surface rutting is:

$$N = 1.05 \cdot 10^{-9} \epsilon^{-4.484}$$

where:

- N = the allowable number of repetitions
- ϵ = the compressive strain on the top of the subgrade

The Asphalt Institute subgrade strain criterion does not address rutting accumulation in the pavement structure. For this analysis, rut depth, rd , was assumed to accumulate as follows:

$$rd = an^b \quad (8)$$

At the limit, then,

$$0.5 = a[1.05 \cdot 10^{-9} \epsilon_c^{-4.484}]^b$$

To prevent simulated rut depths from exceeding measurements, the 13-mm (0.5-in) limit was replaced by 10-mm (0.4-in). The exponent, b , was assumed to be 0.40. In subsequent work, other assumptions will be tested as necessary. The time hardening principle was used, this time to simulate the accumulation of rutting in the unbound layers. The relevant equations are as follows:

$$a = 0.4/[1.05 \cdot 10^{-9} e^{-4.484}]^{0.4} \quad (9)$$

$$rd_i = a[\Delta n_i]^{0.4} \quad (10)$$

$$rd_j = a_j[(rd_{j-1}/a_j)^{(1/0.4)} + \Delta n_j]^{0.4} \quad (11)$$

A calibration process determined the constants in the following equations:

$$a(\text{asphalt concrete}) = \exp(c_0 + c_1 \cdot ac + c_2 \cdot av + c_3 \cdot \text{fines} + c_4 \cdot \text{coarse}) \quad (12)$$

and

$$c(\text{asphalt concrete}) = d_0 + d_1 \cdot ac + d_2 \cdot av + d_3 \cdot \text{fines} + d_4 \cdot \text{coarse} \quad (13)$$

where:

- ac = asphalt content, percent
- av = air void content, percent
- fines = { 1 for fine gradation; 0 for coarse gradation; 0 otherwise }
- coarse = { 1 for coarse gradation; 0 for fine gradation; 0 otherwise }

Data for thirteen WesTrack sections¹ were considered simultaneously in this calibration which used the nonlinear curve-fitting capabilities of Microsoft Excel. The calibrated equations follow:

$$a(\text{asphalt concrete}) = \exp(-1.06222 - 0.82763 \cdot ac + 0.03882 \cdot av + 3.284603 \cdot \text{fines} + 1.979371 \cdot \text{coarse}) \quad (14)$$

and

$$c(\text{asphalt concrete}) = -0.10322 + 0.133529 \cdot ac - 0.00512 \cdot av - 0.36161 \cdot \text{fines} - 0.14705 \cdot \text{coarse} \quad (15)$$

Rutting due to shear deformation within the asphalt concrete layer was then determined from the following expression:

$$\text{rut depth} = K \gamma_j^1 \quad (16)$$

where:

$$k = 5.5 \text{ for a 150-mm (6-in.) layer of HMA}$$

The framework for this procedure is shown in Figure 20 and representative results of this analysis are shown in Figures 21, 22, and 23. In those figures, actual and predicted rut depth versus time are shown for sections 4, 7, and 25 respectively.

Although this model is quite useful in quantifying the progression of permanent deformation and in developing appropriate construction pay factors, it is not useful more generally because it is applicable only to the specific WesTrack mix components (asphalt and aggregate) and aggregate gradations.

¹The sections selected were those with no fatigue cracking at the time of rutting measurement.

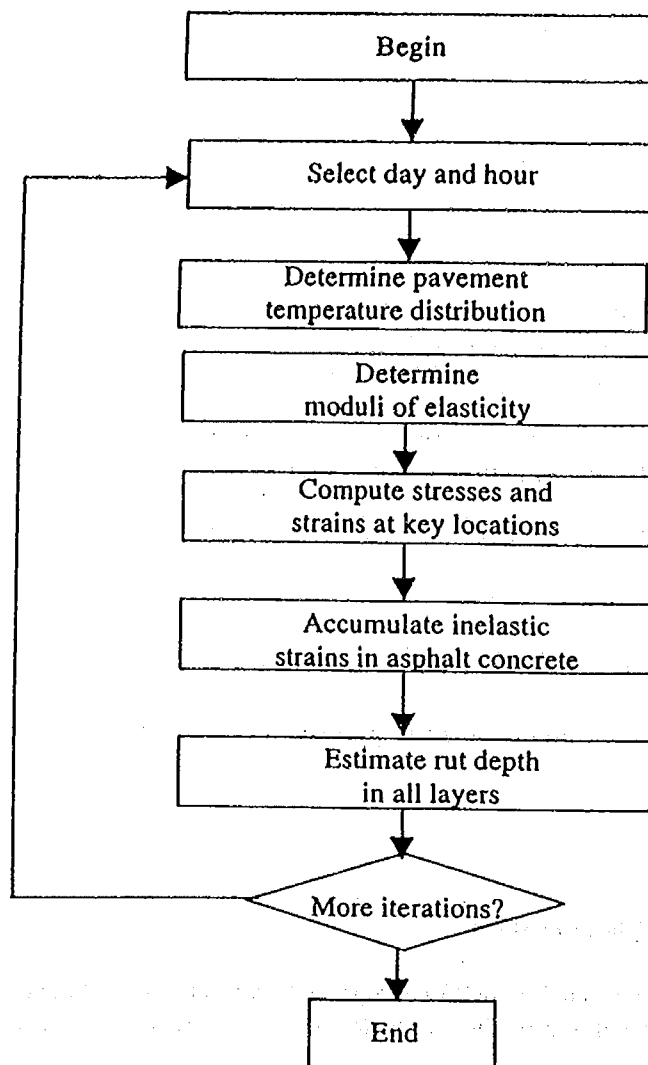


Figure 20. Framework for estimation of sample rut depth

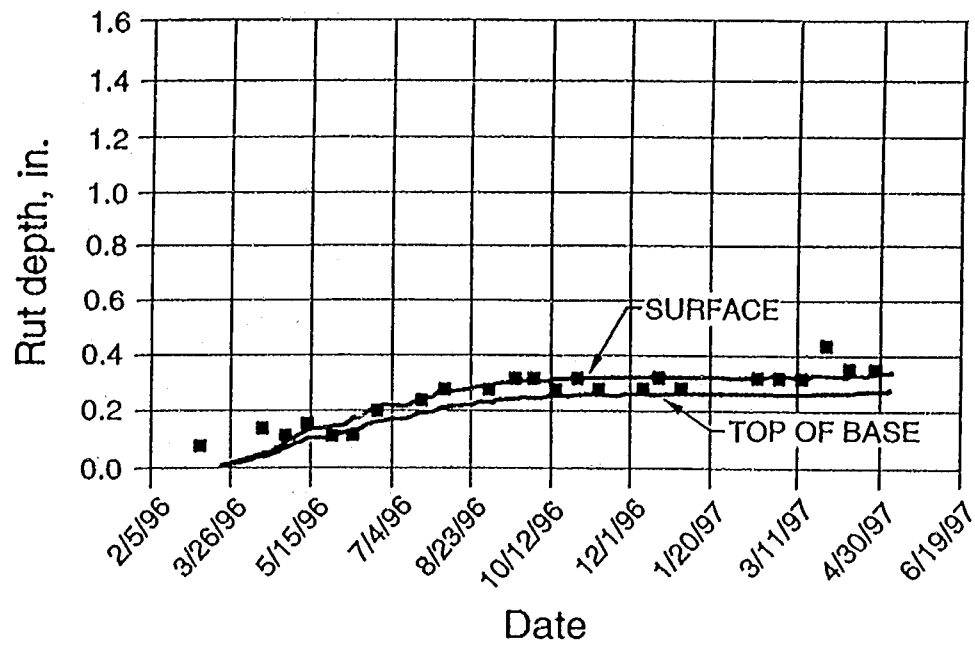


Figure 21. Rut depth vs. time (traffic), Section 4

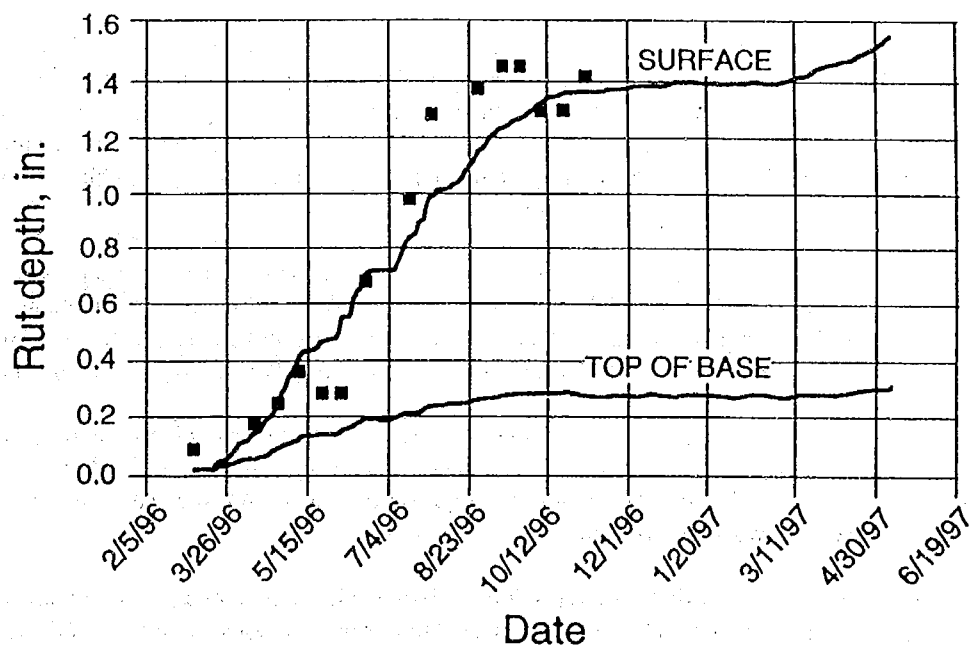


Figure 22. Rut depth vs. time (traffic), Section 7

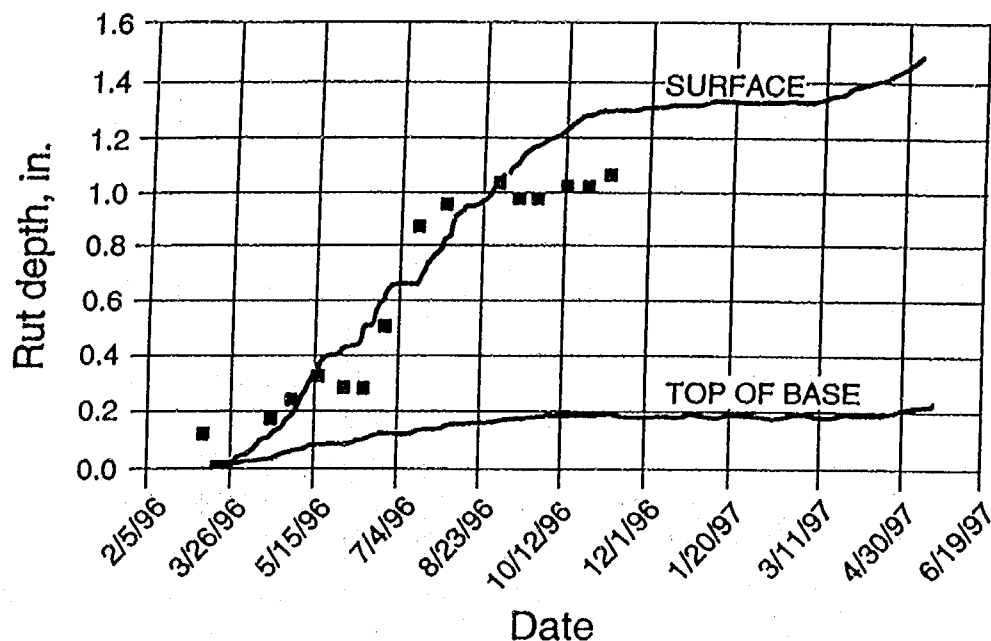


Figure 23. Rut depth vs. time (traffic), Section 25

In subsequent analyses, it is planned to use the results of the RSST-CH tests to capture the effects of mix variables. Accordingly, it is planned to develop a calibration using RSST-CH test results as independent quantities instead of asphalt content, air void content, and aggregate gradation used in the above approach.

Fatigue Cracking. The approach used to predict fatigue cracking is similar to that described in Reference (5). The approach includes several components: flexural fatigue testing of the HMA performance predictions based on the models developed as part of SHRP (6) but extended to efficiently treat in-situ temperatures (4); calibrated to the CALTRANS flexible-pavement design methodology (7); and extended to incorporate construction variability (8). The refined models have been used previously in interpreting the results of the California heavy vehicle simulator (HVS) testing from pavement sections in the CAL/APT program.

The system specifically considers the means and variances of the following HMA construction quantities: asphalt binder content, air void content, and HMA layer thickness. Results of WesTrack will allow aggregate gradation effects to be included. Damaging strains under traffic loading are determined using multilayer elastic system theory. The performance model computes the distribution of pavement fatigue lives using Monte Carlo simulation techniques.

The Monte Carlo process is outlined schematically in Figure 24. Central to this process is the random selection of air void content, asphalt binder content, and asphalt concrete thickness for each simulation. Although not shown in Figure 24, a random selection is also made of the foundation modulus representing the composite effects of base, subbase, and subgrade layers in an "equivalent" two-layer system.

These random selections assume normally distributed random variables with known or assumed means and variances. Of particular significance are the variances that might be expected under normal construction operations. Estimates of these variances were obtained from a combination of literature review, moduli backcalculations from FWD measurements, and data collected as part of the WesTrack project.

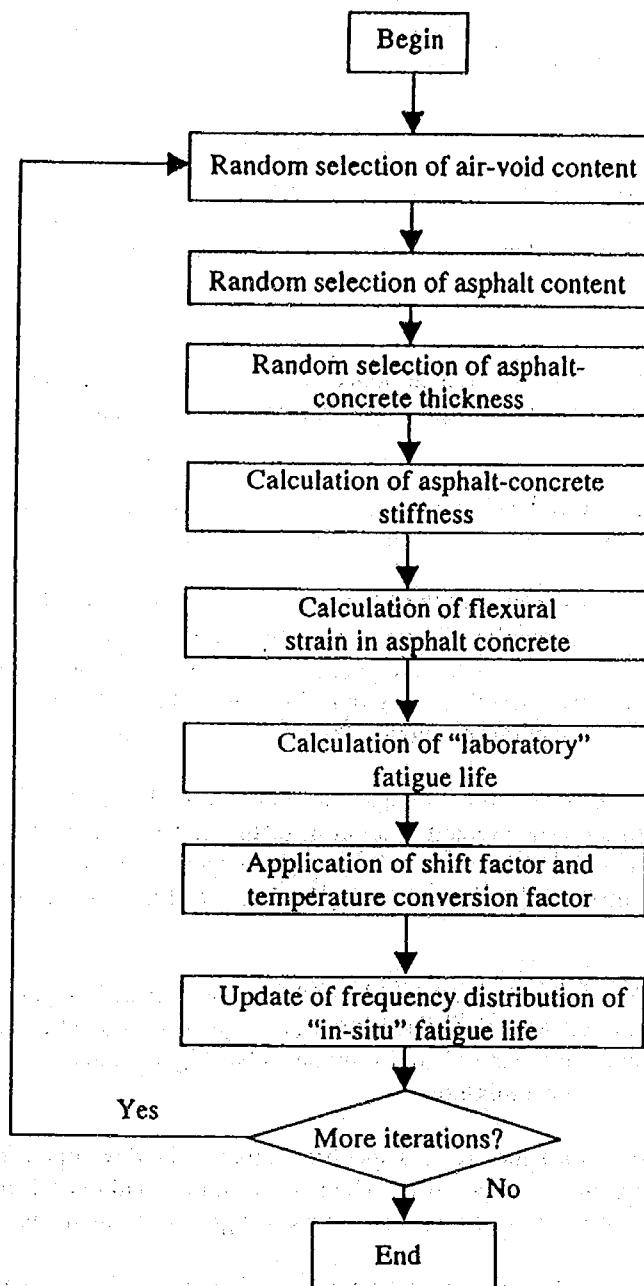


Figure 24. Outline of the pavement performance model simulation

A multilayer elastic program is used to simulate the stress and strain states within the simulated pavement structures. Loading consists of a dual-tire assembly representative of the trucks used at WesTrack. Stiffnesses and fatigue response for mixes in each of the test sections are being developed for use in the analyses.

Each of the Monte Carlo simulations produces an independent estimate of the laboratory fatigue life, N . The corresponding simulated in-situ life, *in-situ reps*, is computed by applying a shift factor, SF , and a conversion factor, CF , representing the combined effects of temperature and subgrade stiffness variations as follows:

$$\text{In-situ reps} = (N \cdot SF) / CF \quad (17)$$

The shift factor is an empirically derived factor that accounts for differences between the laboratory and the in-situ pavement in the rate at which fatigue damage accumulates with each load application. Observed cracking in the various test sections will permit the development of this factor for the WesTrack environment.

SUMMARY AND CONCLUSIONS

A 3-km (1.8-mi) full scale pavement test track has been designed and constructed and is presently under operation near Reno, Nevada. Four driverless trucks are used to traffic the pavements and are capable of accumulating approximately 350,000 ESALs per month.

The primary purpose of the test track is to develop a performance-related specification for hot-mix asphalt and to provide early field verification of the Superpave volumetric mixture design process.

The test track consists of 26 test sections, each 70-m (230-ft) in length. The original 26 sections placed were constructed with a single asphalt binder and a single primary aggregate. Three gradations were placed ("fine," "fine plus," and "coarse"). For each gradation, three levels of asphalt binder content and three levels of initial in-place air voids were placed. Five replicate test sections were also placed. During rehabilitation of the track, a second aggregate and asphalt binder source were utilized to place eight sections of another "coarse" graded mixture.

Extensive sampling and testing and performance monitoring are associated with the project. Information on rutting and fatigue performance has been presented. The greatest amount of rutting has been associated with the high asphalt content mixtures. In general, the high air void content mixtures also experienced slightly higher rutting. The test sections containing "coarse" graded mixtures had higher rut depths than the "fine plus" graded and the "fine" graded hot-mix asphalt mixtures.

The largest amount of fatigue cracking was associated with those mixtures placed at initial high in-place air void contents. Mixtures at low asphalt binder contents also experienced more fatigue cracking than mixtures at higher asphalt binder contents. The test sections containing "coarse" graded mixtures had higher amounts of fatigue cracking than the "fine plus" and "fine" graded hot-mix asphalt mixtures.

Performance prediction models and performance-related specifications will be developed from results from the test track. Extensive laboratory test programs are in progress. The reason for the relative performance differences of the mixtures at WesTrack are awaiting the results of the laboratory test programs and analysis.

According to the present schedule, the loading will be completed in mid-summer of 1998 at approximately 5.5 million total ESALs. Performance monitoring and sampling will continue during this period. Laboratory testing, analysis, and report preparation will continue through April 1999.

ACKNOWLEDGMENT

The authors wish to express their appreciation to several members of the WesTrack team for their efforts in accomplishing the research.

From Nichols Consulting Engineers, we would like to acknowledge Weston Ott, Magdy Mikhail, and Carol Chiappetta for their efforts in project coordination, data collection and processing, analysis and overall technical support. From the University of Nevada, Reno, we would like to express our appreciation to Adam Hand and Peter Sebaaly for their respective efforts in laboratory testing/mix design and instrumentation. From the University of California at Berkeley, we would like to recognize John Harvey for his work in SHRP Superpave testing and prediction model development. From Nevada Automotive Test Center, we would like to thank Paul Pugsley for his work in contract management and oversight of driverless vehicle research and truck loading. Lastly, we especially want to recognize the advice and support of all the FHWA personnel who have been involved, particularly Ray Bonaquist, John D'Angelo, and Chris Williams.

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2.5 Accelerated Pavement Testing in the United States

- 1 ☒ Accelerated Pavement Testing
In the United States
- 2 ☒ Full-Scale Test Tracks
 - North Carolina Test Road
 - Minnesota Test Road
 - Ohio Test Road
 - WesTrack
- 3 ☒ Linear Tracks - States
 - Texas
 - Kansas
 - Ohio
 - Louisiana
 - California
 - Florida - Pending
- 4 ☒ Linear Tracks - Federal
 - Federal Highway Administration
 - Corps of Engineers - Cold Regions Research Engineering Laboratory
 - Corps of Engineers - Waterways Experiment Station
 - Federal Aviation Administration
- 5 ☒ North Carolina Test Road
- 6 ☒ Test road location
- 7 ☒ Experimental Section Layout
- 8 ☒ Features
 - LTPP SPS-2
 - 14 Sections
 - Normal and High Strength PCC
 - Permeable AC, Lean PCC, DGAB, AC Base
 - With and without edge drains
 - Thickness of surface and base
 - 3.7 m vs. 4.3 m lane widths
- 9 ☒ Table 1
- 10 ☒ Status
 - Constructed 1994
 - ~500,000 ESALs per year

- Some cracking developing
- Annual evaluations continue
- Instrumentation and weather data
 - 4 sections instrumented
 - Weather station installed

11 ☒ Minnesota Test Road (Mn/ROAD)

12 ☒ Mn/ROAD

- Located along I-94, 65 km northwest of Minneapolis
- 4.8 km mainline, 4 km low volume loop, total of 40 test sections
- Vary thickness of AC, PCC, and Aggregate
- Constructed 1993-94
- Cost
 - \$25 million initial
 - \$3 million per year to operate

13 ☒ Traffic

- Mainline section
 - Trafficked by Interstate 94 westbound traffic
 - 14,000 vehicles per day
 - 15% trucks
- Low volume section
 - Mn/DOT operated trucks

14 ☒ Major Emphasis

- Freeze-thaw
- Drainage
- Pavement mix design
- Instrumentation
- LTPP GPS 1, 2, and 3

15 ☒ Instrumentation - 4572 Sensors

☒ 1

- LVDT
- Accelerometers
- Tilt meters
- Strain gauge
- Clip gauge
- Pore water pressure
- Resistivity

☒ 2

- Time Domain Reflectometer
- Tipping Bucket
- Neutron Probe
- Weigh-in-motion

- Weather station

16 ☒ Ohio Test Road

17 ☐ Ohio Test Road

- Joint effort of Ohio DOT and consortium of Ohio Universities
- Located northwest of Columbus, OH
- LTPP SPS 1, 2, 8, and 9
- Cost \$12.9 million
- Variables
 - Thickness of surface
 - Thickness of base
 - 5 base types
 - Drainage

18 ☐ Instrumentation

☒ 1

- Strain
- Pressure
- Displacement
- Joint opening
- Weather station
- Weigh-in-motion

☐ 2

- Temperature
- Moisture
- Frost depth
- Soil suction
- Water table elevation

19 ☒ Ohio Accelerated Pavement Load Facility

20 ☐ Ohio Accelerated Pavement Load Facility

- Joint effort of Ohio DOT and consortium of Ohio Universities
- Located at University of Ohio
- Based on Purdue design
- Constructed by ARA/Vertek
- 40-130 kN wheel loads
- Full environmental control
- Wheel speed 8 km/hr

21 ☒ Louisiana Pavement Research Facility (PRF)

- 22 ☐ Louisiana PRF
- Operated by Louisiana Department of Transportation and Development and Louisiana Transportation Research Center
 - ALF apparatus
 - Constructed 1995
 - Cost \$1.8 million
 - Outdoor facility
 - Located in floodplain near Baton Rouge, Louisiana
 - Test lanes built above water table
- 23 ☐ ALF Capabilities
- 40-80 kN wheel load
 - Operating speed 20 km/hr
 - 380 passes per hour
- 24 ☐ Instrumentation
- Deflection
 - Strain at layer interface
 - Pressure
 - Temperature
 - Moisture
- 25 ☐ Studies
- Compared soil cement and aggregate base combinations - 9 sections
 - 4 vs 10 percent cement content
 - Plant vs field mixing of soil cement
 - Soil cement only
 - Aggregate base only
 - Combination of soil cement and aggregate
- 26 ☐ California CAL-APT
- 27 ☐ CAL-APT
- Operated by California Department of Transportation and University of California - Berkeley
 - Operating two refurbished HVS
 - One field application
 - One controlled laboratory facility
 - Constructed 1994
 - Cost \$1.75 million
- 28 ☐ HVS
- 20-100 kN wheel load
 - 12 km/hr wheel speed

- 950 passes/hr
- 29 ☐ Instrumentation
 - Strain
 - Surface deflection
 - MDD
 - Thermocouples
 - Moisture content
 - Crack activity meter
- 30 ☐ Field Testing
 - PCC pavement, Route 14 near Palmdale, CA
 - Examining
 - Rapid set concrete
 - Load transfer devices
 - Thickness
- 31 ☐ Lab Testing
 - Bituminous pavement
 - University of California - Berkeley Richmond Field Station
 - Examining mix design parameters in conjunction with WESTRACK
 - Effect of channelized traffic
 - Fatigue of rubber-bitumen mix
- 32 ☒ Indiana - InDoT-Purdue APT
- 33 ☐ InDoT-Purdue APT
 - Operated by Indiana Department of Transportation and Purdue University
 - Environmentally controlled building and test pits
 - Vary temperature and water table
 - Cost \$140,000
- 34 ☐ Device
 - Designed by Purdue University
 - 91 kN maximum wheel load
 - 8 km/hr wheel speed
 - 1333 passes/hr
- 35 ☐ Instrumentation
 - Strain
 - Temperature
- 36 ☐ Studies
 - Effect of crushed rock in bituminous concrete

- Validation of Superpave mix design
- Tire type
- Tire pressure
- Effect of drainage

37 ☒ Kansas Accelerated Testing Lab (K-ATL)

38 ☐ K-ATL

- Operated by Kansas Department of Transportation and Kansas State University
- Environmentally controlled building and test pit
- Vary temperature and water table
- Constructed 1996

39 ☐ Device

- 178 kN maximum wheel load
- Load controlled by air pressure in axle suspension
- 11 km/hr wheel speed
- 300 cycles/hr
- Tandem axle
- Wander is manual
- Pulse load capability for PCC joints

40 ☐ Instrumentation

- Temperature
- Moisture (TDR)

41 ☐ Studies Conducted

- Cold in-place recycling
- Load transfer devices
 - Steel dowel bars
 - Proprietary fiber dowel bars
 - X-FLEX
- Superpave vs Marshall mix

42 ☐ Studies Underway

- Steel vs composite dowels
- Environmental controls used to induce curling

43 ☒ Texas Mobile Load Simulator (TxMLS)

44 ☐ TxMLS

- Operated by Texas DOT and Center for Transportation Research

- Field applications
- Easily transported between field sites
- Potential to apply loading 20X faster than other APT devices
- Constructed 1995
- Cost \$2.5 million

45 ☐ Device

- 22.2-111.2 kN single wheel load
- 32 km/hr wheel speed
- 6000 axle loadings per hour
- Uses actual truck bogies, axles, and suspensions
- Six truck bogies on chain drive

46 ☐ Planned Studies

- Load equivalency
- Remaining life and rehabilitation
- New pavement materials
- Superpave
- Truck-pavement interaction

47 ☐ Florida

48 ☐ Florida's APT

- Plan to purchase in 1999
- Planned studies
 - Superpave mix design validation
 - Superpave construction procedures
 - Monolithic-composite concrete pavement design
 - Effect of moisture on layer moduli
 - PCC repair techniques

49 ☐ U. S. Army Corps of Engineers
Cold Regions Research Engineering Laboratory (CRREL)

50 ☐ CRREL

- HVS Mark IV
- Housed at Frost Effects Research Facility for environmental control
- 110 kN wheel load
- 200 kN aircraft wheel load
- 11,000 passes per day

51 ☐ Studies

- Study of basic subgrade parameters for pavement design

- CRREL, FHWA, Cornell University, Road and Traffic Laboratory of Finland, and Minnesota Department of Transportation
- Goal - Global subgrade model for AASHTO 2002 Pavement Design Guide
- Variation of tire pressure on performance of low volume roads

52 ☒ U. S. Army Corps of Engineers Waterways Experiment Station (WES)

53 ☒ WES - BIGFOOT

- HVS-Aircraft
 - Wheel loads up to 440 kN
 - Dual aircraft tires
 - Length 119 feet
 - 300 repetition per hour
 - 3 m wander capability
- Delivery November 1998

54 ☐ Planned Studies

- Validation
 - Mechanistic design models
 - Pavement performance models
 - Performance related specifications
- Evaluate
 - Polymer modified bituminous concrete
 - Resin modified pavements
 - Synthetic ties
 - Ballast material

55 ☒ Federal Aviation Administration
National Airport Pavement Test Machine

56 ☐ FAA

- Joint project of FAA and Boeing began in 1992
- Develop/verify design methodology for new aircraft
- Located at the FAA William J. Hughes Technical Center, Atlantic City, New Jersey
- Constructed in 1998
- Startup December 1998

57 ☒ *Self-healing concrete*

58 ☒ *Self-healing concrete*

59 ☐ Device

- Fully enclosed to minimize environmental affects

- building 380 X 31 X 12 m
- **Test Vehicle**
 - 23 x 30 m
 - 4900 kN, 330 kN wheel loads
- **2 - 6 wheel gear configuration**
 - Boeing 777, 5300 kN aircraft
- **8-24 km/hr operating speed (taxi)**

60 ☐ **Test Pavement**

- **Test pads 275 X 18 m**
- **9 test items**
 - 3 subgrades
 - 3 PCC thicknesses
 - Base/subbase combinations under AC
- **Instrumentation 1,130 sensors**

61 ☐ **How**

- **Design / Build Contract**
- **DMJM / Cornell Joint Venture**
 - Weidinger for foundations
 - CTL for pavement instrumentation
 - Design Projects International and Cornell for Test Vehicle Design
- **Army Corps of Engineers, Philadelphia District, for project management**

62 ☐ **How Much**

- **\$21 million contract**
 - \$14 million FAA
 - \$7 million Boeing
- **\$1 to \$3 million continuing annual costs (depending on reconstruction)**

63 ☐

64 ☐

65 ☐

66 ☐ **Coordination**

- **FHWA's Accelerated Pavement Testing Expert Task Group (ETG)**
- **Accelerated Pavement Testing User's Group**
- **TRB Task Force on Accelerated Pavement Testing (A2B52)**

67 ☐ **FHWA's ETG**

- **Superpave validation**

- Binder
- Mix design
- Models
- Experiment design
- Quality control
- Data collection
- Combine capabilities of all facilities

68 ☐ Task Force

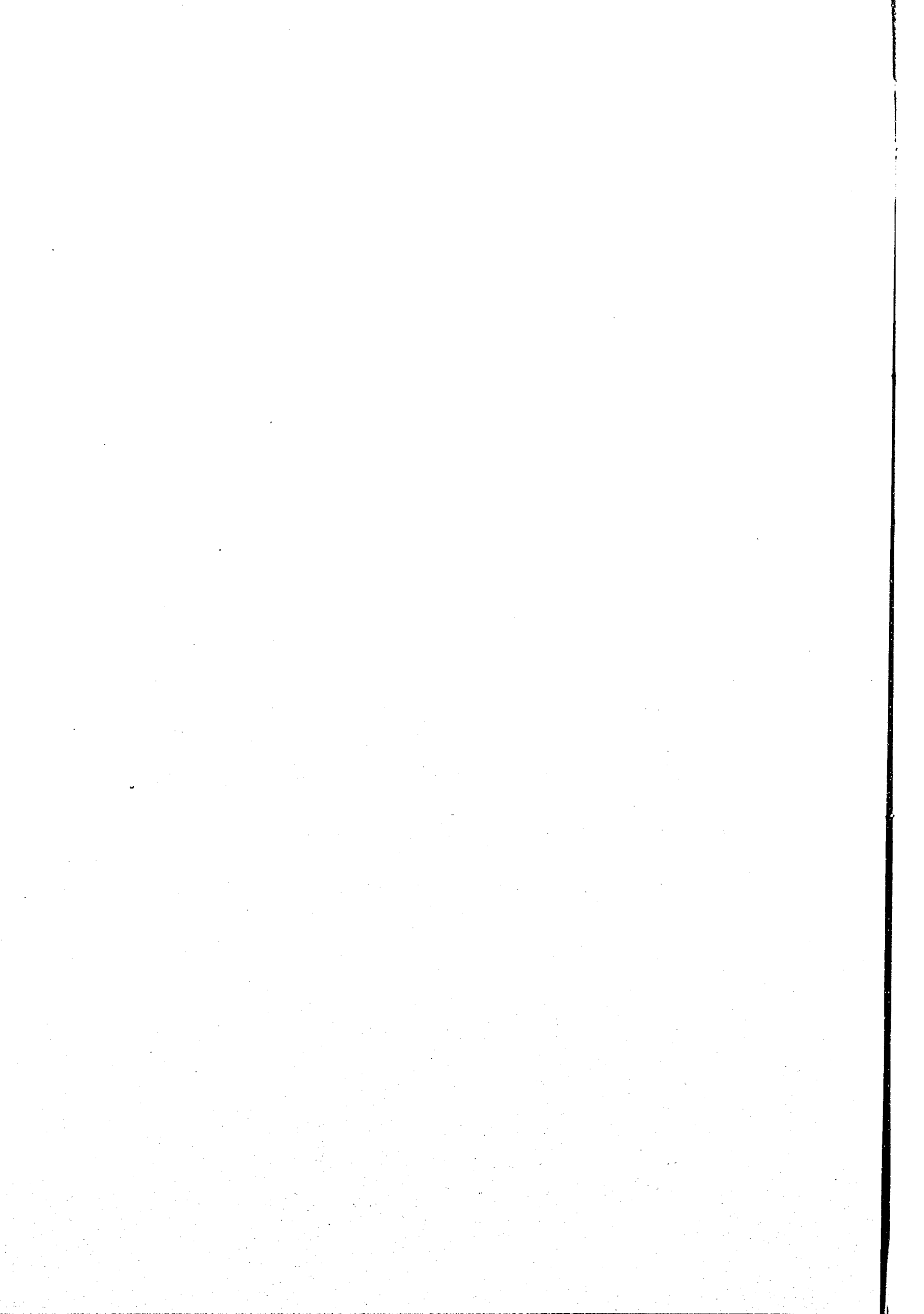
- TRB Circular on world wide APT efforts
 - Standard measurements
 - Standard failure criteria
 - Ongoing Testing
- On TRB Website by January 1999

69 ☐ International Conference

- October 18-20, 1999
- Reno, Nevada

3. Suspension

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Regulation of Axle Load Now and Future



Paul Teng, P.E.
Chief, Pavement Division
Federal Highway Administration

CURRENT LIMITS



- Gross Weight = 36,290 kg (80,000#)
- Single Axle Weight = 9,070 kg (20,000#)
- Tandem Axle Weight = 15, 420 kg (34,000#)

ON GOING STUDY



Comprehensive Truck Size and Weight Study

Background

Study Goal

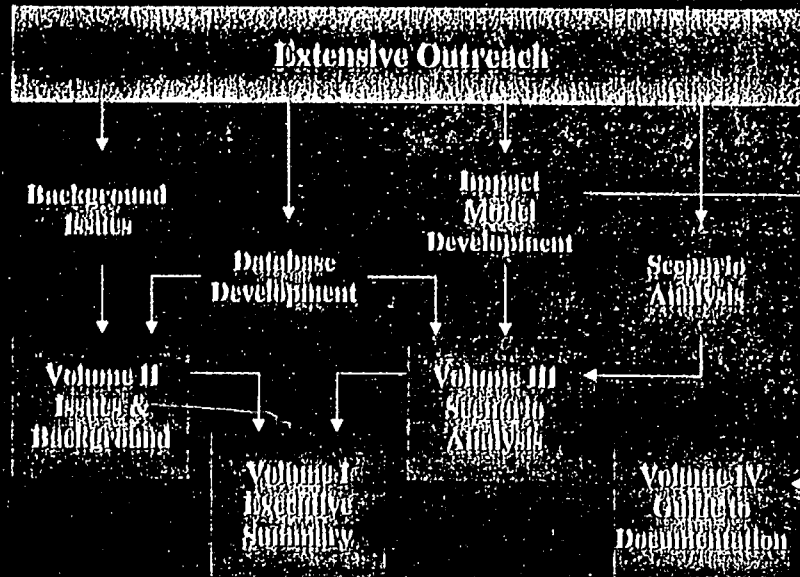
**Support the Decision Process
At Federal and State Levels**

**To Evaluate Truck Size and Weight Policies
that Ensure *Safe* and *Efficient* Freight
Movement on North American Highways in
an *Intermodal* Context.**



Background

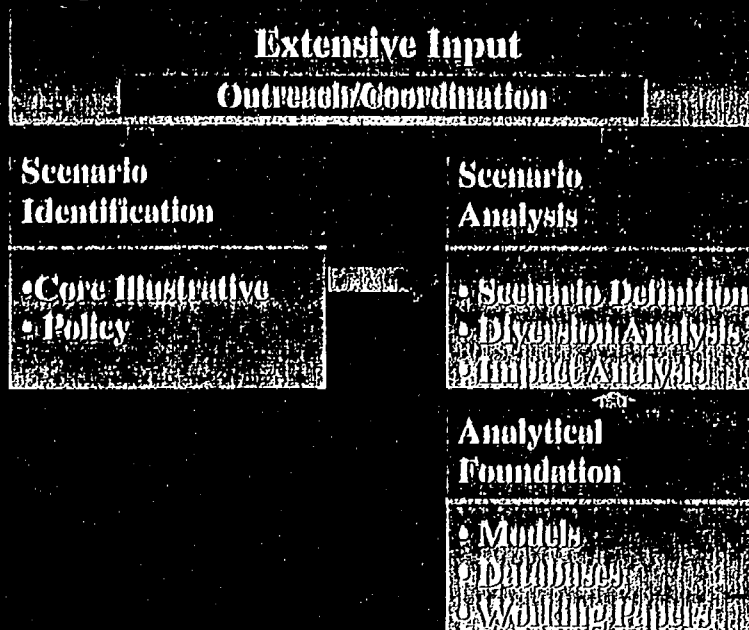
Study Overview



The Department of Transportation's Comprehensive Truck Size and Weight Study

Background

Analytical Overview



The Department of Transportation's Comprehensive Truck Size and Weight Study

Status

Timeline

- **Draft Volume II Distributed, June 1997**
- **Initiated TRB Peer Review Effort, January 1998**
- **Impact Model Review Conference, July 1998**
- **Draft Volume III distributed, Summer 1998**
- **State Videoconference, Summer 1998**
- **Final Report to Congress, Fall 1998**



The Department of Transportation's Comprehensive Truck Size and Weight Study

3.2 Evaluation of Air Suspension

Evaluation of Air Suspensions

Effects of Vehicle Suspension

Dynamic Interaction between
Vehicles and Infrastructure,
DIVINE

- Scientific study of the effects of vehicle dynamics on pavements and bridges



Federal Highway Administration
Truck/Pavement Interaction



Dynamic loading affects pavement performance.

- Thick Pavements (160 mm, bituminous):
 - 10% Increase in dynamic wheel load 7-12 % increase in strain and significant increase in pavement wear.
- Thin Pavements:
 - Horizontal strain less sensitive to dynamic wheel load



Federal Highway Administration
Truck/Pavement Interaction



Dynamic loading affects pavement performance.

- Under mixed traffic dynamic loads tend to concentrate at points (typical intervals 8-10 metres).
- On a smooth road the cumulative sum of axle loads is 10% greater.
- On a rough road at least twice as large.



Federal Highway Administration
Truck Pavement Interaction



Magnitude of Dynamic Loading Depends on:

- Suspension type.
- Profile of the road.
- Vehicle speed.



Federal Highway Administration
Truck Pavement Interaction



Suspension Type

- Smooth roads:
 - Steel suspension, Impact factor = 1.3
 - Air suspension, Impact factor = 1.1-1.15
- Rough roads:
 - Steel suspension, Impact factor = 1.4-1.5
 - Air suspension, Impact factor = 1.2



Federal Highway Administration
Truck Pavement Interaction



Pavement wear can be reduced using air suspension.

- Pavement profile deteriorates faster under steel suspension.
- Some cracking and rut depth were greater under steel suspension.
- Pavement wear 15% greater under steel suspension.



Federal Highway Administration
Truck Pavement Interaction



Vehicle dynamics also affect bridges.

- Bridge surface profile and approach fundamental to suspension response.
- Smooth profile, suspension is insignificant, as roughness increases importance of suspension increases.



Federal Highway Administration
Truck Pavement Interaction



Vehicle dynamics also affect bridges.

- Medium span (20-70 metres):
 - Smooth profile, dynamic response small for steel and air suspension.
- Short span (10 metres):
 - Poor profile, large dynamic response for steel and air suspension.



Federal Highway Administration
Truck Pavement Interaction



Air Suspensions can be "Road-Friendly."

Road-friendly suspensions isolate the vehicle from road roughness to minimize dynamic loading.

DIVINE results: "There is a strong agreement frequency and damping characteristics of suspensions are key attributes of road-friendliness."



Federal Highway Administration
Truck/Pavement Interaction



Air Suspensions can be "Road-Friendly."

- "It is necessary to control dynamic road loading in both low-frequency body modes and high-frequency axle modes."
- DIVINE results showed most profile changes were related to low-frequency body modes.



Federal Highway Administration
Truck/Pavement Interaction



Air Suspensions can be "Road-Friendly."

- In low-frequency modes air suspensions generally have lower natural frequencies and higher damping than steel suspensions. These characteristics can result in significantly less dynamic loading providing the damping is maintained.



Federal Highway Administration
Truck/Pavement Interaction



Air Suspensions can be "Road-Friendly."

- Air suspensions do not necessarily have improved performance in the high-frequency axle modes and again require adequate damping.
- Air and steel suspensions can "tune" with bridge vibrations in specific parts of the spectrum of bridge frequencies, damping and profile conditions and vehicle speed.



Federal Highway Administration
Truck/Pavement Interaction



Air Suspensions can be "Road-Friendly."

- Under specific conditions for short span bridges, air suspensions can produce high-frequency responses.
- Suspensions need to be tested for road-friendliness.
 - European Community, frequency 1.5 Hz or less, damping of 20% or more.



Federal Highway Administration
Truck/Pavement Interaction



3.3 Damage Potential of Wide Base Single Tires

Damage Potential of Wide Bases Single Tires

Assessment of Wide Based Single Tires on Pavement Performance

Objective: Evaluate the relative damage potential of wide based single tires versus dual tires through a comparative analysis of pavement performance (rutting and cracking).

Research was conducted at FHWA's, Turner Fairbank Highway Research Center, Accelerated Loading Facility, 1989-1991.

Test Parameters

- 11R22.5 radial tire in dual configuration
 - Load rating of 23.45 kN per tire, 47.16 kN for the pair.
- 425/65R22.5 wide based single tire
 - Load rating of 46.71 Kn.
- Four test sections for response.
- Four test sections for performance.

Test Parameters

- Two thickness of asphalt pavements:
 - 89 mm asphalt concrete, 25 mm surface course and 64 mm binder course over 305 mm of crushed aggregate base.
 - 178 mm asphalt concrete, 51 mm surface course and 127 mm binder course over 305 mm of crushed aggregate base.

Test Parameters

- Pavement temperatures: low, moderate and high (winter, spring, summer)
- Loading: 41, 54, 64, 71 kN.
- Tire pressure: 520, 712, 959 kPa.
- Instrumentation: Horizontal strain at the bottom of the asphalt concrete layer, average vertical strain in asphalt, crushed aggregate base and upper 152 mm of subgrade and pavement temperature

Results

- The 425/65R22.5 wide based single tire was significantly more damaging to conventional flexible pavements than traditional 11R22.5 dual tires.
- For the same load and tire pressure the wide based single tire produced higher vertical compressive strains in all layers of the pavement and highest tensile strains at the bottom of the asphalt concrete layer.

Results

- Increased strains translate into greater rutting and shorter fatigue life for pavements trafficked with wide based single tires.
- Pavements tested using the wide based single tire exhibited ruts approximately twice as deep as those for the dual tires and the fatigue life of the pavement trafficked by the wide based single tire was one quarter that obtained under dual tire loading.

4. Strategic Highway Research Program (SHRP)

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4.1 Collaborative Study on Gyratory Testing Machine

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Summary

The gyratory testing machine (GTM) has attracted interest as a new facility to replace the Marshall stability test. The Tsukuba Pavement Technology Exchange Group, a group of researchers from the Public Works Research Institute and 16 private companies in the road paving industry, conducted a collaborative study of GTMs to study differences in the compaction properties between different manufacturers. Significant differences in air voids in the mixtures were confirmed. The results also show that differences in the mechanisms used by various manufacturers to maintain the angle of gyration might be the cause of these differences. The differences between the compaction properties of GTMs manufactured by the same company are caused by human errors during the mixing work.

1. Introduction

A gyratory testing machine (GTM) compacts a specimen by applying gyration to the axis of a cylindrical specimen while it is under a load in the vertical direction. It is reported that the compaction mechanism is more similar to that of compaction by rollers at actual road construction sites than the compaction by a Marshall hammer. GTM was introduced as a standard compaction machine specified by SUPERPAVE. The compaction properties of mixtures are evaluated by GTM, when volumetric design is applied.

In Japan, porous asphalt concrete and stone matrix asphalt, which are not suitable for conventional compaction by Marshall hammers, have come into widespread use. Therefore, the paving industry has been anticipating the introduction of a testing machine like GTM with a compaction mechanism similar to that of rollers at road construction sites.

2. Objectives

GTM was first used in Japan for the following purposes:

- (1) To examine the SUPERPAVE mix design method
- (2) To introduce a compaction machine to be used for special mixtures such as porous asphalt concrete

The collaborative test was conducted in order to:

- (1) Study differences in the compaction properties of GTMs manufactured by different makers to clarify differences resulting from variations in the structures of these machines.
- (2) Study differences in compaction properties caused by human error and other factors.

3. GTM Specifications

The collaborative test was conducted as a part of the activities of the Tsukuba Pavement Technology Exchange Group (referred to as "TPT" hereafter). The Head of the Pavement Division of PWRI chairs this TPT, and its members consist of directors of the research laboratories of 16 private companies involved in road paving, while its secretary-general is the Senior Researcher of the Pavement Division of PWRI and 16 researchers from the participating companies also take part in the project. The companies taking part in the collaborative testing were 11 companies out of the TPT who purchased GTMs. The specifications of the GTMs of each company are shown in Table-1.

The basic specifications of GTM for SUPERPAVE are compaction pressure of 600 kPa, gyration speed of 30 rpm, and angle of gyration of 1.25 degrees. The table shows that all of the GTMs satisfied the basic specifications.

Table-1 Typical Specifications of the GTM made by Each Manufacturers

	RAINHART	TROXLER	PINE	BLE	NIKKEN
angle of gyration (deg.)	1.25	0.5 - 2.0	0.5 - 2.0	< 3.0	< 2.0
compaction pressure (kPa)	600	200 - 1,000	200 - 1,000	10 - 1,000	30 - 1,000
diameter of specimen (cm)	10, 15	10, 15	10, 15	10, 15	10.16, 15
speed of gyration (rpm)	30	30	30	6 - 60	10 - 60
preliminary loading function *1	×	×	○	×	×
reforming function *2	×	○	○	×	○
number of GTM	4 *3	3	1	1	2 *4

A detailed study of the compaction mechanism of each GTM revealed that there were differences between GTMs made by TROXLER and those made by other manufacturers. Figure-1 shows an outline of the compaction mechanism of TROXLER's GTMs of, while Figure-2 shows that of the other manufacturers. The principal difference is the method used to make an angle of gyration, 1.25 degrees, during compaction.

TROXLER's GTMs made by are equipped with a mechanism that maintains the angle of gyration by sliding the base that provides reaction force during compaction just enough to incline the mold at 1.25 degrees. The base itself gyrates during compaction.

$$dL = h \times \sin (1.25 \text{ degrees})$$

where,

dL: quantity of slide

h: distance from fixed point of loading ram to the base

The GTMs made by the other manufacturers are equipped with a mechanism that either pulls up or pushes up one of three rollers holding the mold just enough to incline at 1.25 degrees so that these rollers gyrate the mold at an inclination of 1.25 degree during compaction.

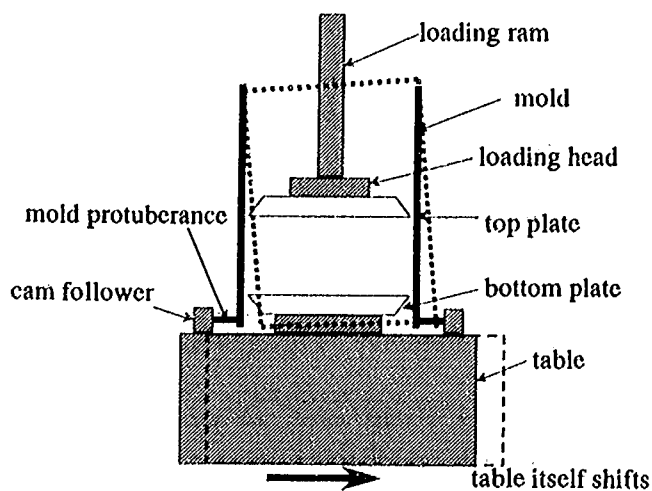


Figure-1 Compaction Mechanism of TROXLER' s GTM

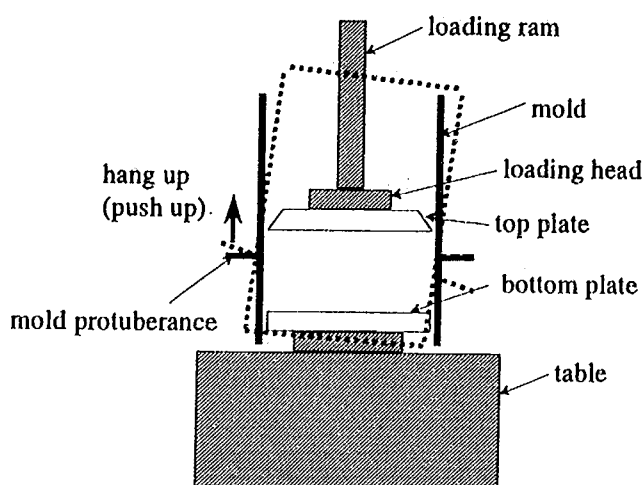


Figure-2 Compaction Mechanism of Other GTM

$$dh = d \times \sin (1.25 \text{ degrees})$$

where,

dh: quantity of displacement of mold protuberance

d: diameter of mold

In theory, both mechanisms can maintain 1.25 degrees. However, in the case of the GTMs not made by TROXLER, the shear stress, generated between the specimen and the mold during compaction, causes stress on the rollers that are either lifted up or pushed up the mold. The durability of the rollers might thus be a key issue in the test results.

4. Test Method

Table-2 shows the conditions of the collaborative test. In order to avoid the effect of variations in the materials, all participating laboratories used the same aggregates and binders prepared by PWRI. The mix design was also unified based on the conventional Marshall method. In the SUPERPAVE specifications, a mixer, which is enough to make asphalt mixture for one specimen, is recommended.

However, this mixer is not popular in Japan yet, so the mixing was done manually in accordance with the Marshall stability test method.

The compaction temperature of mixtures influences the compaction properties. After the mixing was manually done, the mixture was cured in a draft oven for 30 minutes at a temperature of 140 degree Celsius along with the mold in order to minimize the variability of the compaction temperature. Three specimens of each mix were prepared.

Table-2 Common Test Conditions

materials	aggregate, filler : standard materials used in PWRI asphalt : straight asphalt (60-80)
mixture type	dense-graded asphalt concrete(13) dense-graded asphalt concrete(20) fine-graded asphalt concrete(13)
mixture design	Marshall method
mixing procedure	method : manual for each specimen temperature : recommended temperature range by asphalt supplier spading process : 15 times for outskirts, 10 times for center
compaction condition	temperature : 140 degree C pressure : 600kPa angle for gyration : 1.25 degree gyration speed : 30rpm maximum number of gyrations : 360

5. Test Results

Figure-3 shows the relationship between the number of gyrations and the ratio of specific gravity to the theoretical maximum specific gravity in the case of a dense-graded asphalt mix (13) (referred to as "dense-grade 13" hereafter). The ratio is a percentage obtained by dividing the specific gravity of the asphalt mixture by the theoretical maximum specific gravity. The air voids of the asphalt mixture are obtained by subtracting this value from 100. This figure reveals that ELE's GTM always shows a high ratio while those of NIKKENs' show a consistently low ratio. No particular differences were observed between the results for different mixes. However, in the case of fine-grade asphalt mix (13) (referred to as "fine-grade 13" hereafter), when the number of gyrations of PINE's GTM passed 100, its tended to rise more rapidly than it did when the other GTMs were used.

Figure- 4 and 5 show the results for dense-grade 13 and fine-grade 13 respectively. The ratio here is an average of the results obtained by each manufacturer. Excepting the change in compaction properties obtained by PINE's GTM, no clear differences between compaction properties were revealed by these two figures. To determine the cause of the distinct compaction properties of fine-grade 13 tested by PINE's GTM, the compaction curves for the three specimens were examined. It was confirmed that one curve showed a sudden change in specific gravity at about 100 gyrations. If this single curve is eliminated as abnormal data, the results of PINE's GTM are close to those of the GTMs of RAINHART and TROXLER. Therefore, it is concluded that there is no difference in compaction properties between mixtures. The study focused on dense-grade 13 hereafter.

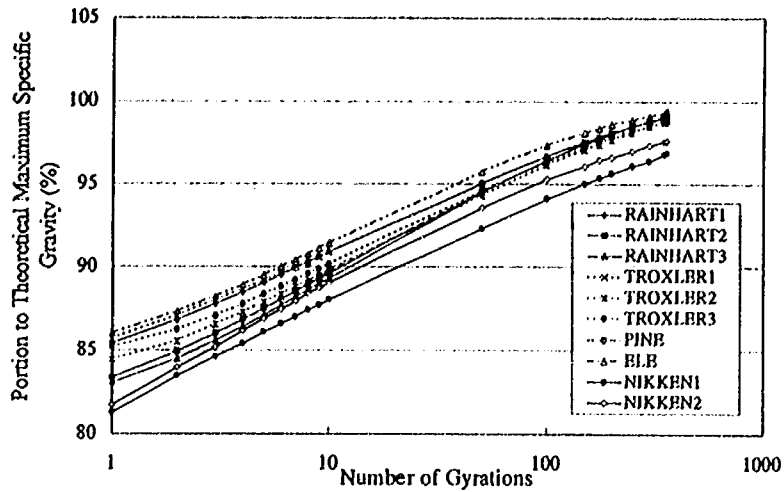


Figure-3 Portion to Theoretical Maximum Specific Gravity (dense-graded AC13)

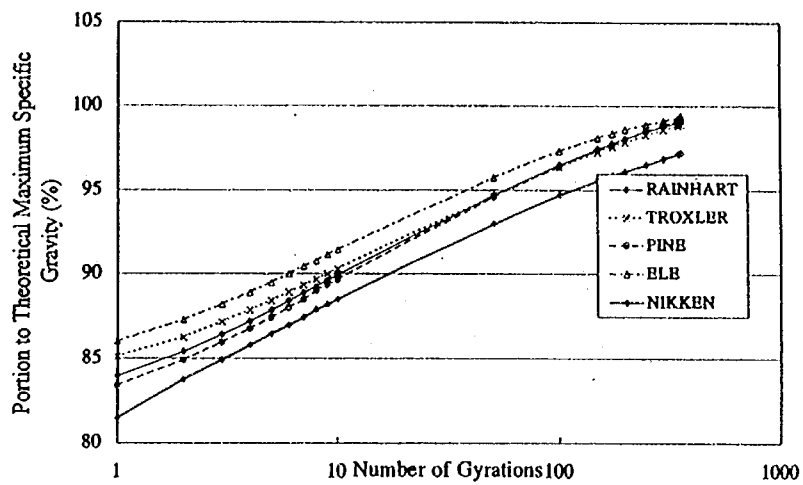


Figure-4 Portion to Theoretical Maximum Specific Gravity (dense-graded AC13, each manufacturers)

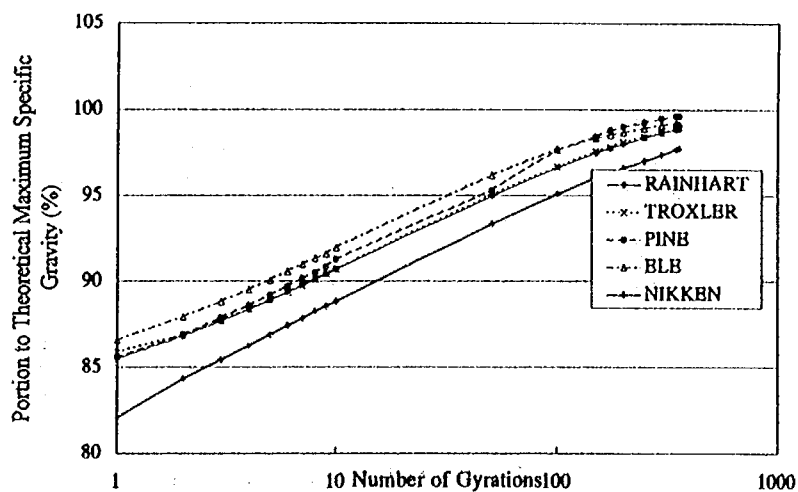


Figure-5 Portion to Theoretical Maximum Specific Gravity (fine-graded AC13)

Figure-6 compares the air voids at 100 gyrations to quantify differences in GTM compaction properties. Except for TROXLER3, the standard deviation of the air voids in the three specimens was found to be less than 0.1, revealing extremely good reproducibility. Figure-7 shows the results of an examination of the significant difference between manufacturers. This examination confirmed that the air voids obtained using the GTMs of RAINHART, TROXLER and PINE are almost identical. The air voids obtained using GTMs of ELE and NIKKEN are significantly different from the results obtained from the GTMs of other companies. With regard to the differences between GTMs of a single manufacturer, it is also confirmed that there were significant differences between RAINHART2 and RAINHART4, between TROXLER1 and TROXLER3, and between NIKKEN1 and NIKKEN2.

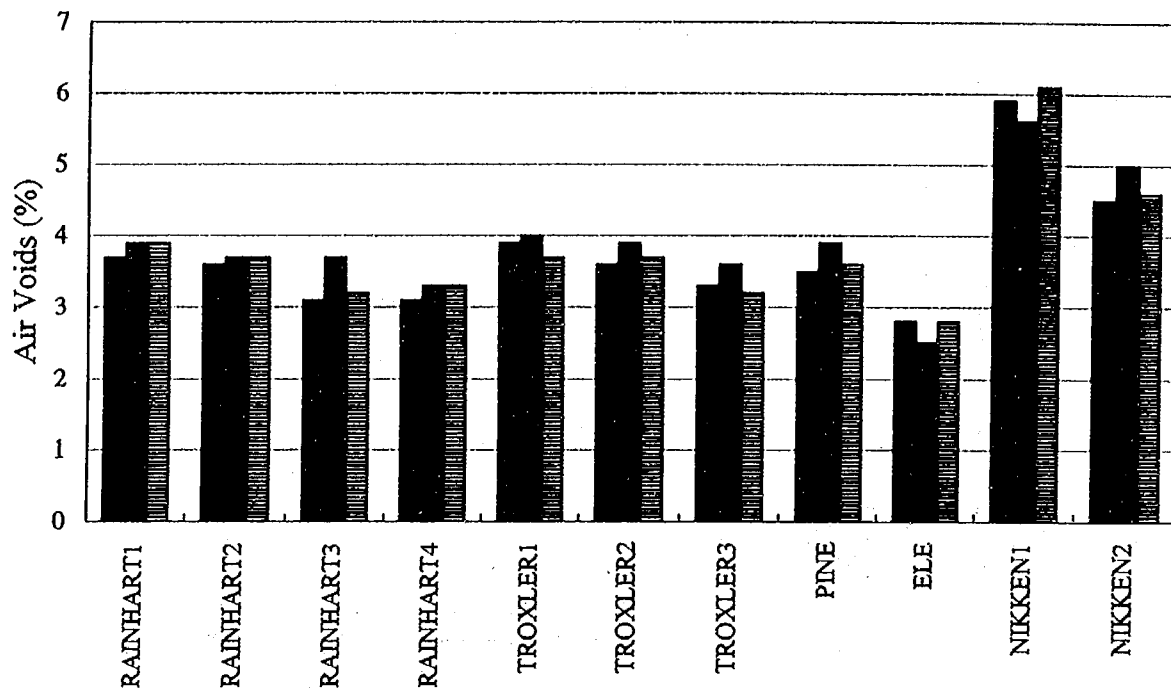


Figure-6 Air Voids at 100 gyrations (%)

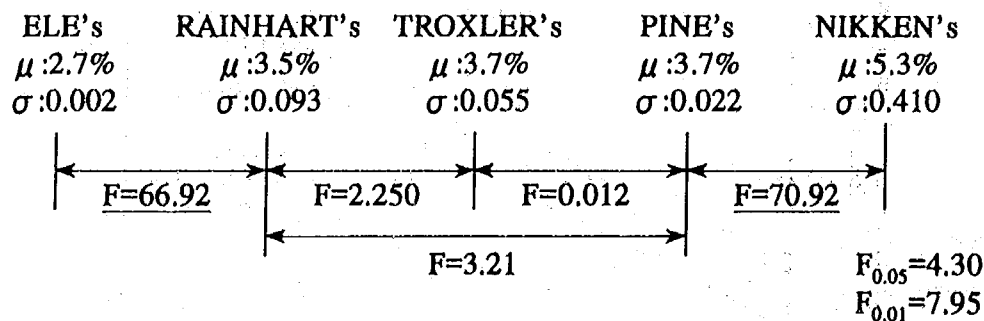


Figure-7 Examination of the significant difference

6. Considerations

This collaborative testing was undertaken to clarify the difference of the compaction properties of GTMs used in Japan in order to clarify significant differences between GTMs and laboratories. As stated in Section 3, "GTM Specifications", it is assumed that discrepancies among manufacturers are influenced by differences between the mechanisms used to maintain the angle of gyration at 1.25 degrees. While ELE's GTM uses air as a medium to transmit compaction pressure, the other GTMs use a hydraulic medium for this purpose. Fluctuation of the volume of the air as it is compressed in ELE's GTM might cause a time lag in compaction pressure control.

The degree of compaction by ELE's GTM tends to be higher than that of the other GTMs. The compaction pressure is set higher in ELE's GTM to compensate for the transmission loss resulting from the use of air as a medium. Another reason for the discrepancies is the decline in the temperature of the mixture during compaction. The temperature at the start of compaction was set uniformly at 140 degrees Celsius for this collaborative testing. Measurements of the surface temperatures of the specimens after compaction found considerable variability ranging from 58 to 87 degrees Celsius. It is assumed that this variability of the temperature was caused by differences such as the system used to maintain temperature, and mold thickness. As shown in Figure-8, almost no relationship was found between the surface temperature of specimens after compaction and the compaction density.

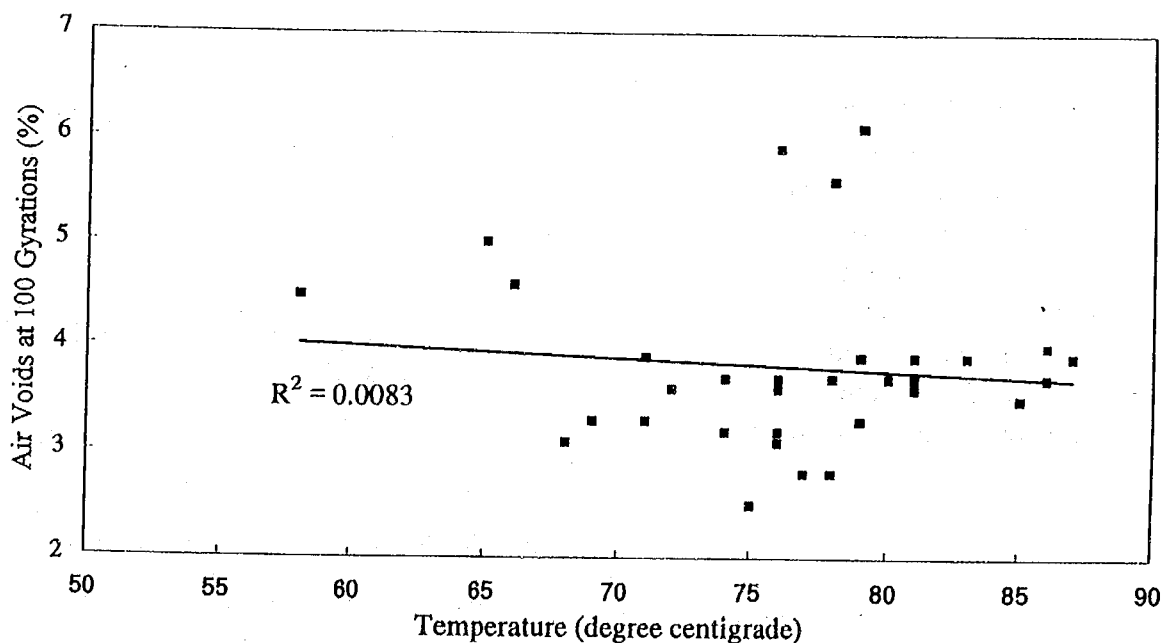


Figure-8 Temperature of Specimen after compaction and Air Voids

It is assumed that significant differences between GTMs from the same manufacturers are the results of individual machine discrepancies originating in the manufacturing process, machine adjustment errors, or human errors occurring during the testing. Since individual differences between GTMs are unavoidable to some extent, this study did not account for the difference. Parts of the work were seriously affected by human errors. This collaborative study was performed in conformity with the

Marshall stability test method. One of the principal objectives of the second part of the collaborative study will be to study human error. This will involve more detailed studies of the following factors that may affect the test results:

- Specimen size (diameters of 10 cm or 15 cm)
- Specimen temperature at start of compaction
- Mixing method (automatic, manual)
- Mix injection method
- Mix forming method

7. Conclusion

It is not clear how GTMs will be used in Japan in the future; GTMs are now being experimentally introduced in studies on SUPERPAVE mix design or the use of new materials. The SUPERPAVE system is superior to the Marshall stability test method, since GTMs reproduce conditions similar to actual roller compaction. Its use for test pavements to study new materials will, therefore, gradually increase. The first collaborative tests and subsequent tests will contribute to the widespread use of GTMs.

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4.2 Superpave Evaluation of Asphalt Binders in Japan

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Introduction

The SHRP project accelerated the development of new performance-based specifications for asphalt pavement. The studies on methods for evaluating the quality of asphalt binder are especially interesting since they have incorporated new ideas into evaluation standards and methods, such as viscoelastic models and performance requirements during asphalt pavement service conditions.

The Chemistry Division of the Public Works Research Institute, Ministry of Construction, has been investigating a new asphalt standard called SUPERPAVE that SHRP had proposed, and used SUPERPAVE for evaluating various kinds of straight and modified asphalt binders used in Japan. The institute worked on this project in cooperation with the Japan Asphalt Association and the Japan Modified Asphalt Association. Three visiting researchers from asphalt manufacturing companies also cooperated in test experiments. The research team had already published some of the study results in relevant journals and conferences¹⁾⁻²⁰⁾.

This report will examine our analyses of data that had been summarized in an Institute bulletin¹⁴⁾.

1. SUPERPAVE binder tests

1.1 Test methods

A flow chart of the SUPERPAVE evaluation is shown in Figure 1. The evaluation comprised aging tests and performance evaluation tests. The rest of this section describes the samples, methods, and evaluation items of the tests.

(1) Samples

(a) Original asphalt

Original asphalt samples were non-deteriorated samples collected immediately after the production or shipment of the asphalt (when users obtained the asphalt).

(b) TFOT asphalt

TFOT asphalt samples had been artificially deteriorated by the thin film oven test (TFOT) [JIS K2207, ASTM D 1754] treatment.

(c) RTFOT asphalt

RTFOT asphalt samples had been artificially deteriorated by the rolling thin film oven test (RTFOT) [ASTM D 2972] treatment.

(d) PAV asphalt

PAV asphalt samples had been accelerated aging by the pressure aging vessel (PAV) treatment.

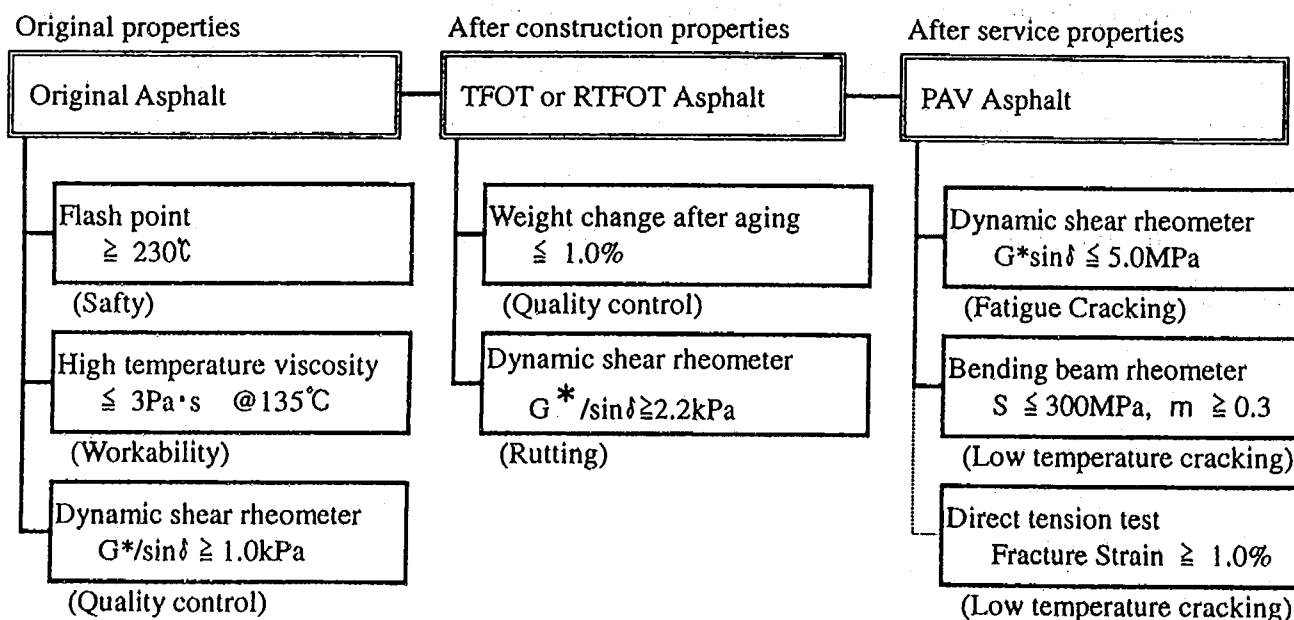


Figure 1 SUPERPAVE Evaluation Flow

(2) Aging test methods

(a) Thin film oven test (TFOT)

TFOT reproduces the heat aging that occurs when asphalt binder and aggregates are hot mixed in a mixing plant or during transportation or construction of asphalt mixture.

The aging test weighs 50 ± 0.5 g of an original asphalt sample, heats the sample on a plate at 165°C for 5 hours under atmospheric pressure. The aged asphalt sample is used for TFOT asphalt evaluation, and determines the change in mass.

(b) Rolling thin film oven test (RTFOT)

Rolling thin film oven test (RTFOT) also reproduces the heat aging during the hot mixing of asphalt binder and aggregates or during the transportation or construction.

The aging test weighs 35 ± 0.5 g of an original asphalt sample, heats the sample in a bottle at 163°C for 85 minutes under the atmospheric pressure. The deteriorated sample is used for RTFOT asphalt evaluation, and determines the change in mass.

The SUPERPAVE evaluation adopted us to use either TFOT or RTFOT. We concluded that the difference between these two tests is small⁷⁾, and decided to use TFOT in this study.

(c) Pressure aging vessel (PAV)

Pressure aging vessel (PAV) simulates the aging of asphalt pavement after 5 to 10 years of service. The test weighs 50 ± 0.5 g of the TFOT asphalt sample, which is heated on a plate at 100°C for 20 hours under the pressure of 2.07MPa. After the test, air babbles are removed in a vacuum oven especially in case of modified asphalt binders. The aged sample is used for PAV asphalt evaluation.

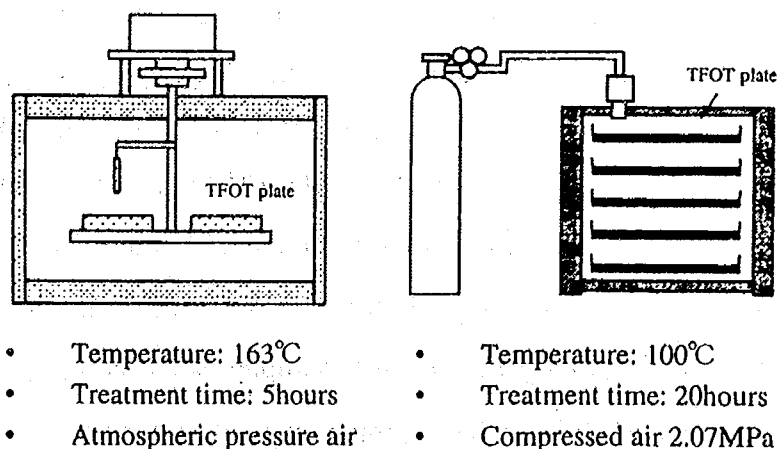


Figure 2 Outline of aging tests

(3) Evaluation items and test methods

(a) Flash point

Flash point is a factor determining the safety for handling asphalt binders.

The test procedure is the same as the present straight asphalt [JIS K 2207] in Japan. SUPERPAVE requires flash points to be no lower than 230°C.

(b) High temperature viscosity

High temperature viscosity (at 135°C) is a factor determining the workability (ease of handling) of asphalt binders during pumping or production of mixtures. SUPERPAVE stipulates that the viscosity at 135°C should be at least 3 Pa·s.

SUPERPAVE requires the viscosity to be measured at 135°C by using a rotary viscometer such as Brookfield and according to the high temperature viscosity measurement method [ASTM D 4402]. Since SUPERPAVE does not provide the shear rate, we measured in various shear rates for viscosity measurements.

(c) Dynamic shear rheometer

Dynamic shear rheometer determines the viscoelasticity of the original, TFOT, or PAV asphalt. SUPERPAVE assumes that there is a link between the viscoelasticity of asphalt and damage to the pavement in service. For original asphalt binders, SUPERPAVE provides that $G^*/\sin \delta$ at the time of manufacture should be at least 1.0 kPa to control the consistency. SUPERPAVE provides that $G^*/\sin \delta$ of TFOT asphalt samples should be at least 2.2 kPa to prevent rutting at high temperatures in service conditions. $G^*\sin \delta$ of PAV asphalt samples should be 5.0 MPa or lower to prevent fatigue cracks that may appear at room temperature on long-term pavement service.

Tests should be conducted by using a dynamic shear rheometer (DSR). Original asphalt and TFOT asphalt samples are prepared both 1 mm thick (gap) on a parallel plate of 25 mm in diameter. PAV asphalt samples are 2mm thick, and the parallel plate was 8 mm in diameter. The angular velocity is always 10 rad/s. SUPERPAVE checks if the asphalt binders meet the above requirements with temperatures controlled at 6°C intervals.

However, we used the following method. We measured the viscoelasticity at temperatures within 40 - 80°C (40 - 70°C for soft samples such as straight asphalt) at 10°C intervals. The measurement of PAV asphalt samples was at temperatures within 0 - 40°C at 10°C intervals.

(d) Bending beam rheometer

Bending beam rheometer determines the viscoelasticity at low-temperature of PAV asphalt samples. SUPERPAVE assumes that the S- and m-values are the viscoelasticity factors related to low-temperature cracks in long-term pavement service. For the requirements, S-values should not fall below 300 MPa and m-values should be at least 0.3 when they are measured at a loading time of 60 seconds of BBR testing. The S-value represents stiffness and is determined by the ratio of stress (σ) over displacement (γ), $S = \sigma / \gamma$, both of which fluctuate over time. On the other hand, the m-value is the rate of change in S-value along time, and $m = -d \log S / \log t$.

Tests should be conducted by using a bending beam rheometer (BBR). PAV asphalt samples are molded into bars of 125 mm $\times$ 12.5 mm $\times$ 6 mm in size by using metal molds. Measurement is conducted by applying a constant load of 100 gf for 240 seconds on the center of each sample placed on a support of 100 mm in span. SUPERPAVE checks if the samples satisfy the requirements at temperatures controlled at 6°C intervals.

However, we conducted bending beam rheometer tests at temperatures within -20 - -5°C at 5°C intervals in this study.

(e) Direct tension test

Direct tension tests are also for determining the elongation related to low-temperature cracks in service.

SUPERPAVE does not require direct tension tests when the S-value is 300 MPa or smaller in bending beam rheometer testing. Therefore, we conducted only bending beam rheometer in this study.

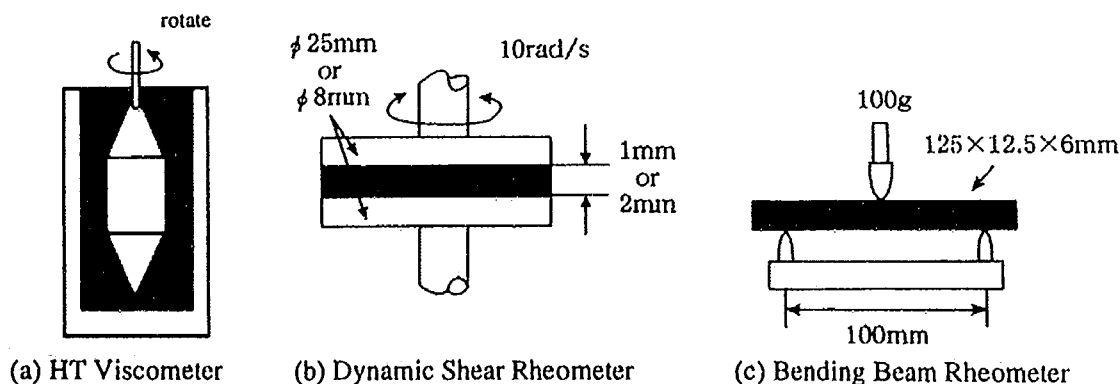
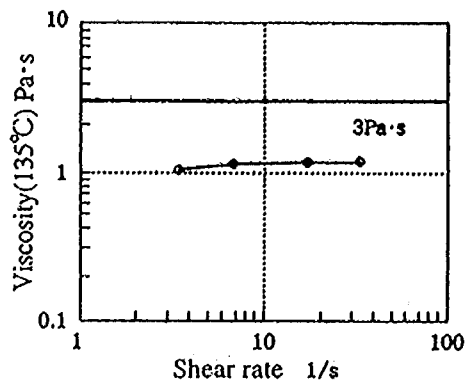
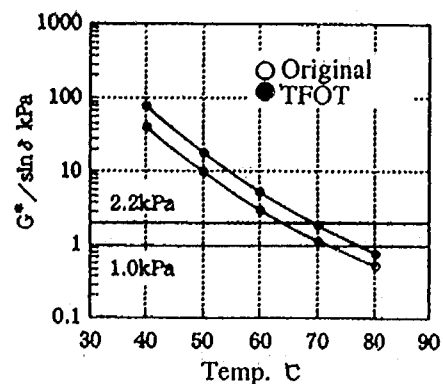


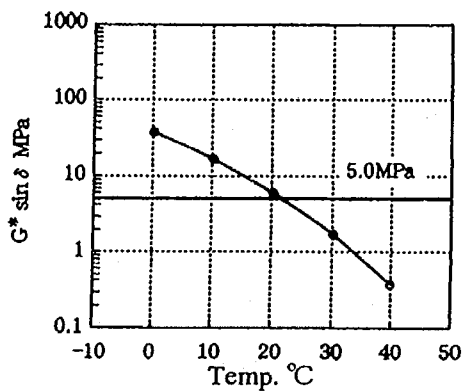
Figure 3 Outline of test methods of binders



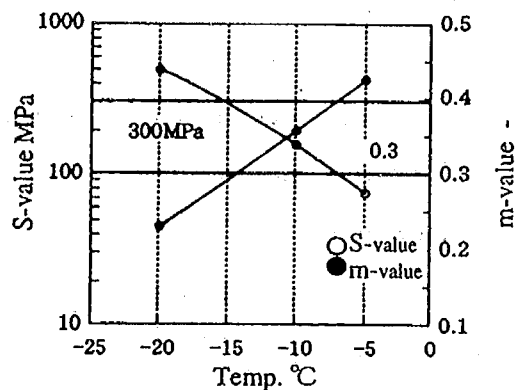
(a) HT Viscometer



(b) Dynamic Shear Rheometer, Org & TFO



(b) Dynamic Shear Rheometer, PAV



(c) Bending Beam Rheometer

Figure 3 Typical results of SUPERPAVE binder tests

1.2 Methods for evaluating performance grades

Instead of conventional specifications, SUPERPAVE classifies asphalt binders in terms of the temperature ranges where they best perform. Asphalt binders used in this temperature range are applicable to general pavement problems, such as rutting, fatigue cracks, and low temperature cracks. SUPERPAVE calls this classification "performance grade" (PG) since it considers the performance states, and expresses the grades as PG○-□ (where, ○ is the maximum and □ is the minimum temperatures for using the asphalt).

We determined Performance Grades in the following manner from the results of original, TFOT, and PAV asphalt samples. As shown in Figure 4, we conducted dynamic shear rheometer and bending beam rheometer tests at 10°C and 5°C intervals, respectively, and determined the temperatures by a degree satisfying the standard values by using regression formulas.

The temperature ranges derived by this evaluation are listed in Table 1. The maximum temperature for service is determined from the results of dynamic shear rheometer of the corresponding original and TFOT asphalt samples. The minimum temperature for service is determined from the result of bending beam rheometer of the PAV asphalt sample. The temperature value requirement is the minimum temperature for using the asphalt.

Table 1 Example of SUPERPAVE binder evaluations

Sample	Test item	Result	Allowable service temperature °C											
			-40	-20	0	20	40	60						
Original	Dynamic shear rheometer $G^*/\sin \delta \geq 1.0\text{kPa}$	71 °C												
TFOT	Dynamic shear rheometer $G^*/\sin \delta \geq 2.2\text{kPa}$	68 °C												
PAV	Dynamic shear rheometer $G^*/\sin \delta \geq 5.0\text{kPa}$	21 °C												
	Bending beam rheometer $S \leq 300\text{MPa}$ $m \geq 0.3$	* -15(-25) °C -14(-24) °C												
General evaluation (applicable service temperature)		-24 ~ 68												

*: 10°C lower than the temperature satisfying the bending beam rheometer requirement

1.3 Samples

The objective of this study is to evaluate the quality of pavement binders used in Japan with the SUPERPAVE evaluation method. Therefore, samples should reflect the standard usage in Japan. We collected samples from various kinds of asphalt binders sold in Japan by considering the following points.

We selected straight and semi-blown asphalt samples (60/80 penetration grade samples in the main) by considering the quantity of production, the crude type and so on. The Japan Asphalt Association provided us the samples. JIS and the Japan Road Association provide the same penetration grades and 60/80 is ordinal grade in Japan for reference.

We selected polymer-modified asphalt binders by referring to the price list issued by the Construction Research Institute. The Japan Modified Asphalt Association and some asphalt companies provided us with the samples. We evaluated these samples by classifying them into four groups: modified asphalt type I, type II, high-viscosity binders for porous asphalt pavement, and other modified asphalt binders. The Japan Road Association had established a quality guideline for modified asphalt types I and II and also modified binders for porous asphalt pavement in Japan, which are applied according to their properties.

Table 2 lists the kinds and numbers of samples tested.

Table 2 List of asphalt samples

Asphalt sample group	Number of samples
Straight asphalt 40/60	4
Straight asphalt 60/80	13
Straight asphalt 80/100	5
Semi-blown asphalt	2
modified asphalt type I	8
modified asphalt type II	10
High-viscosity binders for porous asphalt pavement	6
Other modified asphalt binders	4

2. Results

2.1 Original asphalt binders

(1) Flash points

Figure 5 plots flash points. In Figures 5 to 7, the black dots represent points measured, and the solid lines connect the maximum and minimum values. The flash points were cited from experimental data that asphalt companies had provided. The SUPERPAVE requirement is 230°C or higher. All samples satisfied this requirement since the conventional Japanese standard is at least 260°C.

(2) High temperature viscosity (135°C)

Figure 6 shows high temperature viscosity values measured with a rotary viscometer. We used a constant shear rate (34 s⁻¹) for straight asphalt, which is almost a Newtonian fluid at high temperatures and independent from shear rates. However, we used various shear rates for modified asphalt samples since SUPERPAVE provides no guidelines. Modified asphalt binders are not Newtonian fluid even at high temperatures, and the viscosity is usually higher for faster shear rates. The high temperature viscosity of modified asphalt binders should be determined by selecting a shear rate appropriate for usage.

The viscosity values in the figure are for a shear rate of 34 s⁻¹ (6.8 for high-viscosity modified asphalt). SUPERPAVE requires 3 Pa·s or lower. All but the high-viscosity modified asphalt met this requirement.

Straight asphalt 40/60
Straight asphalt 60/80
Straight asphalt 80/100
Semi-blown asphalt
modified asphalt type I
modified asphalt type II
Other modified asphalt
High-viscosity binder

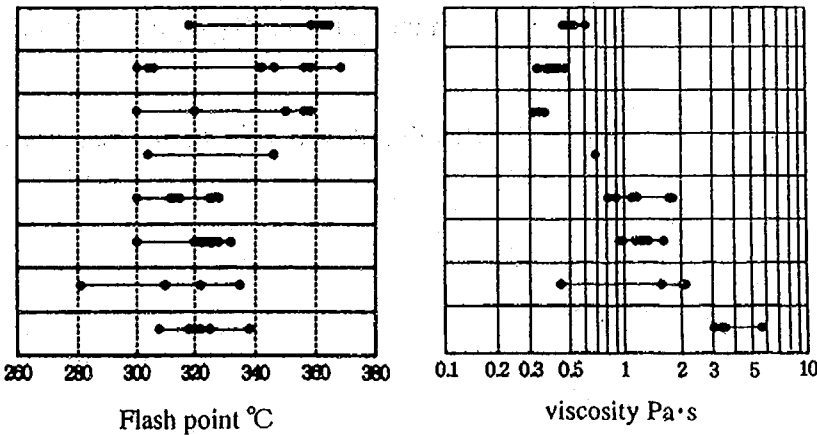


Figure 5 Test results of flash point

Figure 6 Test results of viscosity(135°C)

(3) Dynamic shear rheometer

The results of dynamic shear rheometer are shown in Figure 7 (the black dots in the figure represent original asphalt binders). Straight asphalt binders showed a tendency in which the smaller the penetration grade was, the higher was the temperature for satisfying the requirement. Most of the modified asphalt binders met the requirements at temperatures over 70°C. It is significant to compare the viscoelasticity of high-viscosity modified asphalt binders, but it is not reasonable to use the standard values for dense asphalt mixtures because of the primary use for porous pavement.

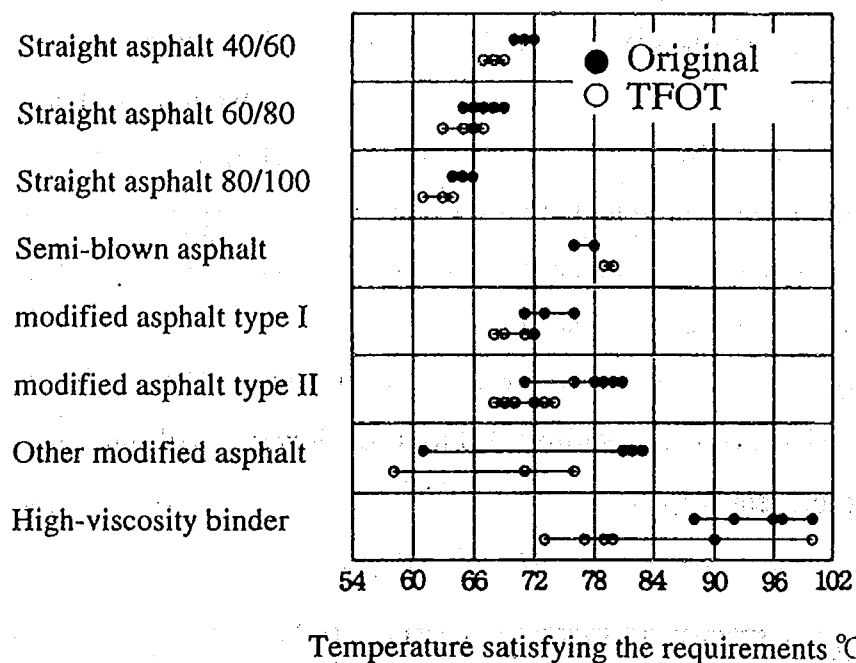


Figure 7 Results of dynamic shear rheometer

2.2 TFOT asphalt samples

(1) Weight change

Our measurements of mass lost from TFOT asphalt samples are plotted in Figure 8. SUPERPAVE requires that weight change should never exceed 1.0%. Since the conventional Japanese standard and the association standard require less than 0.6%, all samples satisfied this SUPERPAVE requirement.

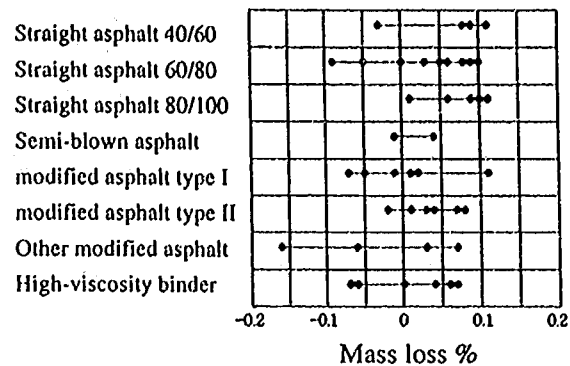


Figure 8 Results of weight change after TFOT

(2) Dynamic shear rheometer

The results of our dynamic shear rheometer are shown in Figure 7. Unshaded circles in the figure represent TFOT asphalt samples. The temperature at which asphalt satisfied the provided values was lower in TFOT asphalt samples than in original ones. SUPERPAVE requires viscoelasticity ($G^*/\sin \delta$) of at least 1.0 kPa for original asphalt binders, and at least 2.2 kPa, a value 2.2 times larger, for TFOT asphalt samples. Most samples we tested did not show such a large change (less than 2.2 times) in viscoelasticity by TFOT aging. Only semi-blown asphalt binders showed higher temperatures in TFOT samples than in the original samples.

Figure 9 shows the viscoelasticity measurements at 60 °C. The increase rate of $G^*/\sin \delta$ between the original and TFOT asphalt samples was the greatest in semi-blown asphalt, followed by straight asphalt and polymer-modified asphalt.

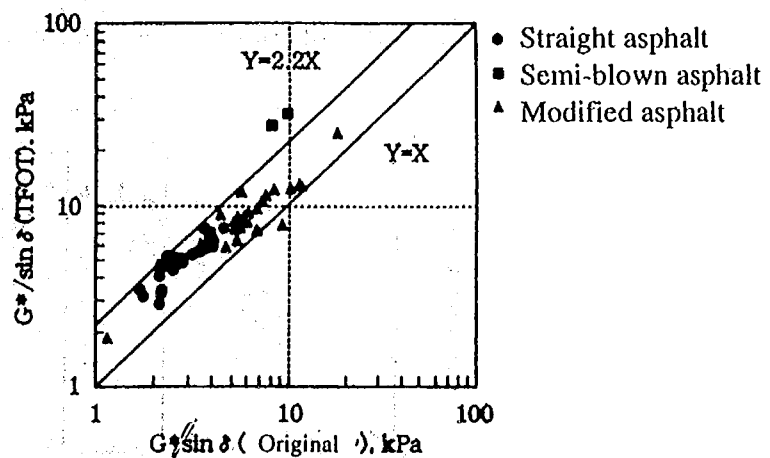


Figure 9 $G^*/\sin \delta$ change during TFOT aging

2.3 PAV asphalt samples

(1) Dynamic shear rheometer

The results of the dynamic shear rheometer of PAV asphalt samples are shown in Figure 10. As shown in the figure, the temperatures satisfying the standard values were higher in straight asphalt binders of smaller penetration grades. For modified asphalt binders, semi-blown asphalt binders met the required values at high temperatures, but polymer-modified asphalt binders were acceptable only at lower temperatures. Figure 11 plots the storage modulus (elastic modulus) at 20°C ($G^* \cos \delta$: elasticity term of the complex modulus G^*) and the loss modulus ($G^* \sin \delta$: viscosity term of G^*) for each sample we tested. The figure shows that the complex moduli of semi-blown asphalt binders characteristically depend on their elastic terms.

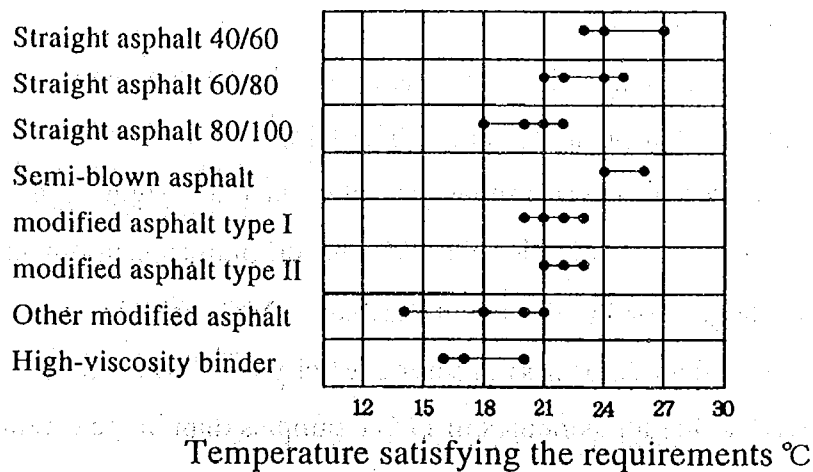


Figure 10 Results of dynamic shear rheometer (PAV asphalt)

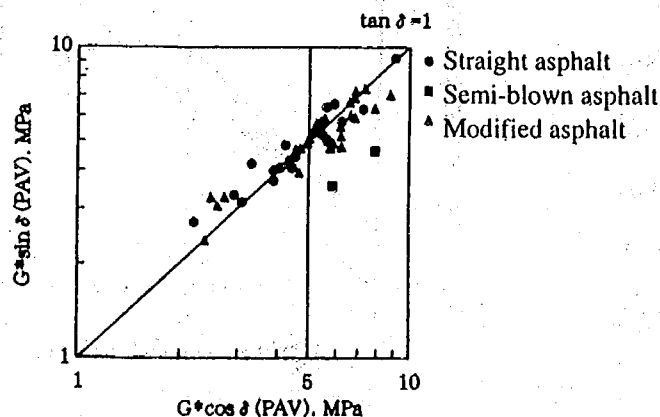


Figure 11 Distribution of $G^* \sin \delta$ and $G^* \cos \delta$ (PAV asphalt)

(2) Bending beam rheometer

The results of the bending beam rheometer of PAV asphalt samples are shown in Figure 12. As shown in the figure, the temperatures satisfying the standard values were lower in straight asphalt binders of larger penetration grades. For modified asphalt binders, semi-blown asphalt binders have striking feature which meet only at least -8 or -9°C . But polymer-modified asphalt binders were acceptable at lower temperatures.

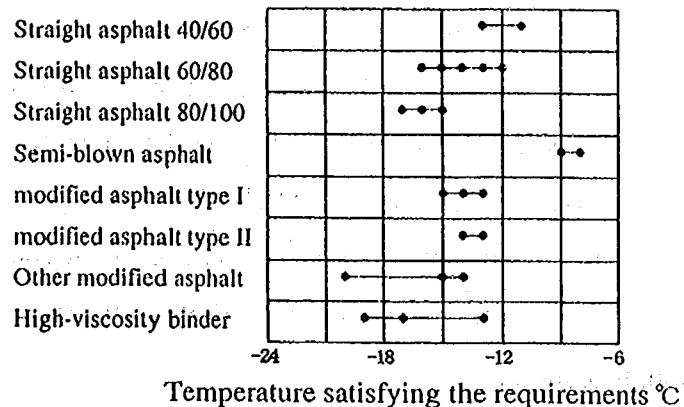


Figure 12 Results of bending beam rheometer

Figure 13 shows the temperatures at which the samples satisfied the required S- or m-values. For most samples, the temperature that satisfied the m-value was higher than the temperature for the S-value, or they were similar. Therefore, m-values determined standard temperatures.

In addition, semi-blown asphalt binders exhibited different properties from the others. Their temperatures satisfying the required values were strongly dependent on their m-values. Figure 14 shows S- and m-values of samples at -10°C . Semi-blown asphalt binders, which have small m-values, should be mostly elastic bodies. We could not confirm such a significant difference between straight and modified asphalt binders.

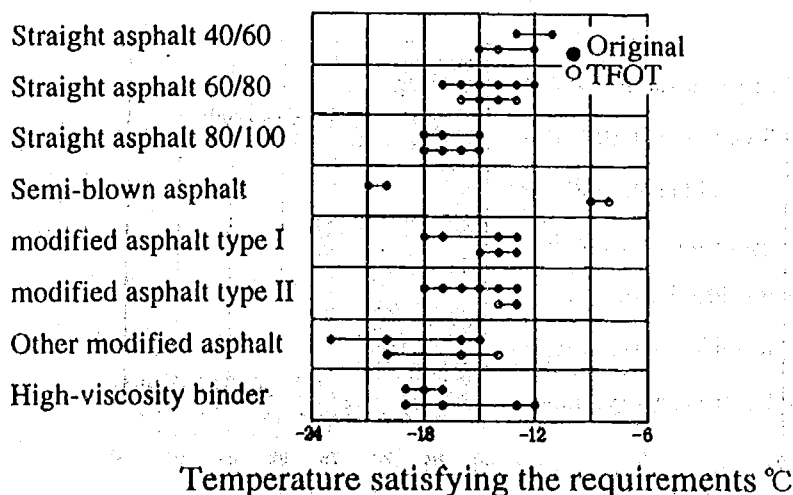


Figure 13 BBR test results in S- and m-value

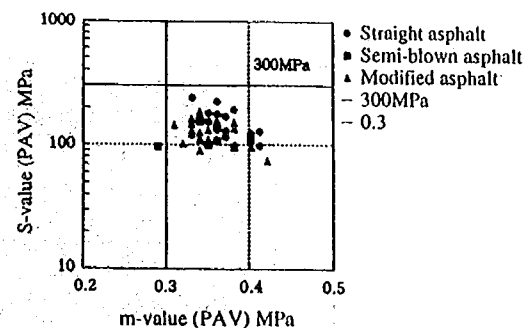


Figure 14 relationship between S- and m-value

2.4 Evaluation with PGs

Figure 15 shows the allowable temperature ranges for using asphalt binders that we determined with SUPERPAVE. We did not show "other modified asphalt binders" group in the figure since their purposes are different.

The maximum allowable temperature for using straight asphalt was higher for samples of smaller penetration grades. For modified asphalt binders, the temperature was the highest in the high-viscosity modified asphalt, followed by the semi-blown asphalt, modified asphalt type II, and modified asphalt type I. The performance of semi-blown asphalt was notably high. Our evaluation revealed that we can use all asphalt binders at 60°C except for some straight asphalt binders.

The lowest temperature for using straight asphalt was again lower for samples of faster penetration grades. For modified asphalt binders, high-viscosity modified asphalt showed the best results, followed by modified asphalt type I, modified asphalt type II, and semi-blown asphalt. The evaluation for semi-blown asphalt is low, but shows it is possible to use the asphalt at -18°C. This evaluation suggests that blowing is effective for improving properties at high temperatures, but plasticity is lowered excessively. The addition of polymers is a better method when low-temperature properties are considered.

SUPERPAVE classifies PGs into groups of 6°C intervals. The X-axis of the figure represents temperature and PGs. SUPERPAVE may classify two asphalt binders into separate groups according to its temperature standard even if the conventional system regards them as a single group.

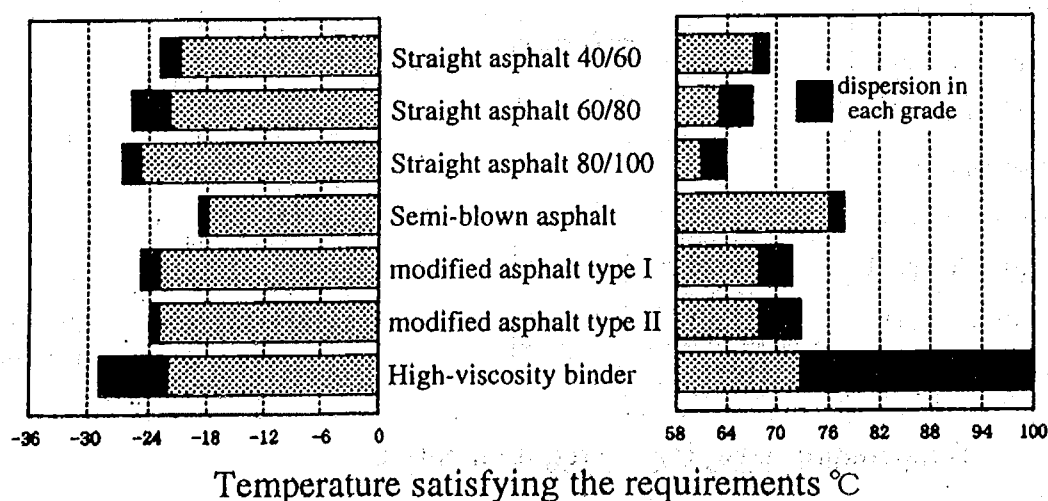


Figure 15 Allowable service temperature determined by SUPERPAVE

3. Conclusion

We tested samples of asphalt binders that are widely used in Japan, and understood the characteristics of SUPERPAVE evaluation.

SUPERPAVE evaluation for straight asphalt was similar to the result of the conventional system. However, for modified asphalt binders types I and II, SUPERPAVE showed little difference in high-temperature performance between samples that the conventional system categorizes as different grades. The correlation between SUPERPAVE classification and the conventional groups was not clear.

Utilization of SUPERPAVE in Japan is a debatable issue. The SUPERPAVE standard values are for dense asphalt mixtures used under the climatic and traffic conditions of the U.S.A. In Japan, rutting is very frequent due to heavy traffic, and the principal concern is dealing with asphalt flow (permanent deformation). There are thus many differences to consider, such as the average speed of vehicles is slower in Japan than in U.S.A. due to traffic congestion, and winter-time weather is less severe. Evaluation conditions and standard values that are adequate for Japan are needed.

Afterword

We have examined the performances of pavement binders that are ordinary used in Japan, which we evaluated with the SUPERPAVE grading system. We hope that this report on binder qualities in Japan helps clarify the application of SHRP standards and develop new systems in Japan and elsewhere.

This report has summarized the data^{14) 19)} that the research team studied and analyzed at the Public Works Research Institute. The experimental project was carried out by Kiyoshi Katawaki, Hiroyuki Sakamoto, Hiroyuki Nitta, and Iwao Sasaki (Public Works Research Institute), and visiting researchers: Toru Tsukagoshi (Nippon Oil Co., Ltd.), Tomoji Tonishi (Showa Shell Sekiyu K.K.), and Masayoshi Tanaka (Nichireki Co. Ltd.).

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4.3 FHWA Binder Task Group

FHWA Binder Expert Task Group

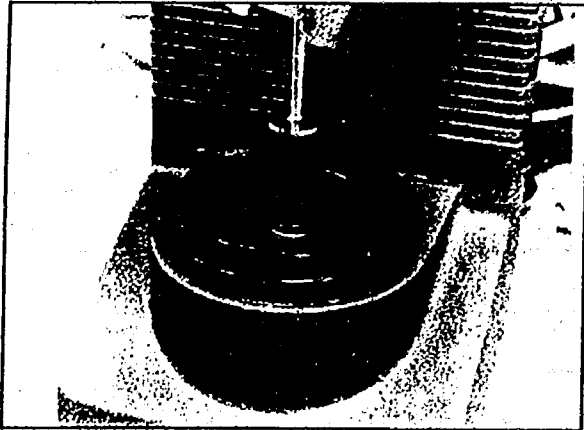
Where are the Superpave Binder Specifications headed.

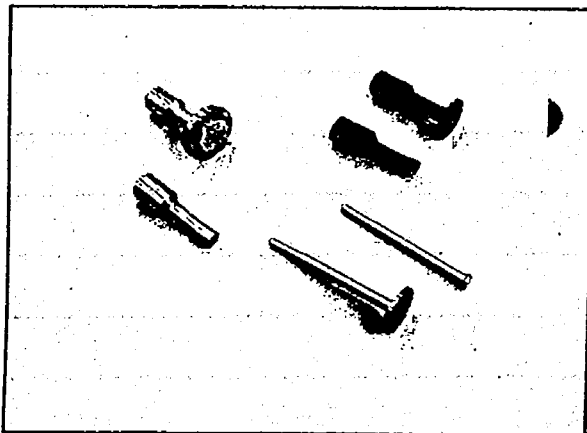
FHWA Binder ETG

- Rotational Viscometer
- Dynamic Shear Rheometer (DSR)
- Bending Beam Rheometer (BBR)
- Direct Tension Tester (DTT)
- Aging Equipment
 - Rolling Thin Film Oven (RTFO)
 - Pressure Aging Vessel (PAV)

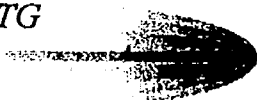
FHWA Binder ETG

- PAV DSR.
 - Test has high variability, CV 40%.
 - Experiment underway to evaluate using larger plates to reduce variability.





FHWA Binder ETG



- PAV DSR.
 - Intermediate PAV DSR testing done with 12 mm plates and 1 mm gap have lower variability than 8 mm plate and 2 mm gap.
 - The experiment is to be expanded to include more materials to verify the results.

FHWA Binder ETG

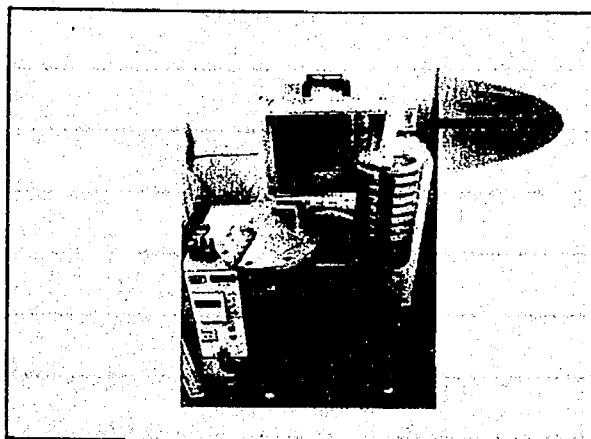
- PAV DSR.

- DSR testing with 8mm plate and 2 mm gap has 2DS CV of 44%.
- Preliminary testing with 12 mm plates and 1mm gap has 2DS CV of 20%.

FHWA Binder ETG

- PAV material.

- Air bubbles in PAV material may effect test results.
- Experiment underway to evaluate vacuum oven to remove air.

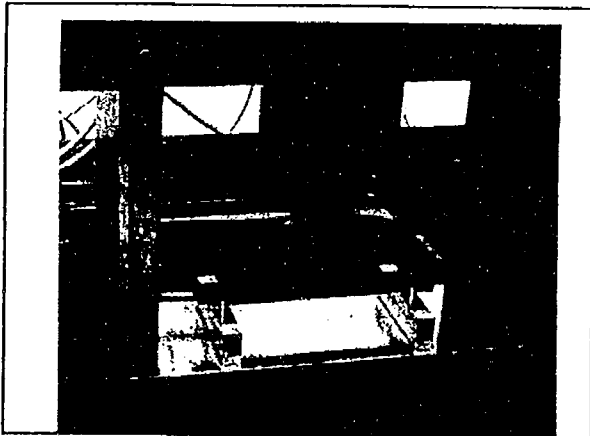


FHWA Binder ETG

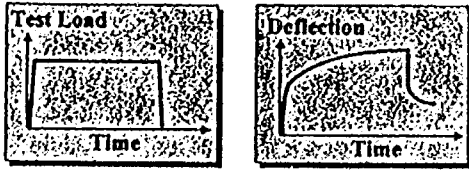
- PAV material.
 - Experiment to evaluate different temperatures, vacuum, and times in oven; on several different binders.
 - Data indicates vacuum oven at 170°C for 30 minutes and 15 kPa absolute pressure will remove most air bubbles with little effect to binder.

FHWA Binder ETG

- Test results from the two BBR manufactures equipment are not the same.
- ETG has done an extensive study to determine the difference.
 - Load start time.
 - Supports.



Overview of BBR Procedure



FHWA Binder ETG

- The BBR works well in determining unmodified binders critical cracking temperature.
 - This has been verified on Canadian and US test sections
- Modified systems need new tools to evaluate critical cracking temperatures.

FHWA Binder ETG

- Direct Tension Tester
 - New Prototype Device Delivered
 - Refinement of Test Procedures Underway
 - Ruggedness - Spring 1998

FHWA Binder ETG

- Low Temperature Specification

- New Specification for Direct Tension Test (DTT)

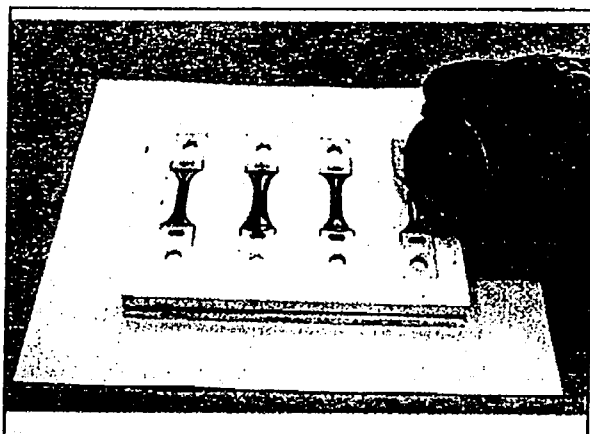
- New molds
 - New Fluid

FHWA Binder ETG

- Low Temperature Specification

- New Specification for Direct Tension Test (DTT)

- Original silicone molds would effect low molecular weight binders and cause early fracture.

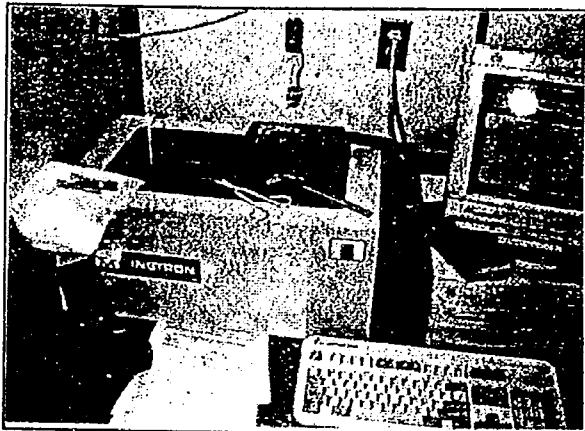


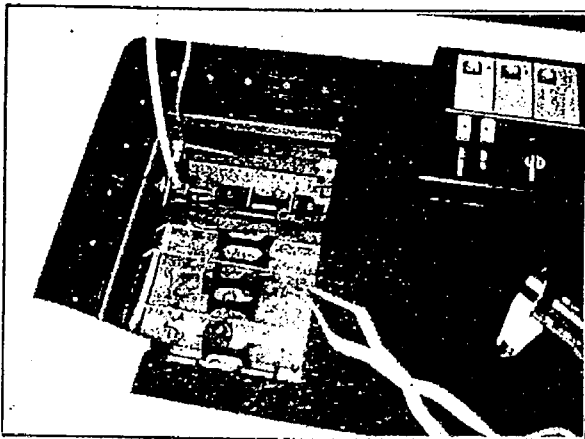
FHWA Binder ETG

- Low Temperature Specification

- New Specification for Direct Tension Test (DTT)

- Alcohol fluid would effect surface of specimen and reduce strength. Potassium Acetate has no effect on binders in DTT.



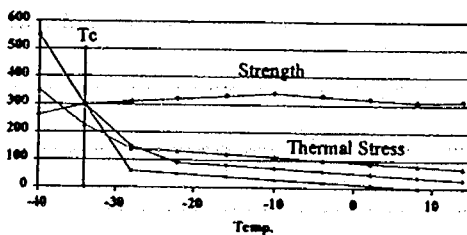


FHWA Binder ETG

- At high temps we bump for traffic.
- At low temp?
 - Binders with the same critical cracking temperature perform differently.
 - The BBR m value indicates the asphalt's ability to dissipate energy. This is related to temperature cycling and loading of the pavement.
 - Asphalts with low m values can perform but not on heavy traffic roads.
 - We should be able to bump for low temp fatigue.

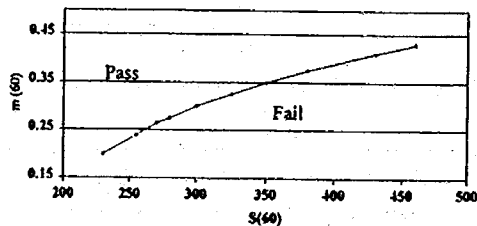
FHWA Binder ETG

Possible Low Temperature Specification



FHWA Binder ETG

Possible Low Temperature Specification



FHWA Binder ETG

- Low Temperature Algorithm

- To accurately evaluate performance you must know the pavement temperature
- The Superpave specification is based on the actual pavement temperature.

FHWA Binder ETG

- Low Temperature Algorithm

- Superpave

- $T_{pav} = T_{air} - n\sigma$

- Canada

- $T_{pav} = 0.859 (T_{air} - n\sigma) + (0.02 - 0.0007 T_{air})D + 1.7^\circ\text{C} - n\sigma$

- LTPP

- $T_{pav} = -1.56 + 0.72T_{air} - 0.004\text{Lat}^2 + 6.264\log(D+25) - z(4.4 + 0.52\sigma^2_{air})^{1/2}$

FHWA Binder ETG

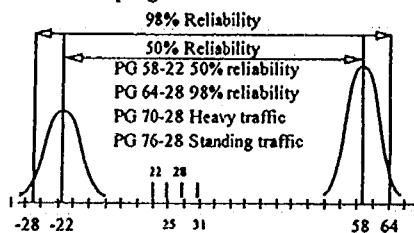
- LTPP low temperature algorithm developed from 30 sites all over North America.
- Each climate type represented in data base.

FHWA Binder ETG

- The Superpave Binder Specifications will continue to evolve.
- As findings from various studies become available the ETG will review these and make recommendation for changes to the Spec.

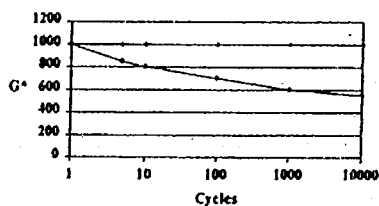
FHWA Binder ETG

- Grade Bumping



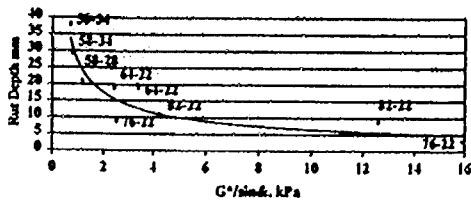
FHWA Binder ETG

Binder Fatigue Testing



FHWA Binder Validation

ALF Study Binder grade to rutting



Models Decision

- Phase II should also focus on development of a performance test to support volumetric mix design process
- The materials characterization developed under Phase II will form the framework for performance prediction models that will be developed under future contracts

IMPACTS

(None)

- PG Binder Specification unchanged
- Volumetric Mix Design unchanged
- Region Centers Continue Testing of SST and IDT

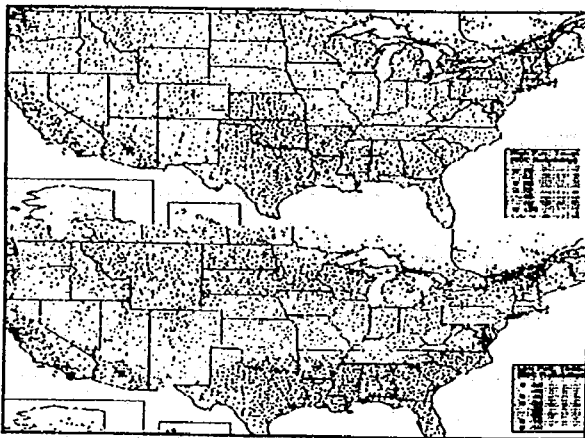
Current Status

- Field Performance Test

- Several potential pieces

- Dynamic Triaxial, confined creep, Shear.

- Preliminary testing to be done over the next few months

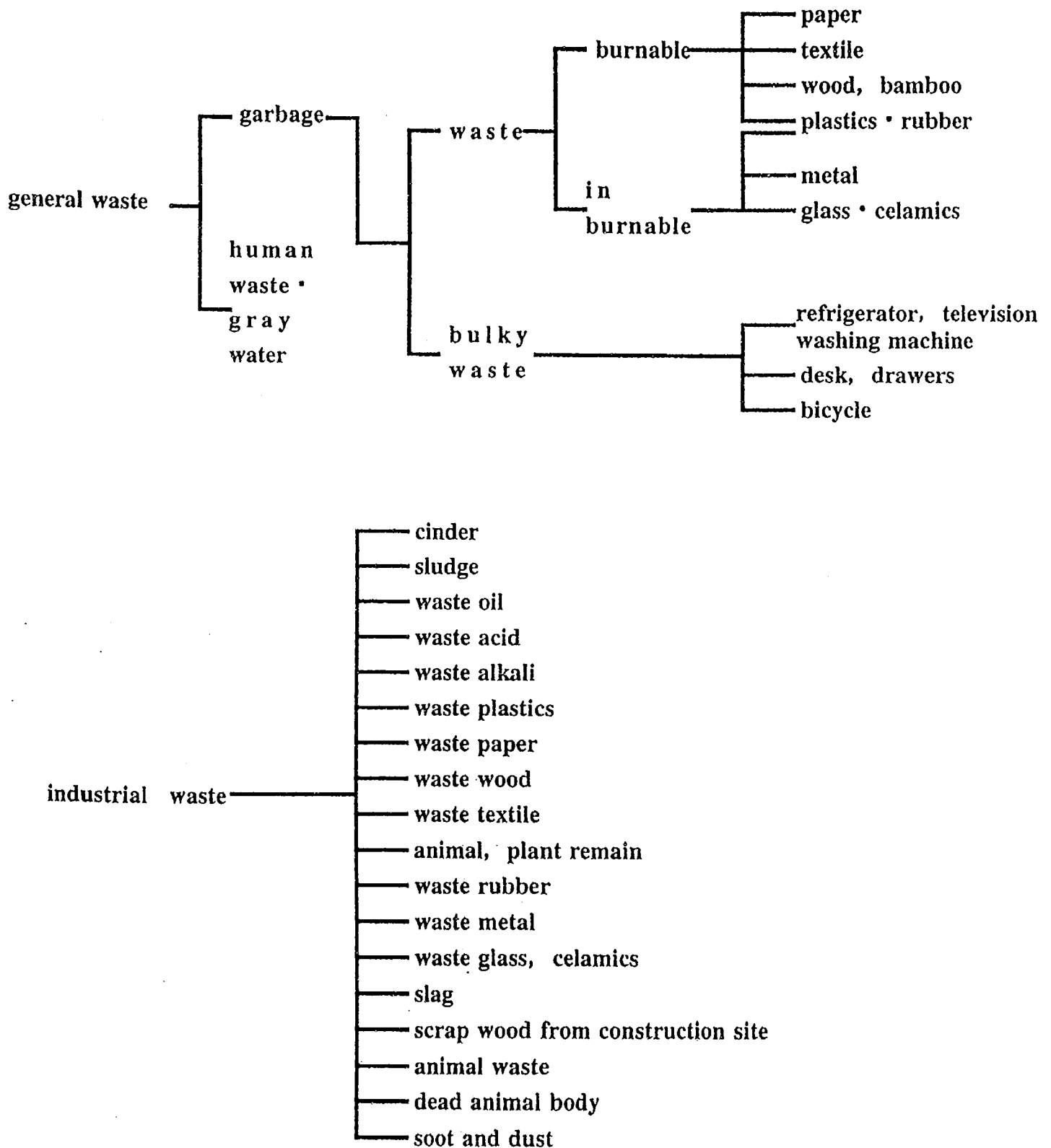


5. Utilization of Non-Road By-Products

5.1 Basic Policy to handle by-Products	177
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5.1 Basic Policy to handle by-Products

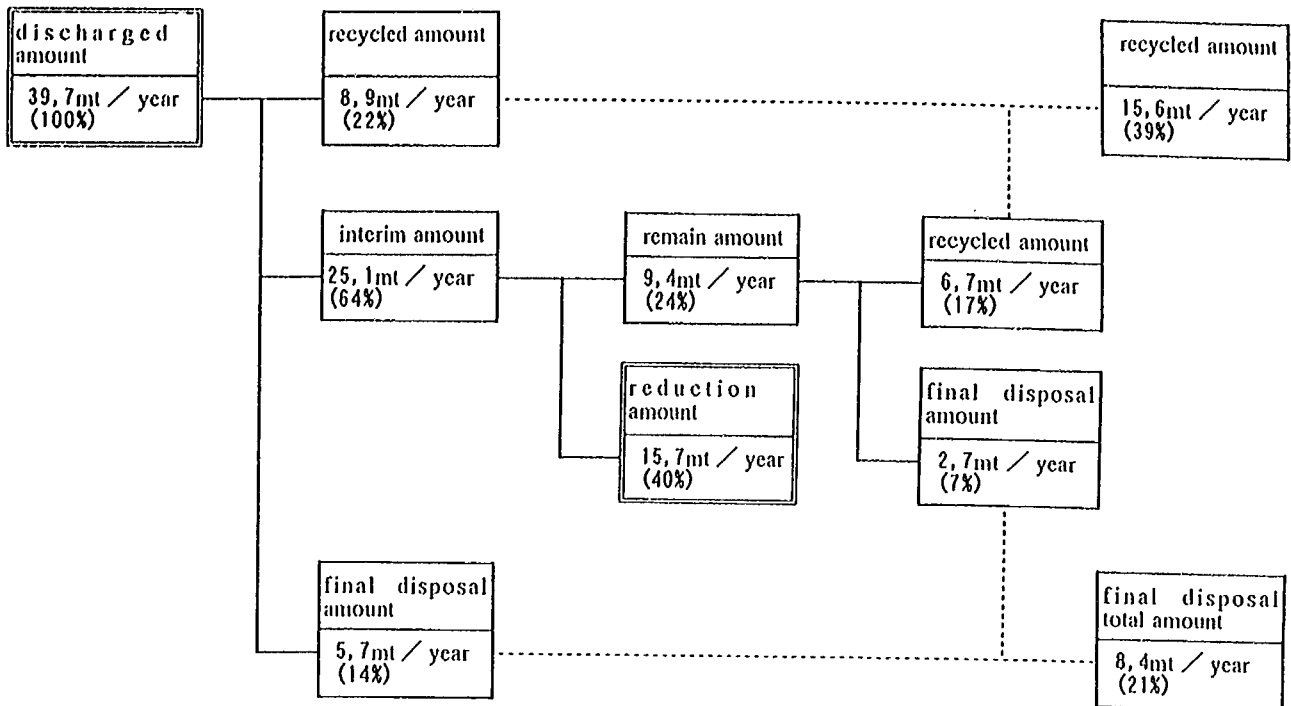
classification by waste law



industrial waste amount

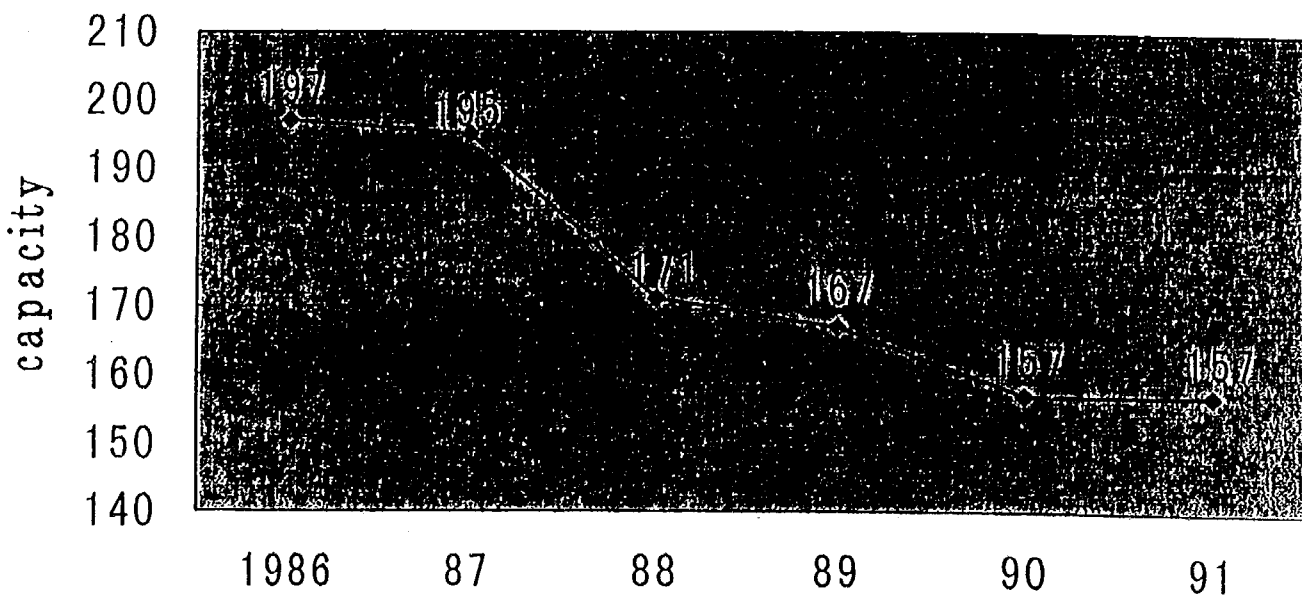
	fy1993	
	thousand t / year	%
cinder	2,696	0.7
sludge	180,490	45.5
waste oil	2,749	0.7
waste acid	2,771	0.7
waste alkali	1,538	0.4
waste plastics	5,348	1.3
waste paper	1,683	0.4
waste wood	6,948	1.8
waste textile	114	0.0
animal, plant remain	3,219	0.8
waste rubber	71	0.0
waste metal	6,028	1.5
waste glass, celamics	6,020	1.5
slag	30,867	7.8
scrap ^{waste} wood from	61,541	15.5
construction site		
animal waste	75,567	19.0
dead animal body	75	0.0
soot and dust	9,144	2.3
others	—	—
計	396,869	100.0

waste flow (fy1993)

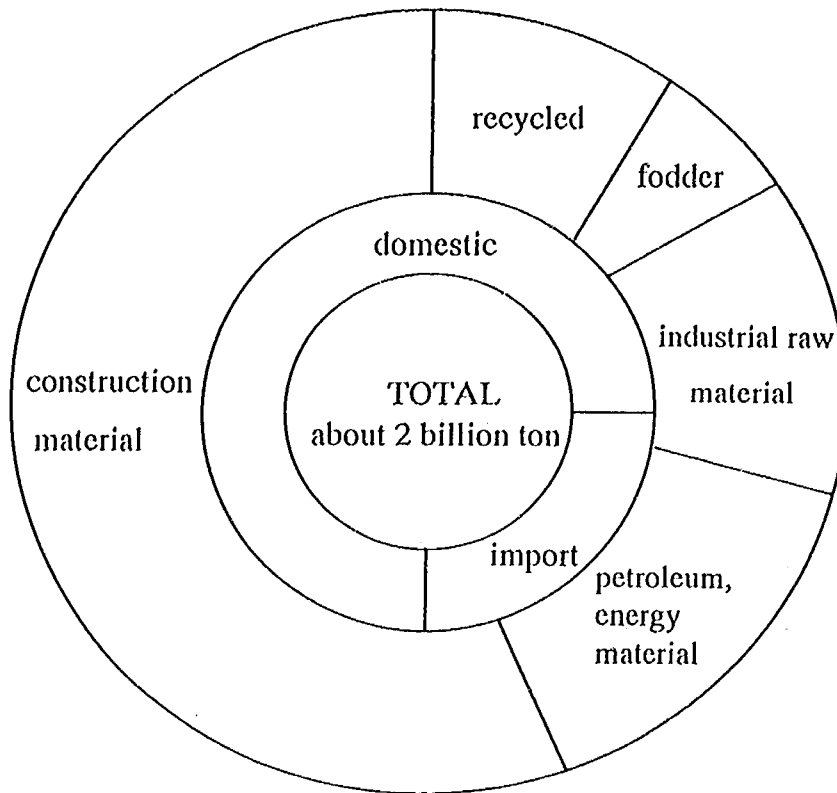


(million m³)

reclamation final disposal capacity



Annual Resource Consumption in Japan



Dealing with Recycle Problem in Public Works by MOC

- 1 . Recycle material from construction field
- 2 . Recycle material from non construction field

Recycle Target by M O C

		fy 2 0 0 0	
construction waste		8 0 %	(5 8 %)
	asphalt • concrete	9 0 %	(8 1 %)
	concrete	9 0 %	(6 5 %)
	sludge from construction site	6 0 %	(1 4 %)
	construction mix waste	5 0 %	(1 1 %)
	construction waste wood	9 0 %	(4 0 %)
construction soil		7 0 %	(3 2 %)

() fy 1 9 9 5

Issues relating to research on recycling

(1) Basic ideas

- * Examination of the balance in the use of recycled and new materials in the construction field (for example whether it is right or wrong to give priority to the use of recycled materials and to the recycling of materials in the construction field)

- * Current status of the system and relevant analysis (for example whether it is right or wrong to establish a system such as the one found in the United States which makes the use of slug cement compulsory.)

(2) Economy

- * Basic ideas relating to price setting when accepting recycled materials (for example whether to use recycled materials when their price has increased?)

- * Investigation into the difference in cost with non-recycled materials

(3) Technical and quality

1. Basic technical policies

- * It is necessary to maintain the functional level applied to new material. After this point is cleared, basic policies on to what extent environmental safety, durability, and repeated recycling performance shall be guaranteed must be set.

2. The testing and evaluation method for typical cases shall be indicated (for example, molten slag and glass cullet) as individual testing methods vary by item. Research conducted by public organizations is chiefly focused on the testing and evaluation methods. Yet development of recycled materials itself becomes a research issue to some extent. When it comes to public works, the specifications of the testing and evaluation method must be the agenda of investigation.

Investigation into the criteria for acceptance of individual recycled materials

(1) Concerning the following items

1. The physical and chemical properties of the following material as well as examples of applications of these material to public works in the past must be investigated and these material classified into the following groups; Group A (preparing the testing and evaluation methods and the utilization technique manual), Group B (preparing the testing and evaluation method only (as well as examples of applications for certain items in the group)), Group C (preparing the utilization examples only) and others.
2. The criteria for the acceptance of individual recycled materials to meet the level of the maturity of these materials as products must be examined.

Items

- * Examination of the application of ashes in general from incineration and sewerage sludge processed through fusion and caking to paving materials (sub base course material and asphalt paving mixture), concrete aggregate and secondary products.
- * Examination of the application of coal ashes processed through cement solidification to filler for asphalt paving, paving materials, subsoil materials (filling, soil reformer, road bed, and others).
- * Examinations of the application of ashes in general from incineration processed through sintering and solidification to sub base course material and the concrete admixture.
- * Examinations of the application of ashes in general from incineration processed through sintering and crushing (cement clinker) to cement and secondary products.
- * Examination of the application of glass cullet processed through crushing to asphalt paving mixture materials (for the surface layer) and sub base course material.
- * Examination of the application of plastics to asphalt paving reformer and aggregate, sub base course material and secondary products (dummy wood and peg).
- * Examination of the application of rubber (waste tires) to porous, elastic paving material, the elastic material for sidewalk paving, the freezing inhibiting paving material and the secondary products (blocks for sidewalk paving).
- * Examination of the application of used paper to asphalt paving and the secondary products (concrete mold).

* The application of sewage sludge processed through polymerized incineration to sidewalk blocks.

(2) Selected recycled materials must go through testing in order to examine the matters above and verify whether the materials will cause elution of harmful substances at a level equal to or greater than the relevant environmental criteria set for soil analysis and testing.

Soil Environment Criteria Relating to Heavy Metals

Item	Elution Criteria
Cadmium	0.01 mg/l (max.)
Lead	0.01 mg/l (max.)
Hexad chrome	0.01 mg/l (max.)
Arsenic	0.01 mg/l (max.)
Total mercury	0.0005 mg/l (max.)
Selenium	0.01 mg/l (max.)

5.2 Recycling of Non-Road By-Products in Japan

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Introduction

Although 87.5% of ordinary waste produced in Japan undergoes incineration or mechanical compression in order to reduce its volume, ultimately it is disposed of at final landfill sites. It is, however, becoming increasingly difficult to secure final disposal sites amid growing public concern over environmental problems in recent years. In order to overcome the problems, a system must be created to utilize the waste as resources as well as reduce its volume, recycle and reuse it.

This paper introduces the utilization of recycled materials from ordinary waste in Japan in three municipal governments and one private company.

1. Reusing Glass Bottle Cullets to Make Asphalt Mixture

1.1 State of Recycling of Glass Bottles

Approximately 4.2 million tons of glass are produced in Japan every year, with glass bottles accounting for about 2.4 million tons of this total. The remainder is used to make plate glass, glass wool products, and other glass products. Some of these bottles are returnable bottles that are washed and reused, but a large number of disposable bottles, called "one-way bottles", are manufactured.

Almost all of these one-way bottles are crushed to form powder or granules of glass (referred to as "cullets" hereafter). At present, about 55% of cullets are recycled to produce glass products again, but the rest is still disposed of at landfill sites. Figure-1 shows the annual production of glass bottles and recycling rate of the cullets.

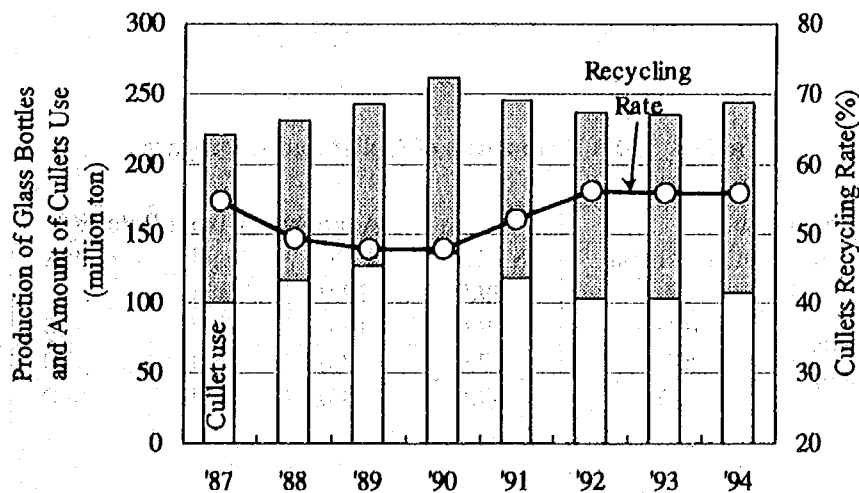


Figure-1 Annual Production of Glass Bottles and Recycling Rate of the Cullets

1.2 Cullets

Cullets for road paving are made by a type of impact crusher to form particles smaller than 20 mm that have no sharp crushed surfaces. The produced cullets are therefore safe to handle.

1.3 Outline of the Testing Pavement

Approximately 5,300 m² of test pavement was constructed on the entrance road to an ordinary waste disposal site in Fukushima Prefecture. Figure-2 shows how the test pavement was divided into sections. Table-1 shows the mix proportion of asphalt mixture for each section.

A follow-up study six months after construction revealed that the road surface properties in every section were good.

The results of this test pavement have confirmed that, by crushing glass into cullets, it is possible to use it as an aggregate for asphalt mixtures. The results of laboratory testing, done before the test paving, also confirmed that if the mixing rate of the cullets is high, the Marshall stability and dynamic stability of the asphalt mixture both tend to decrease. It is therefore appropriate to limit the amount of cullets up to about 10% of aggregates. Large-diameter glass fragments are flat and have inferior properties for use as aggregate. Furthermore, their use would cause safety problems, endangering the workers who handle them and causing tire punctures. The grain size of the cullets should be 5 mm or less.

The results showed that if the grain size and mixing rate are carefully adjusted by laboratory tests, asphalt mixture containing glass cullets is as easy to manipulate as ordinary asphalt mixture.

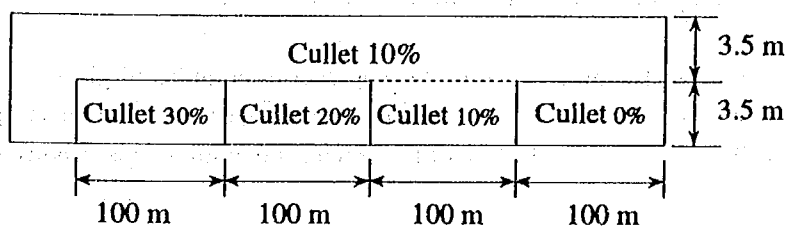


Figure-2 Test Pavement of Cullets

Table-1 Mix Proportion of Cullet and Aggregate

Aggregate		Aggregate Mixing Rate (%)				
Type of Mixture	Cullet Content	S - 13	S - 5	Sand	Cullet	Filler
Dense Grade Asphalt Concrete Mixture (13mm)	0%	39.0	19.0	35.0	-	7.0
	10%	39.0	14.0	30.0	10.0	7.0
	20%	39.0	8.0	26.0	20.0	7.0
	30%	39.0	3.0	21.0	30.0	7.0

2. Recycling of Ash Produced by the Incineration of Urban Waste Material (Funabashi City)

In Funabashi City, sintering using the ash produced by incinerating ordinary waste was studied for two years from April 1993 until March 1995. The results showed that a recycled product made from incinerator ash as the raw material can be used as a base course material or permeable blocks.

2.1 Recycled Material Containing Incineration Ash

(1) Recycled Aggregate

Recycled aggregate containing incinerator ash (referred to as "recycled aggregate" hereafter) is made by adding clay or sludge from water filtration plants. After adding water, the material is mixed and pelletized, then solidified in a rotary kiln heated by an oil burner. The sintering temperature ranges from 1,100 to 1,150 degree Celsius and the retention time for the sintering process ranges from 40 to 60 minutes. The mixing ratio of incineration ash and clay is 60 to 40. Table-2 shows the manufacturing conditions of the recycled aggregate.

(2) Recycled Permeable Blocks

Recycled permeable blocks containing incinerator ash (referred to as "recycled permeable blocks" hereafter) are made as follows. First, recycled aggregate is crushed and screened. Then particles with a size ranging from 1 to 3.5 mm are mixed with glass powder as a binder. After this has been press-formed, it is placed inside a shuttle kiln, where it is sintered for approximately 9 hours until it reaches its maximum temperature of 1,050 degree Celsius. Table-3 shows the manufacturing conditions of recycled permeable blocks.

Table-2 Manufacturing Conditions of Recycled Aggregate Containing Incinerator Ash

Mixing Ratio		Solidifying Temp. and Time	Pelletizing Water Content Rate (%)	Hardness (N)	Coefficient of Water Absorption (%)	Bulk Specific Gravity in Saturated Surface-dry
MSWI Ash	Clay					
6	: 4	1,098°C 90min	17.9	539 - 902	10.6 - 22.0	1.87 - 2.26

Table-3 Manufacturing Conditions of Recycled Permeable Blocks

Binder			Backing Temp. and Time	Size (mm) L * W * H
Glass Powder (%)	Poly Vinyl Alcohol (%)	Forming Pressure (kN/m ²)		
27	5.4	14,710	1,050°C 8h45m	210 * 100 * 60

2.2 Outline of the Testing Pavement

(1) Recycled Aggregate

In order to use recycled aggregate as base course materials, the materials, mixed as shown in Table-4, were used for the test pavement. The cross section of the test pavement is shown in Figure-3. Repeated loading by heavy vehicles on the test section revealed that rutting was equal to that in a comparison section constructed with crusher-run. The recycled aggregate containing incinerator ash can be used as a base course material for roads where traffic volume is low.

(2) Recycled Permeable Blocks

On a sidewalk in a seashore park in Funabashi City, recycled permeable block paving was laid on an area of 17.4 m² and conventional permeable block paving was laid on an area of 16.0 m². The results of a follow-up study revealed that the recycled permeable blocks performed as well as the conventional permeable blocks. Other recycled permeable blocks that have been laid in the public space in front of the Japan Railway station in Funabashi and in other parks within the city have demonstrated the good performance of this recycled product.

Table-4 Mix Proportion and Properties of Recycled Aggregate

Mix Proportion and Tests	Unit	Properties	Standard of Sub Base Course
1. Size 1) 9.0 - 10.0 mm	%	30.0	-
2) 3.5 - 9.0 mm	%	36.0	-
3) 1.0 - 3.5 mm	%	22.0	-
4) -1.0 mm	%	12.0	-
2. Hardness	N	657	-
3. Impact Completion Test	%	16.1	-
1) Optimum Moisture Content			-
2) Maximum Dry Density	g/cm ³	1.481	-
4. Modified CBR	%	33	20 ≤
5. Swelling Test	%	0	

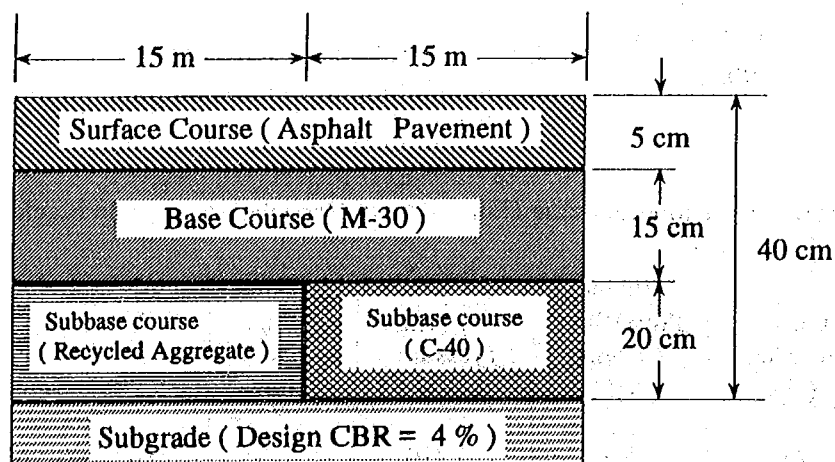


Figure-3 Cross Section of the Test Pavement

3. Effective Use of Incinerator Ash (Kanagawa Prefecture)

Kanagawa Prefecture also faces difficulties securing final disposal sites in its waste management. In order to recycle the incinerator ash that accounts for most of the waste generated in the area, it studied the melting and sintering of this waste.

3.1 Recycled Material Containing Incinerator Ash

(1) Recycled Aggregate

Melting is a technology used to melt incinerator ash at high temperatures ranging from 1,200 to 1,600 degree Celsius to solidify it in the form of slag. This melting technology was used to make recycled aggregate.

The first advantage of transforming incinerator ash into this slag is that it reduces the volume of the waste material. By transforming incinerator ash into slag, the volume is reduced to between 1/2 and 1/3. The second advantage is that it stabilizes the material. Melting incinerator ash volatilizes the lead, zinc, and other heavy metals with low melting points that are found in incinerator ash. Other hazardous heavy metals are sealed inside the slag so that there is little chance of leaching from the material. The melting furnaces, used for the processing, are electric arc furnaces, plasma melting furnaces, and electric resistance furnaces, which can use the electric power generated by the heat of the incinerators installed at the same site. Another advantage of such furnaces is that they generate relatively little exhaust gas.

(2) Recycled Blocks

Sintering is a technology used to make bricks or tiles by solidifying incinerator ash, either pure or mixed with secondary raw materials (clay, aggregate, binders, etc.). Two problems must be overcome to improve sintering technology. The first is the need for a method of dealing with the variable quality of the incinerator ash when large quantities of blocks are manufactured. The second is that, unlike the formation of slag by melting the incinerator ash, this method can not prevent the leaching of heavy metals. It is, therefore, not suitable for processing incinerator ash containing large quantities of harmful heavy metals.

3.2 Application of Recycled Materials Containing Incinerator Ash

(1) Base Course Material

Since the demand for base course materials fluctuates seasonally, it is difficult to ensure a constant supply of slag in large volumes as a base course material.

(2) Material Used to Make Asphalt Mixtures

There is a method to replace one-third of the sand used in asphalt mixes with granulated slag. This form of usage maintains the supply and demand balance in a region where there is no temporary high demand as in the case of a base course material.

(3) Concrete Aggregate

As in the case of base course aggregate, it is difficult to supply large quantities of slag with stable quality.

It is not considered appropriate for use as concrete aggregate.

4. Use of Melted Slag to Make Asphalt Mixes (Omiya City)

Omiya City introduced an electric arc furnace in March 1993 to reduce the pollution produced by incinerator ash, to reduce its volume, and to promote recycling of the slag. It has used this facility to melt incinerator ash, and granulated slag is formed by quickly cooling the melted waste material.

Recycling this material as pavement blocks is not enough to significantly reduce the quantity of incinerator ash. In order to extend the service lifetime of landfill sites, Omiya City studied the possibility of using it to make asphalt mixtures, which could consume a large amount of slag.

4.1 Outline of the Testing Pavement

Test pavement was constructed between October and December, 1996 in Omiya City. The test pavement was laid in four lanes equivalent to B traffic (traffic volume of large vehicles 100 - 250 (vehicles/day - direction)).

The results of laboratory tests showed that the higher the mix ratio of the slag, the lower its moisture resistance and rutting resistance (Figure-4, 5). A mixing ratio of 10% was set for slag, since the properties of asphalt mixture are almost the same as those of normal asphalt mixtures. Different asphalt plants and contractors were allocated to each test section to evaluate the material at a practical level. For comparison purposes, the lanes in the opposite direction were covered with conventional asphalt mixtures. Table-5 shows the properties of the materials and the mixtures used for the test pavement.

The results of visual inspections of the surface of all lanes in the test pavement, which were carried out two years later, confirmed that the pavement was in good condition.

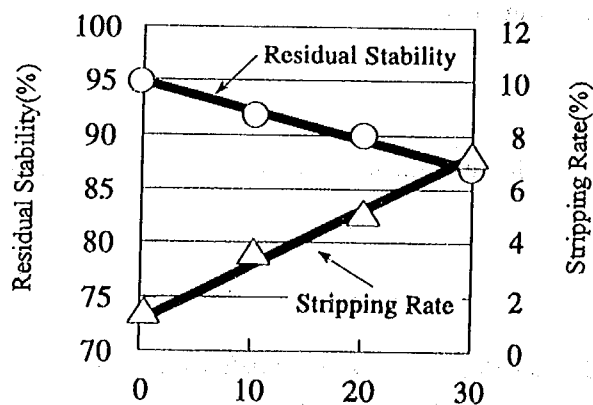


Figure-4 Relationship between Slag mixing Rate and Properties of Mix

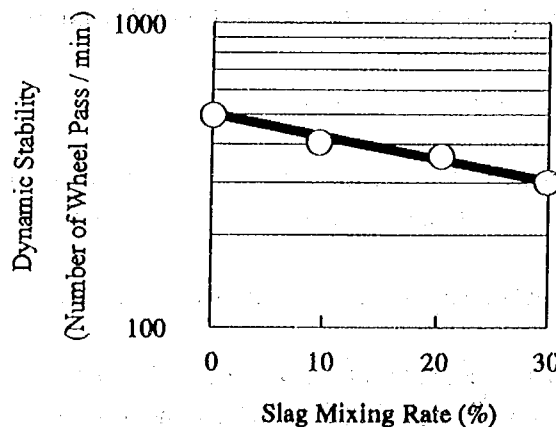


Figure-5 Relationship between Slag Mixing Rate and Dynamic Stability

Table-5 Material Properties and Mix Proportion

Aggregates	Density(g/cm ³)			Water Absorption Rate (%)	Aggregate Mixing Ratio (%)	
	Saturated Surface-dry	Bulk	Apparent		Normal Dense Grade	Dense Grade with Slag
S - 13	2.647	2.631	2.673	0.59	39.0	38.0
S - 5	2.640	2.621	2.671	0.72	16.0	17.0
Sand	2.585	2.523	2.689	2.45	29.0	18.0
Screenings	2.616	2.586	2.687	1.18	11.0	12.0
Slag	2.670	2.660	2.688	0.40	-	10.0
Filler	-	-	2.700	-	5.0	5.0
Total	-	-	-	-	100	100

5. Conclusion

This paper has introduced the projects undertaken by four organizations. In all cases, the materials have a glassy property, which is not desirable as an aggregate for asphalt mixture, since it may cause stripping problems. Faced with a shortage of final disposal sites, however, the recycling of waste is essential. With regard to safety, guidance was provided to regional governments to encourage them to use slag in their public works. The Guidelines Concerning the Recycling and Reuse of Slag Made by Melting Ordinary Waste Material (Ministry of Health and Welfare) defines six key items for quality control: leaching standards for cadmium, lead, hexavalent chromium, arsenic, total mercury, and selenium based on environmental standards for soil pollution. Therefore, it is necessary to standardize the grain size and mixing ratios of glassy aggregates for asphalt mixture, which show performance equal to that of conventional asphalt mixtures. The Public Works Research Institute is now studying this standardization task.

Acknowledgments

The author acknowledges the cooperation of Kanagawa Prefecture, Omiya City, Funabashi City, and Nihon Hodo Ltd. for their assistance in preparing this paper.

5.3 Crumb Rubber Modifier (CRM) Activities in the United States

Crumb Rubber Modifier (CRM) Activities in the United States

Paul Teng
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Federal Highway Administration

Crumb Rubber Modifier in the United States

- Intermodal Surface Transportation Efficiency Act of 1991
 - mandated the use of specific quantities by States
 - required CRM research
- NHS Designation Act of 1995
 - repealed usage mandate
 - required research - Superpave performance based specifications

Continuing CRM Activities

- Technical assistance
- Technology Transfer
- Research in-house and contracts

CRM Related Research

- Western Research Institute
 - Fundamental properties of asphalt and the interaction of CRM and asphalt
- NCHRP 9-10
 - Superpave protocols for modified binders, including CRM

CRM Research - Continued

- Oregon State University contract
 - Pooled fund from 33 States
 - Investigated the use of CRM as related to;
 - Pavement design
 - Construction
 - Recycling
 - Prepared a summary of the practice in three leading States

FHWA in-House CRM Research

- CMCRM - Chemically modified crumb rubber modifier
 - Developed by FHWA researchers
 - Goal was to improve the overall binder performance
 - Successful in the laboratory
 - Recently scaled up and placed two pilot projects

Environmental Evaluation of CRM

- Interagency agreement between FHWA and the National Institute for Occupational Safety and Health (NIOSH)
- Evaluated the potential health effects of CRM asphalt compared to conventional asphalt
- Evaluations conducted at seven paving projects throughout the United States

Environmental Evaluation by NIOSH

- Summary conclusions and report now being prepared
- Preliminary results on individual projects:
 - Air and breathing zone samples for total particulates, polycyclic aromatic compounds (PACs), and benzene soluble particulate fractions (BSF) were generally higher during CRM paving, but levels for both CRM and conventional did not exceed recommended exposure limits

Other NIOSH Activities

- Engineering Controls for Asphalt Pavers
 - Cooperative effort between NIOSH, FHWA, and the asphalt industry
 - Voluntary guidelines issued January 1997
 - Paver manufacturers should develop and install exhaust ventilation systems
 - For pavers manufactured after July 1, 1997
 - For pavers weighing 16,000 pounds (7273kg) or more

Any Questions?

Crumb Rubber Modifier in the United States

Background

Section 1038(d) of the Intermodal Surface Transportation Efficiency Act (ISTEA) mandated the States' use of quantities of asphalt pavement containing recycled rubber. This Section also contained specific penalties for those States unable to certify to the annual usage requirement. Section 205(b) of the National Highway System (NHS) Designation Act of 1995 amends Section 1038 by striking subsection (d) eliminating the crumb rubber mandate and all associated penalties.

In Section 327 of the NHS Designation Act of 1995, Section 1038 of ISTEA is further amended to require research and development of tests and specifications for use of crumb rubber modified (CRM) asphalt in conformance with the Superpave performance-based specifications. The section requires consultation with the crumb rubber modifier industry and other interested parties when developing these procedures. This section also establishes the basis for a grant program for States to develop programs to use crumb rubber from scrap tires to modify asphalt pavements and defines the term "asphalt containing recycled rubber." No specific funding was provided for this section. The interpretation of 205 and 327 has been evaluated and implementation guidance was issued on March 15, 1996.

Current Activities

FHWA continues to encourage the use of waste tire rubber in engineering applications, including asphalt paving, when it is both cost effective and it can be properly engineered. States are not required to use crumb rubber in asphalt paving, but, when requested, FHWA provides technical assistance and will continue to provide technology transfer. FHWA has a number of CRM research projects underway, and the need for additional research related to engineering aspects is not anticipated.

The FHWA has three major CRM research contracts underway or nearing completion. One of these contracts addresses worker health related issues. The other two FHWA-sponsored research contracts address engineering aspects related to the use of crumb rubber as an asphalt binder modifier. Industry and agency representatives are involved in the research contracts now underway. These studies, described briefly below, were the result of ISTEA provisions.

Under an interagency agreement between the National Institute for Occupational Safety and Health (NIOSH) and the FHWA, funding was provided for NIOSH researchers to evaluate possible differences in the occupational exposures and potential health effects of crumb rubber modified hot mix asphalt and conventional HMA, as used in highway paving operations. To date, health hazard evaluations have been completed at seven paving projects around the country (Michigan, Indiana, Florida, Arizona, Massachusetts, California(2)). The repeal of the mandated use of crumb rubber has made it difficult to find additional suitable field tests, so NIOSH's overall assessment will be made using data from the seven projects evaluated to date. While NIOSH has released some preliminary data on the individual projects, a report documenting overall conclusions, risk assessments, or recommendations has not yet been issued. This composite report addressing issues of sampling methods, worker exposures, and health effects associated with conventional versus CRM asphalt paving is due by the end of 1998. While summary conclusions have not yet been made, the data from individual projects indicates that air and breathing zone samples for total particulates, polycyclic aromatic compounds (PACs), and benzene soluble particulate fractions (BSF) were generally higher during CRM paving, but levels for both CRM and conventional did not exceed recommended exposure limits.

Under Section 6016 of ISTEA, the Western Research Institute-Laramie, Wyoming (WRI) is conducting research for FHWA on the fundamental properties of asphalt. As a part of this research, WRI investigated the interaction between asphalt and CRM. Under provisions in the Transportation Efficiency Act for the 21st Century (TEA-21), WRI will be summarizing their previous research.

In September 1994, FHWA awarded a research contract to Oregon State University-Corvallis, Oregon (OSU).

This is approximately a \$2.5 million pooled-fund effort with thirty-three States participating. This research involved the design, construction, and evaluation of asphalt pavement containing recycled rubber using different mixtures, plant configurations, and environmental conditions for both recyclability and performance. The primary objective of this research was to develop mixture and construction guidelines for crumb rubber modified asphalt pavements. OSU is scheduled to provide FHWA with these guidelines in December 1998. Another product of this research was the development of a document that summarizes the practices in three States (Arizona, California, and Florida) that have relatively more experience in CRM usage.

In addition to FHWA's contracted research projects, we are conducting an in-house research project to establish the performance of a chemically modified crumb rubber modifier (CMCRM) developed by FHWA researchers. The CMCRM has been developed by FHWA researchers in an effort to improve the overall performance of asphalt binder. The product is still in the experimental stages of development, however, initial indications of its performance are promising. In conjunction with extensive laboratory testing of the CMCRM product, an agreement has been made with a crumb rubber manufacturer and the several States to lay down test sections so that field performance of the CMCRM can be determined. An initial project was recently placed in Connecticut and the large scale production of this process appears to be successful. With time, an evaluation of its performance will indicate whether this is a cost-effective use of the technology.

FHWA is also coordinating its CRM research with the National Cooperative Highway Research Program (NCHRP). NCHRP 9-10 is a research project entitled "Superpave Protocols for Modified Binders." FHWA is currently reviewing a proposal submitted by the NCHRP 9-10 researchers to establish Superpave asphalt binder protocols for CRM asphalt. It is anticipated that this proposal will be approved and the current NCHRP 9-10 research on modified binders will be expanded to specifically include CRM and CMCRM.

FHWA/NIOSH ACTIVITIES

Background

An interagency agreement between the National Institute for Occupational Safety and Health (NIOSH) and the Department of Transportation, Federal Highway Administration (FHWA) provided funding for NIOSH researchers to evaluate possible differences in the occupational exposures and potential health effects of crumb rubber modified (CRM) hot mix asphalt (HMA) and conventional HMA, as used in highway paving operations. This exposure and health evaluation has been performed through a series of seven NIOSH Health Hazard Evaluations (HHEs) conducted from 1994 through 1997. The specific objectives of the HHEs include: 1) characterization of occupational exposures to CRM asphalt and conventional asphalt using available methods; 2) development and field testing of new analytical methods to evaluate asphalt fume exposures; and 3) collection of information concerning the potential health effects associated with CRM in HMA compared with conventional HMA exposures. Additionally, this interagency agreement was amended to reflect another important goal, the development and evaluation of engineering controls to reduce road worker exposures to asphalt fumes during paving operations. This engineering control research was conducted through NIOSH's Division of Physical Science and Engineering, Engineering Control and Technology Branch (DPSE, ECTB).

Crumb Rubber Related Health Risk Evaluation

As a result of the crumb rubber provisions of ISTEA, FHWA entered into this interagency agreement with NIOSH to evaluate the potential increase in environmental and human health effects associated with the use of crumb rubber modified (CRM) asphalt. To be included in the evaluation, a suitable site must 1) include both conventional and CRM hot mix asphalt (HMA) pavement that use asphalt binder from the same crude source, 2) have sufficient quantities of both mixtures to allow at least three days of monitoring, and 3) include a CRM wet process with at least 8 kg of crumb rubber per metric ton of mix. To date, site evaluations have been performed at seven paving projects around the country (Michigan, Indiana, Florida, Arizona, Massachusetts, California(2)). While NIOSH has released some preliminary data on the individual projects, a report documenting overall conclusions, risk assessments, or recommendations has not yet been issued.

Current Efforts

The repeal of the mandated use of crumb rubber has made it difficult to find additional suitable field tests, so NIOSH's overall assessment will be made using data from the seven projects evaluated to date. A composite report of the overall findings and conclusions is currently being prepared by NIOSH. This report will address issues of sampling methods, worker exposures, and health effects associated with conventional versus CRM asphalt paving. While summary conclusions have not yet been made, the data from individual projects indicates that air and breathing zone samples for total particulates, polycyclic aromatic compounds (PACs), and benzene soluble particulate fractions (BSF) were generally higher during CRM paving, but levels for both CRM and conventional did not exceed recommended exposure limits.

Engineering Controls for Asphalt Pavers

In December 1995, the Occupational Safety and Health Administration (OSHA) identified asphalt fumes as a priority for non-regulatory action. A significant step to control exposures to asphalt fumes through a non-regulatory process has been achieved by a cooperative effort between the asphalt industry, NIOSH, and FHWA. This effort has resulted in the January 1997 issuance of NIOSH's "Engineering Control Guidelines for Hot Mix Asphalt Pavers - Part 1, New Highway-Class Pavers."

Current Efforts

The NIOSH guidelines are voluntary compliance and state that, "each paver manufacturer should develop and install exhaust ventilation systems with a minimum controlled indoor capture efficiency of 80% on all new self-propelled HMA pavers weighing 16,000 pounds or more and manufactured after July 1, 1997." Provisions are also included for testing, certifying, and

maintaining the systems, as well as for training workers and inspectors in their use. On January 9, 1997, representatives from the paver manufacturers, Department of Labor, National Asphalt Paving Association (NAPA), FHWA, and the labor unions signed an agreement agreeing to the guidelines. Copies of the guidelines along with NAPA's Winter 1996 "Focus on HMA" which contains an article concerning this effort were distributed to FHWA's Region and Division Offices with a March 20, 1997 memo from FHWA's Director of the Office of Engineering.

NIOSH intends to address at a later date the application of engineering controls for nonhighway-class (weighing less than 16,000 pounds) pavers and for the retrofit of all existing pavers. It is anticipated that FHWA will be involved as these guidelines are developed and issued.

Planned Research

On June 24, 1997, NIOSH hosted a Forum on Asphalt Fume Health Effects Research. The meeting attendees included NIOSH researchers and attorneys and representatives from OSHA, FHWA, NAPA, the Asphalt Institute, labor unions, oil companies, contractors, and consultants. The purpose of the meeting was to present an update on the research efforts completed, underway, and planned on the health effects due to exposure to asphalt fumes.

In the area of new research, two independent efforts were discussed. In the more advanced of the two, NIOSH has a new facility in Morgantown, West Virginia that houses the Health Effects Laboratory Division (HELD). Once fully staffed, this division is planning a two-year chronic bioassay study of asphalt fumes. Under this research, field, chemistry, animal (male rats), and exposure studies are planned. NIOSH assured the industry representatives present for this meeting that they would be kept involved as the specific protocols were developed.

The other planned effort is in its early stages, where representatives of the unions representing laborers and operating engineers have had discussions with NAPA about conducting a feasibility study on asphalt exposure. The Asphalt Institute has also been involved in these discussions, but work is still pending.

5.4 University of New Hampshire Recycled Materials Resource Center

University of New Hampshire

Recycled Materials Resource Center

TEA-21 Provision [Section 5117(b) (8)] Transportation Technology Innovation and Demonstration Program

- Establishes Center at UNH
- Designates Activities
- Authorizes the use of Test Site /
Demonstration Projects Under Actual
Field Conditions

TEA-21 Provision [Section 5117(b) (8)] Transportation Technology Innovation and Demonstration Program (continued)

- Provides for Review and Evaluation
NLT Every 2 Years
- Funds at \$1,500,000/yr for 6 years

UNH/FHWA Cooperative Agreement to Establish the Technical/Administrative/ Financial Process to Carry out TEA-21

- Best Addresses the intent of
TEA-21
- Recognizes the Technical/
Administrative Strengths of UNH
Consortium

UNH/FHWA Cooperative Agreement to Establish the Technical/Administrative/ Financial Process to Carry out TEA-21 (continued)

- Strengthens Existing Partnership
Between UNH/FHWA
- Addresses Common Objectives/Areas
of Interest

UNH/FHWA Cooperative Agreement to Establish the Technical/Administrative/ Financial Process to Carry out TEA-21 (continued)

- Permits Interaction /Participation of
Federal/State/Industry/Academia in
Carrying Out TEA-21 Provisions
- Allows for Flexibility in Center
Operation/Scheduling and Financing

UNH/FHWA Cooperative Agreement to Establish the Technical/Administrative/Financial Process to Carry out TEA-21 (continued)

- Contains Checks/Balances Through Government Acquisition Procedures/Regulations

Events in Secondary Materials Leading up to UNH Recycled Materials Resource Center (continued)

- OECD Scientific Group Participation "Recycling Strategies for Road Works"
- UNH Cooperative Agreements under 1997 DOT Appropriations Act
- User Guidelines Publication

Events in Secondary Materials Leading up to UNH Recycled Materials Resource Center (continued)

- Development of Master Secondary Materials Plan in Conjunction with Pavement Technology Program/PMCG
- Activities by Other Offices Recognized
- Establishment of Internal FHWA Secondary Materials Team

Events in Secondary Materials Leading up to UNH Recycled Materials Resource Center (continued)

- Requests for Technical/Program Assistance/Information
 - ◆ Internet Secondary Materials Site
 - ◆ Case Studies Site
 - ◆ Technical/Program Participation

Center Operation

- Key Personnel
- Center Advisory Board
- Strategic Plan
- Annual Work Plans

Center Operation (continued)

- Website/Clearinghouse Activities
- Self Evaluation Program
- Center Financial Plan Designed to Leverage Funds

Center Research

- Materials Specific R&D Projects
- New Materials and Innovative Technology
- Investigative Research Projects

Center Research (continued)

- Small Research Projects
- Testing and Evaluation Guidelines Projects
- Test and Field Demonstration Participation Projects

Center Research (continued)

- Jump Start Several Projects of Particular Interest to UNH
- Each New Project to Contain Proposal/Work Plan/Budget
- Opportunity for Participation by Others

Center Research (continued)

- Work with Board /FHWA/Others in Looking at Candidate Projects
- Need to Identify Potential Test & Field Demonstration Projects

Center Outreach

- Conference Co-sponsorship
- Conference Participation
- Seminars/Scientific Exchanges
- Scanning Visit

Center Outreach (continued)

- Short Course/Training Program
- Technical Support Team
- Technical Resources Include UNH/Outside/ International
- Coordination with NHI/UNH T² Center

*** FHWA Activities**

- Maintain FHWA Databases Currently Under Development
- Updates of Web Based Products/ Electronic Versions of Published Material
- Co-Sponsorship for Secondary Materials Technical Seminars/ Conferences/ Scanning Visits

*** FHWA Activities**

- Development of "Handbook of Recycling Information"
- Development of Multimedia High-Tech Exhibit on Waste/Recycling
- Within House Research Studies -
 - ♦ Recyclability Issues
 - ♦ Maintenance Management Techniques
 - ♦ Improvement of Post Consumer Waste Streams

**** Test and Demonstration**

- Federal-Aid Construction Projects with SP&R/Other Evaluations in Combination with UNH Participation

Transportation Equity Act for the 21st Century

- Provides for a Transportation Technology Innovation and Demonstration Program
- Establishes a Recycled Materials Resource Center at UNH

Transportation Equity Act for the 21st Century (continued)

- Builds on Recycling/Waste Utilization Language Contained in 1997 DOT Legislation & Activities Underway at UNH

Transportation Equity Act for the 21st Century (continued)

- Designates Specific Activities/Test Sites and Demonstration Projects/ Center Evaluation Procedures
- Funds the Center at Total of \$9 Million over 6 years

UNH/FHWA Cooperative Agreement

- Utilizes Strong UNH Professional/Support Staff
- Builds on Technical Strength of UNH Consortium Previously Established
 - ◆ Rutgers University
 - ◆ Cornell University
 - ◆ University of Rhode Island

UNH/FHWA Cooperative Agreement (continued)

- ◆ Corps of Engineers Cold Regions Lab
- ◆ National Renewable Energy Lab
- ◆ International Partners
 - ◆ Sweden (Dr. Harten)
 - ◆ Netherlands (Dr. Van Der Sloot)
 - ◆ Japan (Dr. Sakai)

UNH/FHWA Cooperative Agreement (continued)

- Uses Expert Task Groups Where Appropriate
 - ◆ FHWA
 - ◆ State DOT's
 - ◆ Federal/State EPA's
 - ◆ Industry Members
 - ◆ Associations
 - ◆ Academia