



MERCOSUR/ GADCIVT-LV /ACTA N° 02/24

**III REUNIÓN DEL GRUPO AD HOC CIVT PARA VEHÍCULOS ESPECIALES Y
LIMITADOR DE VELOCIDAD (GADCIVT-LV)**

Se realizó por sistema de videoconferencia, según lo establecido en la Resolución N° 19/12 "Reuniones por el Sistema de Videoconferencia", bajo la Presidencia Pro Tempore de Uruguay (PPTU), el día 23 de agosto de 2024, la III Reunión Ordinaria del Grupo Ad Hoc CIVT para Vehículos Especiales y Limitador de Velocidad, en el marco de la V Reunión Ordinaria de la Comisión Técnica del Subgrupo de Trabajo N° 5 "Transporte" con la participación de las Delegaciones de Argentina, Brasil, Paraguay y Uruguay.

Las Delegación de Chile participó por el sistema de videoconferencia de conformidad a la Decisión CMC N° 18/04 "Régimen de Participación de los Estados Asociados al MERCOSUR".

La Lista de Participantes consta como ANEXO I.

La Agenda consta como ANEXO II.

El Resumen del Acta consta como ANEXO III.

En la reunión fueron tratados los siguientes temas:

**1. REVISIÓN DE LA RESOLUCIÓN N°35/19 SOBRE LA BASE DE LA
RESOLUCIÓN GMC N°45/17 – LIMITADORES DE VELOCIDAD**

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La delegación de Uruguay realizó una presentación relativa a las definiciones que contiene el Reglamento Técnico MERCOSUR de Limitadores de Velocidad aprobado por la Resolución GMC N°35/19, en la cual además planteó una serie de propuestas de parte de la delegación de Uruguay para el tratamiento del tema y para agregar a las propuestas de Revisión de la mencionada Resolución al amparo de la Resolución GMC N°45/17. La presentación se agrega como Anexo IV.

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En la exposición se describieron los dos tipos de funciones de ajustes de la velocidad que poseen los dispositivos, por un lado una función que permite establecer una velocidad fija que no puede ser rebasada, y por otro lado una velocidad ajustable por el conductor.

Asimismo, la propuesta concreta involucra el establecimiento de una fecha para que se comience a exigir la obligatoriedad del dispositivo de limitador de velocidad fijo y ajustable, para vehículos nuevos en la cual se describen las categorías de vehículos involucradas.

La propuesta también incluye el establecimiento de una velocidad máxima de "seteo" la cual deberá ser acordada por los países. Dicho valor debería ser superior a los máximos autorizados en cada Estado, a los efectos de contemplar las maniobras de emergencia que puede requerir realizar el conductor por motivos de seguridad. La delegación de Uruguay recordó además que los dispositivos son elementos de asistencia a la conducción y no de fiscalización, la cual se mantiene a cargo de los organismos inspectivos de los países

La delegación de Argentina agradeció la propuesta y reiteró su postura de que es necesario que se comience a exigir el dispositivo de limitador de velocidad a la brevedad, debiendo previamente definirse todas las cuestiones al respecto tales como los plazos de implementación, definición de las velocidades, categorías de los vehículos afectados, debiendo tener presente el no generar asimetrías o desigualdades para las empresas del sector.

La delegación de Brasil manifestó que el tema está siendo analizando internamente en su país por parte de la ANTT y de los demás organismos competentes, entre ellos la SENATRAN, la Policía Rodoviaria y los propios representantes ante la Comisión de la Industria Automotriz del SGT N°3. Señalaron además que se requiere de un estudio o análisis de impacto al tratarse de grandes flotas y parques vehiculares en su caso.

A su tiempo la delegación de Paraguay informó que el tema también se está analizando internamente en su país por la DINATRAN, por la Agencia Nacional de Tránsito y Seguridad Vial (ANTSV), y el Instituto Nacional de Tecnología, Normalización y Metrología, y consideraron la importancia de que se solicite la opinión del sector privado tanto de las empresas operadoras como de las empresas fabricantes de los vehículos.

La delegación de Chile se mostró interesada por el nuevo enfoque de la propuesta de Uruguay sobre todo en el dispositivo de ajuste variable de velocidad que no había sido mencionado en reuniones anteriores.

Las delegaciones acordaron realizar una evaluación preliminar de las propuestas de cara a la reunión de la Comisión Técnica del SGT N°5 y la forma de incorporar las mismas al proyecto de revisión del Reglamento a enviar al SGT N°3.

El tema continúa en agenda.

2. CITY PARA VEHÍCULOS ESPECIALES

La delegación de Uruguay realizó una presentación sobre el tratamiento de la inspección técnica de vehículos especiales en su país, repasando las definiciones relativas a vehículos especiales y cargas especiales, y realizó una propuesta en relación al formato del Certificado de Inspección Técnica Vehicular de este tipo de vehículos. La presentación se agrega como Anexo V.

Básicamente la propuesta de Uruguay consiste en consignar en el campo Observaciones al reverso del CAT, los floms relativos a las condiciones especiales de circulación y del vehículo para que los demás países las puedan apreciar en el mismo certificado.

La delegación de Argentina mencionó la su normativa vigente en su país, en concreto la Disposición de la SSTA N°1/2022, que establece en sus anexos el CAT para vehículos especiales. Manifestaron que analizarán la propuesta de Uruguay junto a su Dirección Nacional de Vialidad.

Del mismo modo, las delegaciones de Brasil y Paraguay agradecieron la propuesta la cual estarán analizando junto a los organismos competentes de sus países.

La delegación de Chile informó que en su país existe un sistema nacional licitado para las inspecciones técnicas vehiculares que cuenta con un manual de procedimiento. Frente a la dificultad de poder ingresar a la línea de inspección ciertos vehículos especiales entienden que la alternativa es contar con una inspección visual y que quedarán atentos a la propuesta definitiva.

El tema continúa en agenda.

3. ESTADO DE LA PROPUESTA DE REVISIÓN DE LAS RESOLUCIONES GMC N°65/08 y 26/11

La delegación de Uruguay realizó una presentación en la cual expuso en relación al contenido de dos propuestas para la modificación de las Resoluciones GMC N°65/08 y 26/11. La presentación se agrega como Anexo VI.

Las delegaciones intercambiaron pareceres en relación a los pesos y dimensiones admitidos en sus países, las necesidades del sector y la realidad actual de los vehículos que están circulando en la región. Además se incorporó a la discusión la cuestión de las asimetrías existentes en materia de tolerancias en los pesos en función de los diferentes sistemas de pesaje utilizados en los países.

Asimismo las delegaciones estuvieron de acuerdo en que el análisis de este tema involucra necesariamente tener en cuenta aspectos relacionados con la infraestructura, la situación actual de las empresas operadoras, de la industria automotriz, así como de los procedimientos de fiscalización de transporte, en la medida en que ya se encuentran circulando vehículos sobredimensionados. Se consideró relevante arribar a los entendimientos necesarios en estos temas para dar señales claras a las empresas y a la industria.

La delegación de Paraguay, manifestó que en su país existe una Comisión Técnica de Pesos y Dimensiones a cargo del MOPC, a quienes solicitarán su parecer con respecto a los proyectos de resoluciones y análisis de los anexos.

La delegación de Uruguay anunció que además de la presentación, elaboró dos borradores de proyectos de modificación de las Resoluciones mencionadas, los cuales se agregan como Anexo XVII los que propone sean analizados y eventualmente modificados considerando todos los aspectos mencionados previamente, a los efectos de lograr una norma aplicable y confiable para el control de los pesos y las dimensiones en el transporte internacional terrestre por carretera.

El tema será retomado en la reunión de la Comisión Técnica del SGT N°5.

4. PESOS ADMISIBLES EN EJES CON NEUMATICOS SUPERANCHOS

La delegación de Uruguay elaboró y realizó una presentación sobre una investigación sobre materiales y experiencias internacionales para evaluación de las delegaciones en relación a los pesos admisibles en ejes con neumáticos superanchos. La presentación se agrega como Anexo VIII.

La delegación de Argentina informó sobre su normativa relativa a los neumáticos superanchos establecida en el Decreto N°32/18 del Ministerio de Transporte, modificativo de la Resolución N°497/94.

Por su parte la delegación de Brasil aportó también su norma interna relativa a los "pneus extralargos", Resolución CONTRAN N° 913 de 28 de marzo de 2022.

Las delegaciones en general agradecieron la presentación y se comprometieron a analizar la misma para realizar sus comentarios y aportes al respecto.

El tema será retomado en la reunión de la Comisión Técnica del SGT N°5.

5. ACOPLADOS 4 EJES

La delegación de Uruguay realizó una presentación sobre su propuesta en torno a los vehículos acoplados de 4 ejes la cual se agrega como Anexo IX, la cual amplía el alcance a vehículos simples y establece sus características, los pesos admisibles y valor de carga ficta.

La delegación de Argentina aportó su normativa sobre el tema, en concreto el Anexo R del Decreto N°775/95 reglamentario de la Ley de Tránsito N°24.449 a los efectos de que sea tenida en cuenta en la propuesta.

Se aclaró en relación a la traducción de los términos utilizados al referirse al acoplado que es equivalente al remolque.

La delegación de Brasil tomó nota de los informes mencionados y mencionó que serán evaluadas internamente con los organismos competentes. Por fin, se comprometió presentar un parecer técnico en la próxima reunión.

El tema será retomado en la reunión de la Comisión Técnica del SGT N°5.

6. INFORME DE CUMPLIMIENTO DEL PROGRAMA DE TRABAJO 2023-2024 Y PROGRAMA DE TRABAJO 2025-2026

La PPTU recordó que se debe confeccionar el Informe de Cumplimiento del Programa de Trabajo 2023-2024 y el Programa de Trabajo 2025-2026 para lo cual circulará una propuesta a aprobar en las próximas reuniones virtuales.

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7. APORTES DEL SECTOR PRIVADO

El sector privado agradeció la posibilidad de participar en la reunión resaltando la importancia de la presencia de los organismos competentes en las cuestiones de vialidad para el análisis de los temas, y manifestó que en todo caso se ampliarán comentarios en la nota que habitualmente presentan en conjunto las empresas de transporte de carga internacional agrupadas en el CONDESUR en las reuniones plenarias.

PRÓXIMA REUNIÓN

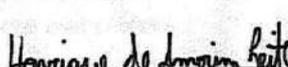
La próxima reunión del GADCITY-LV, será convocada oportunamente por la PPT.

ANEXOS

Los Anexos que forman parte de la presente Acta son los siguientes:

Anexo I	Lista de Participantes
Anexo II	Agenda
Anexo III	Resumen del Acta
Anexo IV	Presentación de Uruguay sobre la Revisión de la Resolución GMC N°35/19
Anexo V	Presentación de Uruguay sobre ITV de vehículos especiales
Anexo VI	Presentación de Uruguay sobre propuestas para la modificación de las Resoluciones GMC N°65/08 y 26/11
Anexo VII	Proyectos de Resolución GMC elaborados por Uruguay para la modificación de las Resoluciones GMC N°65/08 y 26/11
Anexo VIII	Presentación de Uruguay sobre pesos admisibles en ejes con neumáticos superanchos.
Anexo IX	Presentación de Uruguay sobre Acoplados de 4 ejes


Por la delegación de Argentina
Jorge Zarbo


Por la delegación de Brasil
Henrique De Amorim Leite


Por la delegación de Paraguay
Juan Velázquez


Por la delegación de Uruguay
Nicolás Van der Maesen



MERCOSUR/ GADCITY-LV /ACTA N° 02/24



**III REUNIÓN ORDINARIA DEL
GRUPO AD HOC CITY PARA VEHÍCULOS ESPECIALES Y LIMITADOR DE
VELOCIDAD**

**PARTICIPACIÓN DE ESTADOS ASOCIADOS
Ayuda Memoria**

La delegación Chile participó en su condición de Estados Asociado, de conformidad con lo establecido en la Decisión CMC N° 18/04, de la III Reunión Ordinaria del Grupo Ad Hoc CITY para Vehículos Especiales y Limitador de Velocidad (GADCITY-LV) en el tratamiento de los siguientes temas de la agenda y manifestó su acuerdo respecto al Acta.

Los temas tratados fueron:

1. REVISIÓN DE LA RESOLUCIÓN N°35/19 SOBRE LA BASE DE LA RESOLUCIÓN GMC N°45/17 – LIMITADORES DE VELOCIDAD
2. CITY PARA VEHÍCULOS ESPECIALES
3. ESTADO DE LA PROPUESTA DE REVISIÓN DE LAS RESOLUCIONES GMC N°65/08 y 26/11
4. PESOS ADMISIBLES EN EJES CON NEUMATICOS SUPERANCHOS
5. ACOPLADOS 4 EJES
6. INFORME DE CUMPLIMIENTO DEL PROGRAMA DE TRABAJO 2023-2024 Y PROGRAMA DE TRABAJO 2025-2026
7. APORTES DEL SECTOR PRIVADO

Por la delegación de Argentina
Jorge Barbo

Por la delegación Paraguay
Juan Velázquez

Por la delegación Brasil
Henrique De Amorim Leite

Por la delegación Uruguay
Nicolás Van der Maesen

Por la delegación Chile
Pablo Ortiz

**REUNIÓN ORDINARIA DEL
GRUPO AD HOC CIVT PARA VEHÍCULOS ESPECIALES Y LIMITADOR DE
VELOCIDAD (GADCITY-LV)**

23 de agosto de 2024

**ANEXO I
LISTA DE PARTICIPANTES**

DELEGACIÓN DE ARGENTINA

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DELEGACIÓN DE URUGUAY

NOMBRE	ORGANISMO	E-MAIL
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DELEGACIÓN DE CHILE

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**REUNIÓN ORDINARIA DEL
GRUPO AD HOC CITY PARA VEHÍCULOS ESPECIALES Y LIMITADOR DE
VELOCIDAD (GADCITY-LV)**

ACTA N° 02/2024

23 de agosto de 2024

ANEXO II

AGENDA

- 1. REVISIÓN DE LA RESOLUCIÓN N°35/19 SOBRE LA BASE DE LA RESOLUCIÓN GMC N°45/17 – LIMITADORES DE VELOCIDAD**
- 2. CITY PARA VEHÍCULOS ESPECIALES**
- 3. ESTADO DE LA PROPUESTA DE REVISIÓN DE LAS RESOLUCIONES GMC N°65/08 y 26/11**
- 4. PESOS ADMISIBLES EN EJES CON NEUMATICOS SUPERANCHOS**
- 5. ACOPLADOS 4 EJES**
- 6. INFORME DE CUMPLIMIENTO DEL PROGRAMA DE TRABAJO 2023-2024 Y PROGRAMA DE TRABAJO 2025-2026**
- 7. APORTES DEL SECTOR PRIVADO**

**REUNIÓN ORDINARIA DEL
GRUPO AD HOC CITV PARA VEHÍCULOS ESPECIALES Y LIMITADOR DE
VELOCIDAD (GADCITV-LV)**

23 de agosto de 2024

ANEXO III

RESUMEN DEL ACTA

I - BREVE INDICACIÓN DE LOS TEMAS TRATADOS

Fueron tratados todos los temas de la Agenda, que consta como Anexo II del Acta N°02/24 del Grupo Ad Hoc CITV para Vehículos Especiales y Limitador de Velocidad.

II - PROYECTOS DE NORMAS

No se eleva.

III - DOCUMENTOS ELEVADOS A CONSIDERACIÓN DEL SGT N°5/CT

No se eleva.

IV - SOLICITUDES AL GMC

No se eleva.

V REUNIÓN ORDINARIA DE LA COMISIÓN TÉCNICA DEL SUBGRUPO DE TRABAJO N°5 “TRANSPORTE” DEL MERCOSUR



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GRUPO AD HOC CITV PARA VEHÍCULOS ESPECIALES Y LIMITADOR DE VELOCIDAD (GADCITV-LV)

REVISIÓN DE LA RESOLUCIÓN GMC N° 35/19 SOBRE LA BASE DE LA RESOLUCIÓN GMC N° 45/17



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REVISIÓN DE LA RESOLUCIÓN GMC N° 35/19 SOBRE LA BASE DE LA RESOLUCIÓN GMC N° 45/17

DEFINICIONES/SIGLAS

Limitación de velocidad (V): la velocidad máxima del vehículo, cuyo diseño o equipamiento no permite una respuesta después de una acción positiva sobre el mando del acelerador.

Velocidad limitada ajustable (Vadj): la velocidad fijada voluntariamente por el conductor.



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REVISIÓN DE LA RESOLUCIÓN GMC N° 35/19 SOBRE LA BASE DE LA RESOLUCIÓN GMC N° 45/17

Función de limitación de velocidad: función destinada a controlar la alimentación de combustible del vehículo o la gestión del motor para limitar la velocidad del vehículo a un valor máximo fijado.

Función ajustable de limitación de velocidad (FALV): función que permite al conductor fijar una velocidad limitada (V_{adj}) y que, cuando está activada, limita automáticamente el vehículo a dicha velocidad.



REVISIÓN DE LA RESOLUCIÓN GMC N° 35/19 SOBRE LA BASE DE LA RESOLUCIÓN GMC N° 45/17

Dispositivo de limitación de velocidad “DLV”: dispositivo cuya principal función es la de controlar la alimentación de combustible o la gestión del motor con el fin de limitar la velocidad del vehículo en el valor especificado.

Dispositivo ajustable de limitación de velocidad (DALV): dispositivo que permite al conductor fijar una velocidad limitada ajustable (V_{adj}) y que cuando está activado, limita automáticamente el vehículo a dicha velocidad.



REVISIÓN DE LA RESOLUCIÓN GMC N° 35/19 SOBRE LA BASE DE LA RESOLUCIÓN GMC N° 45/17

La función del dispositivo de limitación de velocidad DLV y las conexiones necesarias para su operación, excepto las esenciales para el funcionamiento del vehículo, deberán ser protegidas de cualquier ajuste no autorizado y de la interrupción del suministro de energía, mediante un sistema que asegure su inviolabilidad.

La función del DALV no deberá afectar a la velocidad del vehículo en circulación si se aplica una acción positiva en el acelerador cuando el vehículo circula a la velocidad fijada. (* propuesta modificación 5.6)



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REVISIÓN DE LA RESOLUCIÓN GMC N° 35/19 SOBRE LA BASE DE LA RESOLUCIÓN GMC N° 45/17

PROPUESTA DE URUGUAY:

Todo nuevo vehículo 0 Km de las categorías M2, M3, N2 y N3 que se incorpore al parque vehicular de los Estados Partes a partir del 1° de setiembre de 2025 deberá estar equipado con sistemas de limitadores de velocidad fijo (DLV) y ajustable (DALV) provistos por la terminal automotriz (fábrica).



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REVISIÓN DE LA RESOLUCIÓN GMC N° 35/19 SOBRE LA BASE DE LA RESOLUCIÓN GMC N° 45/17

PROPUESTA DE URUGUAY:

- La velocidad media de seteo de los dispositivos de limitación de velocidad DLV deberá ser de 135 Km/h.
- La velocidad limitada ajustable (V_{adj}) de los DALV podrá ser fijada voluntariamente por el conductor a la velocidad máxima autorizada por el Estado Parte correspondiente para el tipo de vehículo y para el tramo de la red vial por la cual circula.



MUCHAS GRACIAS



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LXVI REUNIÓN ORDINARIA DEL SUBGRUPO DE TRABAJO N°5 “TRANSPORTE” DEL MERCOSUR



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ITV de vehículos especiales

Área Ingeniería de Transporte



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Definiciones

Vehículos especiales: Serán aquellos que no tienen capacidad de carga, es decir, solamente pueden transportar su tara. Ejemplo grúas autoportantes, bombas de hormigón, etc. Estos se registrarán como Vehículo especial.



Distinción para vehículos especiales de carga.

Vehículos de carga con condiciones especiales de circulación: Todo vehículo autopropulsado o remolcado, con peso bruto mayor a 3,5t cuya configuración de ejes, dimensiones y/o pesos totales o por eje difieran de las reglamentarias o por su uso cuentan con equipamiento fijo en la caja de carga que lo limita en la capacidad de carga. Se registrarán con un tipo de vehículo correspondiente a su naturaleza.



CAT

En el certificado emitido (CAT) deberá figurar con la siguiente leyenda en la parte de observaciones en todo caso: “Vehículo con condiciones especiales de circulación.”

Y dependiendo del caso:

- A) PESOESP – figurará el peso en orden de marcha en sus ejes y ó conjuntos de ejes
- B) DIMSIMP - Velocidad máxima de circulación: 50km/h. No circular de noche, con tormenta o con visibilidad menor a 1km. En tramos angostos de ancho menor a 9 m, circular con acompañamiento de un vehículo ubicado delante, con una luz destellante color ambar. Señalización lateral y posterior reglamentaria, indicando dimensiones.
- C) DIMESP - Este vehículo solo podrá circular con un permiso especial específico para cada viaje.
- D) DIMVAR- Vehículo con dimensiones variables en el: ancho, alto, largo, altura de cama, etc. Dependiendo del caso.
- E) NEUMAESP- nada.
- F) SALIENTES - Especificar dimensión de saliente y ubicación.



CAT

Según formato RES
GMC 65/08

REPUBLICA ORIENTAL DEL URUGUAY DIRECCION NACIONAL DE TRANSPORTE		AUTENTICACION ELECTRONICA- AUTENTICAÇÃO ELECTRONICA
MERCOSUR CERTIFICADO N° 456197		DIMENSIONES DEL VEHICULO / DIMENSÕES DO VEICULO
CERTIFICADO DE APTITUD TECNICA = CAT CERTIFICADO DE REVISIÓN TECNICA CERTIFICADO DE INSPEÇÃO TECNICA VEICULAR = CITY		20 ALTURA/AUTURA: 21 ANCHO/LARGURA: 22 LARGO/COMPRIMENTO:
VTP <input type="checkbox"/> VTC <input type="checkbox"/>		CHASIS BASTIDOR / CHASSI
Certifico que el vehículo identificado en el presente, cumple las exigencias establecidas en la Resolución GMC 75 / 97. Certifico que o veículo identificado no presente, cumpre as exigencias estabelecidas na Resolução GMC 75 / 97.		23 MARCA/MARCA: 24 MODELO/MODELO: 25 NUMERO/NUMERO: 26 CANTIDAD DE EJES/CANTIDADE DE EIXOS: 27 TIPO DE TRINQUE/TIPO DE EIXO (*): 28 TARA/TARA (*): 29 PESO BRUTO TOTAL/PESO BRUTO TOTAL: 30 CAPACIDAD/LOTACAO(*): 31 CMT/CMT (*):
01 TITULAR/PROPIETARIO: 02 R.U.D.C.I./D.N.U.C.P.E.L: 03 DOMICILIO/ENDEREÇO: 04 CIUDAD/MUNICIPIO: 05 CODIGO POSTAL/C.P. (*): 06 TELEFONO/TELEFONE: 07 E-MAIL/E-MAIL (*): 08 DEPARTAMENTO/PROVINCIA/UF:		MOTOR / MOTOR
09 MATRICULA/DOMINIO/PLACA: 10 REGISTRO/REGISTRO: 11 AÑO/AÑO: 12 CATEGORIA VEHICULO/CATEGORIA VEICULO:		32 NUMERO/NUMERO(*): 33 COMBUSTIBLE/COMBUSTIVEL(*): 34 POTENCIA/POTENCIA(*):
13 FECHA DE INSPECCION/DATE DE INSPEÇÃO: 14 FECHA DE EMISION/DATE DE APROVAÇÃO: 15 FECHA DE VENCIMIENTO/DATE DE VENCIMENTO: 16 CENTRO DE REVISION TECNICA/ NOME DO ORGÃO DE INSPEÇÃO: 17 CODIGO CENTRO DE REVISION/ CODIGO DO ORGÃO DE INSPEÇÃO: 18 RESPONSABLE TECNICO/ RESPONSÁVEL TÉCNICO: 19 N° DE REGISTRO N° DE REGISTRO:		PARA VEHICULOS DE PASAJEROS / PARA VEICULOS DE PASSAGEIROS
FIRMA RESP. TECNICO ASSINATURA RESP. TÉCNICO		35 MARCA CARROTERIA/MARCA CARROÇARIA: 36 CLASE DE SERVICIO/CLASSE DE SERVIÇO: 37 TIPO/TIPO: 38 CANTIDAD DE ASIENTOS/QUANTIDADE DE ASSENTOS:
*Llenado no obligatorio / Item de preenchimento facultativo		PARA VEHICULOS DE CARGA / PARA VEICULOS DE CARGA
ORIGINAL		39 CLASE DE CARGA/CLASSE DA CARGA: 40 TIPO DE VEHICULO/CLASSE DE VEICULO: 41 TIPO DE CAJA/TIPO DE CAIXA:
cuatrocinco seisuno nueveocho		TACÓGRAFO REGISTRADOR DE VELOCIDAD/REGISTRADOR DE VELOCIDADE
		42 MARCA/MARCA (*): 43 NUMERO/NUMERO (*):
		OBSERVACIONES / OBSERVAÇÕES
		A B C MIRAR REVERSO



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CAT

REVISIÓN A LA VERA DE LA RUTA

OBSERVACIONES REVISIÓN:

ACA IRIAN LAS ESPECIFICACIONES

REVISIÓN A LA VERA DE LA RUTA

FECHA	LUGAR	OBSERVACIONES	RESPONSABLE FIRMA / ACLARACION	SELLO



Cuando no puedan ingresar

Vehículos especiales se deberán inspeccionar en todos los casos salvo cuando:

1) La trocha de exterior de neumático a exterior de neumático supere los 3 metros

2) El eje tenga más de 4 neumáticos, impidiendo así su ingreso a fosa.

En estos casos la inspección será visual, y, en el CAT deberá figurar la leyenda: VEHICULO CON INSPECCION VISUAL, NO CIRCULAR A MAS DE 30 KM/H, NO INGRESÓ A FRENÓMETRO.



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V REUNIÓN ORDINARIA DE LA COMISIÓN TÉCNICA DEL SUBGRUPO DE TRABAJO N°5 “TRANSPORTE” DEL MERCOSUR



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GRUPO AD HOC CIVT PARA VEHÍCULOS ESPECIALES Y LIMITADOR DE VELOCIDAD (GADCITV-LV)

PROPUESTA DE REVISIÓN DE LAS RESOLUCIONES GMC N°65/08 Y N°26/11



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REVISIÓN DE LAS RESOLUCIONES GMC Nº 65/08 Y Nº 26/11

PBM total	6,0	10,5
		
PBM total	10,0	18,0
		
PBM por eje constituyente	<u>6</u> <u>6</u>	<u>10</u> <u>10</u>
PBM total	14,0	
		
PBM por eje constituyente	6 10	
PBM total	15,0	25,5
		
PBM por eje constituyente	<u>6</u> <u>6</u> <u>6</u>	<u>9</u> <u>9</u> <u>9</u>
PBM total	22,0	25,5
		
PBM por eje constituyente	6 <u>9</u> <u>9</u>	<u>9</u> <u>9</u> <u>9</u> <u>9</u>

REFEENCIAS	
	Eje de dos neumáticos
	Eje de cuatro neumáticos



REVISIÓN E LA RESOLUCIÓN GMC N° 35/19 SOBRE LA BASE DE LA RESOLUCIÓN GMC N° 45/17

Nuevo Artículo: El Peso Bruto Total máximo de un vehículo simple de tipo ómnibus, camión, tractor, o remolque será igual a la sumatoria de los Pesos Brutos máximos de sus grupos de ejes, con un tope máximo de 28,5t.

Artículo modificado: El límite máximo para el Peso Bruto Total de las combinaciones de camión con remolque o tractor con semirremolque será igual a la sumatoria de los Pesos Brutos máximos de sus grupos de ejes, con un tope máximo de 45t.



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REVISIÓN DE LAS RESOLUCIONES GMC Nº 65/08 Y Nº 26/11

Largo máximo (m)	
Camión simple	14,0
Camión con remolque	20,0
Remolque	8,6
Tractor con semirremolque	18,6
Ómnibus de larga distancia	15,0
Ancho máximo (m)	2,6
Altura máxima (m)	4,3



REVISIÓN DE LAS RESOLUCIONES GMC Nº 65/08 Y Nº 26/11

No será necesario tener en cuenta para la determinación del **ancho máximo** del vehículo los siguientes dispositivos y equipos:

- Dispositivos de visión indirecta
- Parte abultada del neumático en el punto de contacto con la calzada
- Indicadores de defecto y/o presión de los neumáticos
- Luces de galíbo, luces indicadoras de dirección, luces de posición, ni catadióptricos laterales
- Estribos de acceso, asideros, escalones, rampas de acceso, plataformas ni pasarelas, siempre que no sobresalgan más de diez centímetros (10cm) por los lados del vehículo y siempre que sus vértices estén redondeados con un radio no inferior a los cinco centímetros (5cm) y sus bordes estén redondeados con un radio no inferior a dos centímetros y medio (2,5cm).
- Dispositivos para sujetar la lona y sus protecciones, siempre que no sobresalgan más de cinco centímetros (5cm) por los lados del vehículo y siempre que sus bordes estén redondeados con un radio no inferior a dos centímetros y medio (2,5cm).



REVISIÓN DE LAS RESOLUCIONES GMC Nº 65/08 Y Nº 26/11

Para la verificación de la **altura total** no será necesario tener en cuenta las antenas de radio o radionavegación para la determinación de la altura del vehículo.

Para la verificación del **largo máximo** de los vehículos, no será necesario tener en cuenta los dispositivos de visión indirecta, limpiaparabrisas, parasoles exteriores, placas de matrícula, accesorios de observación y detección tales como radares, plataformas elevadoras o rampas de acceso (siempre que no sobresalgan más de treinta centímetros), ni dispositivos para sujetar la lona y sus protecciones (siempre que no sobresalgan más de cinco centímetros y siempre que sus bordes estén redondeados con un radio no inferior a dos centímetros y medio).

Para los vehículos de tipo remolque las barras de tracción (lanzas) deberán estar en posición horizontal y alineada con la línea central del vehículo al momento de la medición, debiendo además en el caso de barras de tracción regulables estar en su posición más extendida.



REVISIÓN DE LAS RESOLUCIONES GMC Nº 65/08 Y Nº 26/11

- CCU DE Camión de 2 ejes: 8 t
- CCU DE Camión de 3 ejes: 14 t
- CCU DE Camión de 4 ejes: 14 t
- CCU DE Remolque de 2 ejes: 13 t
- CCU DE Remolque de 3 ejes: 19 t.
- CCU DE Remolque de 4 ejes: 19 t.
- CCU DE Semirremolque de 1 eje: 12 t.
- CCU DE Semirremolque de 2 ejes: 18 t.
- CCU DE Semirremolque de 3 ejes: 23 t.
- CCU DE Semirremolque de cuatro ejes o más: 25t.

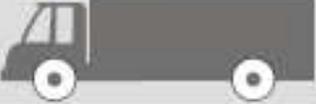


REVISIÓN DE LAS RESOLUCIONES GMC Nº 65/08 Y Nº 26/11

- CCU DE Semirremolque de 2 ejes simples de cuatro ruedas separados una distancia mayor a 2,40m: 19t
- Ccu DE Semirremolque de un eje simple de cuatro ruedas y un eje doble de ocho ruedas separados una distancia mayor a 2,40m: 23t
- Ccu de semirremolque de 3 ejes simples de cuatro ruedas separados una distancia mayor a 2,40m: 23t
- Ccu DE trACTOR DE 3 EJES: 5t



REVISIÓN DE LAS RESOLUCIONES GMC Nº 65/08 Y Nº 26/11

	Combinación	PBT máximo (t)	CCU (t)
C11		12,0	8,0
C11		16,5	8,0
C12		24,0	14,0
C22		28,0	14,0



REVISIÓN DE LAS RESOLUCIONES GMC Nº 65/08 Y Nº 26/11

	Combinación	PBT máximo (t)	CCU (t)
C11-R11		16,5+21,0 → 37,5	8,0+13,0=21,0
C11-R12		16,5+28,5 → 45,0	8,0+19,0=27,0
C11-R22		16,5+28,5 → 45,0	8,0+19,0=27,0
C12-R11		24,0+21,0 → 45,0	14,0+13,0=27,0
C12-R12		24,0+28,5 → 45,0	14,0+19,0=33,0
C12-R22		24,0+28,5 → 45,0	14,0+19,0=33,0



REVISIÓN DE LAS RESOLUCIONES GMC Nº 65/08 Y Nº 26/11

	Combinación	PBT máximo (t)	CCU (t)
T11-S1		16,5+10,5 → 27,0	12,0
T11-S2		16,5+18,0 → 34,5	18,0
T11-S11		16,5+21,0 → 37,5	19,0
T11-S111(*)		16,5+23,3 → 39,8	23,0
T11-S12		16,5+28,5 → 45,0	23,0
T11-S3		16,5+25,5 → 42,0	23,0



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REVISIÓN DE LAS RESOLUCIONES GMC Nº 65/08 Y Nº 26/11

	Combinación	PBT máximo (t)	CCU (t)
T12-S1		24,0+10,5 → 34,5	5,0+12,0=17,0
T12-S2		24,0+18,0 → 42,0	5,0+18,0=23,0
T12-S11		24,0+21,0 → 45,0	5,0+19,0=24,0
T12-S111(*)		24,0+23,3 → 45,0	5,0+23,0=28,0
T12-S12		24,0+28,5 → 45,0	5,0+23,0=28,0
T12-S3		24,0+25,5 → 45,0	5,0+23,0=28,0



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REVISIÓN DE LAS RESOLUCIONES GMC Nº 65/08 Y Nº 26/11

	Combinación	PBT máximo (t)	CCU (t)
T11-S4		16,5+25,5 → 42,0	25,0
T12-S4		24,0+25,5 → 45,0	5,0+25,0=30,0



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MERCOSUR/GMC/RES. N° xx/24

SISTEMA NORMALIZADO DE MEDICIÓN DE LA CARGA ÚTIL DE LOS VEHÍCULOS DE TRANSPORTE INTERNACIONAL DE CARGAS

VISTO: El Tratado de Asunción, el Protocolo de Ouro Preto y las Resoluciones N° 58/94 y 14/06 del Grupo Mercado Común.

CONSIDERANDO:

Que es pertinente contemplar las nuevas configuraciones de ejes de vehículos de transporte de cargas por carretera en el MERCOSUR en el momento de asignar la carga útil convencional en el marco de lo establecido en la Resolución GMC N° 58/94, con la redacción dada en el artículo 1 de la Resolución GMC N° 14/06.

**EL GRUPO MERCADO COMÚN
RESUELVE:**

Art. 1 - Sustituir el numeral 6 literal a) del Anexo de la Resolución GMC N° 58/94, con la redacción dada por el Artículo 1° de la Resolución GMC N° 14/06, por el siguiente texto:

"Ser propietaria de una flota que tenga una capacidad transportativa dinámica total mínima de 80 (ochenta) toneladas, la cual podrá integrarse a través de equipos del tipo tractor con semirremolque, camiones con acoplado, o vehículos del tipo camión, que se determinará tomando en cuenta los valores de carga útil convencional que se indican a continuación:

- Camión de 2 ejes: 8 t
- Camión de 3 ejes: 14 t
- Camión de 4 ejes: 14 t
- Remolque de 2 ejes: 13 t
- Remolque de 3 ejes: 19 t.
- Remolque de 4 ejes: 19 t.
- Semirremolque de 1 eje: 12 t.
- Semirremolque de 2 ejes: 18 t.
- Semirremolque de 3 ejes: 23 t.
- Semirremolque de 2 ejes simples de cuatro ruedas separados una distancia mayor a 2,40m: 19t.
- Semirremolque de un eje simple de cuatro ruedas y un eje doble de ocho ruedas separados una distancia mayor a 2,40m: 23t
- Semirremolque de 3 ejes simples de cuatro ruedas separados una distancia mayor a 2,40m: 23t
- Semirremolque de cuatro ejes o más: 25t.

Cada tractor de tres (3) ejes implicará un aumento de cinco (5) toneladas a los efectos del cálculo de la capacidad transportativa.

Los valores indicados anteriormente serán independientes del tipo de carrocería, no existiendo por lo tanto diferencia entre vehículos de carga general, refrigerada, líquida y otras especializadas".

Art. 2 – Esta Resolución deberá ser incorporada al ordenamiento jurídico de los Estados Partes antes del 01/IX/2025.

GMC – Montevideo, 03/IX/24.

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Propuesta de modificación de RESOLUCIÓN GMC N° 26/01

MERCOSUR/GMC/RES. N° xx/24

**ACUERDO SOBRE PESOS Y DIMENSIONES DE VEHÍCULOS DE TRANSPORTE
POR CARRETERA DE PASAJEROS Y CARGAS**

VISTO: El Tratado de Asunción, el Protocolo de Ouro Preto.

CONSIDERANDO:

El “Acuerdo sobre Pesos y Dimensiones de Vehículos”, aprobado en la segunda reunión cuatripartita del Subgrupo de Trabajo N° 5 “Transportes” del Mercosur, celebrada entre los días 19 e 20 de junio de 1991;

Que es conveniente actualizar el referido Acuerdo a fin de adecuar sus disposiciones a la evolución técnica;

Que la presente norma busca establecer un equilibrio racional entre los parámetros actualmente utilizados en cada país miembro, a fin de minimizar el impacto técnico y económico-social de la presente armonización.

**EL GRUPO MERCADO COMUN
RESUELVE:**

Art. 1 - Aprobar el “Acuerdo sobre Pesos y Dimensiones para Vehículos de Transporte por Carretera de Pasajeros y Cargas”, que figura como Anexo y forma parte de la presente Resolución.

Art. 2 – Solicitar a los Estados Partes que instruyan a sus respectivas Representaciones ante la Asociación Latinoamericana de Integración (ALADI) a protocolizar el texto aprobado en la presente Resolución en la forma de Acuerdo de Alcance Parcial en el ámbito del Tratado de Montevideo de 1980, incluyendo una cláusula de vigencia en los términos del Artículo 2º del Anexo I de la Resolución GMC N° 43/03.

Art. 3 – Los Estados Partes deberán incorporar la presente Resolución a sus ordenamientos jurídicos internos antes del 01/IX/25.

GMC – Montevideo, 03/IX/2024

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Propuesta de modificación de RESOLUCIÓN GMC N° 26/01

ANEXO

**ACUERDO SOBRE PESOS Y DIMENSIONES DE VEHÍCULOS DE TRANSPORTE
 POR CARRETERA DE PASAJEROS Y CARGAS**

Artículo 1º. Fíjense los pesos y dimensiones a ser aplicados a la flota vehicular de los Estados Partes que realizan transporte internacional de cargas o pasajeros.

Artículo 2º. La circulación de vehículos especiales o conjuntos de vehículos que superen las dimensiones y/o pesos máximos establecidos en este Acuerdo, solamente se admitirá mediante el otorgamiento previo de autorizaciones especiales expedidas por las autoridades competentes en base a las normas establecidas en el país transitado.

Artículo 3º. La presente norma no obstaculizará la aplicación de las disposiciones vigentes en cada Estado Parte en materia de circulación por carretera que limiten los pesos y/o dimensiones de los vehículos en determinadas rutas o determinadas construcciones de ingeniería civil.

Artículo 4º. Los límites de pesos permitidos para la circulación de vehículos de transporte de carga y de pasajeros en el ámbito del MERCOSUR, son:

PBM total	6,0	10,5
		
PBM total	10,0	18,0
		
PBM por eje constituyente	6 6	10 10
PBM total	14,0	
		
PBM por eje constituyente	6 10	
PBM total	15,0	25,5
		
PBM por eje constituyente	6 6 6	9 9 9
PBM total	22,0	25,5
		
PBM por eje constituyente	6 9 9	9 9 9 9

REFEENCIAS	
	Eje de dos neumáticos convencionales
	Eje de cuatro neumáticos convencionales

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Propuesta de modificación de RESOLUCIÓN GMC N° 26/01

4.1 Se entiende por eje doble el conjunto de 2 (dos) ejes, cuya distancia entre centro de ruedas es igual o superior a 1,20 m e igual o inferior a 2,40 m.

4.2 Se entiende por eje triple el conjunto de 3 (tres) ejes, cuya distancia entre centro de ruedas es igual o superior a 1,20 m e igual o inferior a 2,40 m.

4.2 Se entiende por eje cuádruple el conjunto de 4 (cuatro) ejes, cuya distancia entre centro de ruedas es igual o superior a 1,20 m e igual o inferior a 2,40 m.

Artículo 5º. Hasta que sea armonizado un procedimiento de pesaje en el ámbito del MERCOSUR, regirá la norma vigente en el país transitado.

Artículo 6º. Las infracciones a las disposiciones establecidas en este Acuerdo son de carácter administrativo y serán sancionadas de acuerdo a las normas MERCOSUR vigentes, sin perjuicio de las responsabilidades civiles y penales derivadas.

Artículo 7º. El Peso Bruto Total máximo de un vehículo simple de tipo ómnibus, camión, tractor, o remolque será igual a la sumatoria de los Pesos Brutos máximos de sus grupos de ejes, con un tope máximo de 28,5t.

Artículo 8º. El límite máximo para el Peso Bruto Total de las combinaciones de camión con remolque o tractor con semirremolque será igual a la sumatoria de los Pesos Brutos máximos de sus grupos de ejes, con un tope máximo de 45t.

Artículo 9º. Las dimensiones máximas permitidas para la circulación de vehículos de transporte de carga y de pasajeros en el ámbito del MERCOSUR, son:

Largo máximo (m)	
Camión simple	14,0
Camión con remolque	20,0
Remolque	8,6
Tractor con semirremolque	18,6
Ómnibus de larga distancia	15,0
Ancho máximo (m)	
	2,6
Altura máxima (m)	
	4,3

Para la determinación de la **altura total** no será necesario tener en cuenta las antenas de radio o radionavegación.

No será necesario tener en cuenta para la determinación del **ancho máximo** del vehículo los siguientes dispositivos y equipos:

- Dispositivos de visión indirecta
- Parte abultada del neumático en el punto de contacto con la calzada
- Indicadores de defecto y/o presión de los neumáticos
- Luces de gálibo, luces indicadoras de dirección, luces de posición, ni catadióptricos laterales
- Estribos de acceso, asideros, escalones, rampas de acceso, plataformas ni pasarelas, siempre que no sobresalgan más de diez centímetros (10cm) por los lados del vehículo y siempre que sus

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vértices estén redondeados con un radio no inferior a los cinco centímetros (5cm) y sus bordes estén redondeados con un radio no inferior a dos centímetros y medio (2,5cm).

- Dispositivos para sujetar la lona y sus protecciones, siempre que no sobresalgan más de cinco centímetros (5cm) por los lados del vehículo y siempre que sus bordes estén redondeados con un radio no inferior a dos centímetros y medio (2,5cm).

Para la determinación del **largo máximo** de los vehículos, no será necesario tener en cuenta los dispositivos de visión indirecta, limpiaparabrisas, parasoles exteriores, placas de matrícula, accesorios de observación y detección tales como radares, plataformas elevadoras o rampas de acceso (siempre que no sobresalgan más de treinta centímetros), ni dispositivos para sujetar la lona y sus protecciones (siempre que no sobresalgan más de cinco centímetros y siempre que sus bordes estén redondeados con un radio no inferior a dos centímetros y medio).

Para los vehículos de tipo remolque, las barras de tracción (lanzas) deberán estar en posición horizontal y alineada con la línea central del vehículo al momento de la medición, debiendo además en el caso de barras de tracción regulables estar en su posición más extendida.

LXVI REUNIÓN ORDINARIA DEL SUBGRUPO DE TRABAJO N°5 “TRANSPORTE” DEL MERCOSUR



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NEUMATICOS SUPERANCHOS Y SU ASIGNACION DE PESO EN LA REPÚBLICA ORIENTAL DEL URUGUAY

Área Ingeniería de Transporte



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Introducción

El motivo de este estudio es el pedido de parte de los distintos actores en el transporte de mercancías en el Uruguay, de aumentar el peso que se asigna a los ejes y conjuntos de ejes que utilizan neumáticos supersingle o super anchos como se denominaran de aquí en adelante

En Uruguay, según Decreto N° 311 del 2007, se consideran super ancho a partir de (385mm)



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Ventajas y desventajas del uso del NGWB (New generation wide base)

445/50R22.5

455/55R22.5

- Beneficios económicos, de seguridad y ambientales
- La resistencia a la rodadura representa cerca del 13 por ciento del uso de energía del camión.
- La Asociación Americana de Transporte por Camión (ATA) reportó un potencial de ahorro de combustible como resultado de la mejorada resistencia a la rodadura y la reducción de peso que en promedio varía entre un 2 y un 3 por ciento, y posiblemente hasta un 8 por ciento.
- Finalmente, los neumáticos NGWB parecen generar menos desperdicio ya que contienen menos área de pared lateral en comparación con los neumáticos dobles
- Parece que el desgaste de la banda de rodamiento puede aumentar en operaciones locales y urbanas
- Aumento en las tasas de falla de recauchutado que pueden resultar en daños al vehículo.

Et al Greene-Toros-Kim-Byron-Choubane - Impact of wide base single tires on pavement damage.



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Pesos actuales en la normativa Uruguaya

Eje Simple			
PBM	6,2	10,9	7
Eje Doble			
PBM Total por eje	Eje homogéneo 10,4	Eje homogéneo 18,7	Eje homogéneo 14
PBM por eje constituyente	6,2 6,2	10,4 10,4	7 7
PBM Total por eje		Eje no homogéneo 14,6	Eje no homogéneo 15,5
PBM por eje constituyente		6,2 10,4	6,5 10
Eje Triple			
PBM Total por eje	Eje homogéneo 15,6	Eje homogéneo 26,5 *	Eje homogéneo 21
PBM por eje constituyente	6,2 6,2 6,2	9,4 9,4 9,4	7 7 7
PBM Total por eje		Eje no homogéneo 22,9	Eje no homogéneo 24 *
PBM por eje constituyente		6,2 9,4 9,4	6,5 9 9

Referencias

- Eje de 2 neumáticos convencionales
- Eje de 4 neumáticos convencionales
- Eje de 2 neumáticos "superanchos" **

***Solo en corredores habilitados para 25,5t, sino 22,9t**

Nota: Los semirremolques con ejes cuádruples (S4) tendrán los mismos límites que los de ejes triples (S3), en las mismas condiciones en cantidad y tipo de neumáticos por eje. Sólo se habilitan grupos cuádruples homogéneos.



Comparativa con pesos otorgados en superancho en la región.

Brasil:

- Está solo autorizado en el caso de transporte de pasajeros en los ejes direccionales, otorgando a estos 7000 kg.

Argentina Decreto 32/18:

- Con ruedas individuales 8t
- Tandem: 14t, 7 por eje
- Triple eje: 19.5t

En el caso de Chile estos no están autorizados y Paraguay los autorizó de forma experimental en ejes delantero de ómnibus con un peso de 7t



Estudio Americano

En el estudio hecho por "National Cooperative Highway Research Program" que se titula:

"Determination of Pavement Damage From Super-single and Singled-out Dual Truck Tires" de 1997, se hace un estudio exhaustivo sobre el desgaste a distintos tipos de pavimentos comparando entre los ejes con neumáticos super anchos y los ejes de 4 neumáticos convencionales.



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Rotura de pavimentos

Según un análisis presentado en el antedicho informe, teniendo en cuenta que AC layer refiere a la capa de rodadura en mezcla asfáltica, y que, se analiza en dos distintos espesores:

Tire Type Axle Load 84 kN (18.9 kip)	AC layer 79 mm (3.1") Damage ratio	AC layer 150 mm (5.9") Damage ratio
12R22.5 Duals	0.33	0.35
265/70R19.5	0.87	0.58
445/65R22.5 Super single	1.23	1.14
385/65R22.5 Super single	2.34	1.22
350/75R22.5 Super single	2.37	1.28

Factor de equivalencia de fatiga para diferente configuraciones de neumáticos



Rotura de pavimentos

Tire Type	AC Layer 79 mm (3.1")	AC layer 150 mm (5.9")
	Equivalent Axle Load	Equivalent Axle Load
12R22.5 Duals	100 kN (22,5 kip)	100 kN (22,5 kip)
265/70R19.5 Duals	86 kN (19,3 kip)	93 kN (20,9 kip)
445/65R22.5 Super single	81 kN (18,2 kip)	81 kN (18,2 kip)
385/65R22.5 Super single	65 kN (14,6 kip)	78 kN (17,5 kip)
350/75R22.5 Super single	61 kN (13,7 kip)	75 kN(16,9 kip)

Carga equivalente para dañar el pavimento en la misma medida que un eje estándar

Los resultados muestran que los neumáticos super anchos son más dañinos que los neumáticos dobles



Equivalencia entre ejes con distintos neumáticos

Se pueden calcular factores de equivalencia de fatiga, para un pavimento con numero estructural fijo (SN=4), teniendo en cuenta las deformaciones por huella y fatiga hasta la falla del pavimento con un eje estandar de 80 kN o 18 kips. La siguiente tabla se calcula a partir de una relación teórica entre estas magnitudes.

Equivalent 80 kN Dual Tire. Single Axle Loads					
Axle Load (kN)	Single Tire Width (mm)				
	254	305	356	406	457
44.5	0.631	0.479	0.373	0.297	0.241
53.4	1.029	0.781	0.608	0.484	0.392
62.3	1.555	1.181	0.919	0.732	0.593
71.2	2.224	1.689	1.315	1.047	0.848
80.1	3.050	2.316	1.804	1.435	1.163
89.0	4.046	3.072	2.393	1.904	1.542
97.9	5.223	3.966	3.089	2.458	1.991
106.8	6.596	5.001	3.901	3.104	2.515
115.7	8.175	6.206	4.834	3.847	3.116
124.6	9.972	7.571	5.897	4.692	3.801
133.4	11.998	9.109	7.096	5.646	4.573
142.3	14.264	10.829	8.435	6.712	5.438
151.2	16.782	12.741	9.924	7.897	6.397
160.1	19.561	14.851	11.568	9.205	7.457
169.0	22.612	17.167	13.372	10.640	8.620
177.9	25.946	19.698	15.343	12.209	9.891



Si realizamos una aproximación de polinomios de segundo grado con los primeros 5 términos de carga para los neumáticos 305, 356, 406 y 457, podríamos calcular el factor de fatiga que tendría con un neumático 305mm (el más parecido al neumático convencional 295 utilizado en nuestro país) bajo una carga de 6t.

$f=1,06$, reemplazando:

- 356 carga de 64.6 kN
- 4065 carga de 72 kN
- 457 carga de 77.7 kN

No se interpolan anchos de neumáticos.



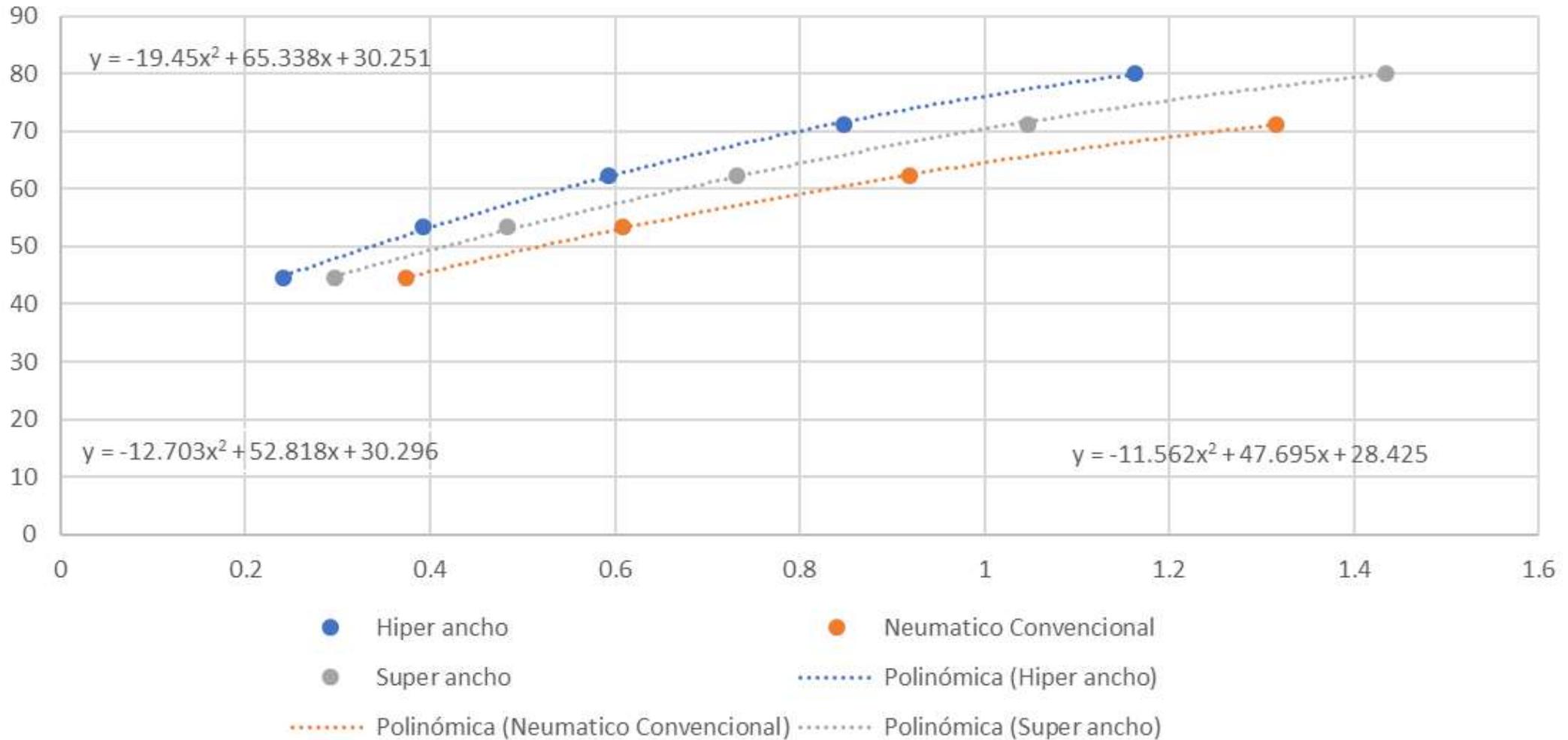
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Comparativa de Neumáticos



Conjunto de ejes

El antedicho informe norteamericano es muy claro en las mediciones de fatiga de un conjunto de ejes simples, pero, no es así en conjuntos de ejes de dos o mas ejes.

Es de interés mencionar que los bulbos de presión de los ejes con neumáticos superanchos son grandes que los de neumáticos convencionales, por lo que deberíamos penalizar aun mas el peso asignado a los conjuntos de ejes superanchos, ver diapositiva 7 para entender estos criterios de asignación de pesos.



Conclusiones

- La evidencia marca que 7 toneladas por eje simple es un valor correcto.
- Tampoco en la región está extendido su uso y, mucho menos, un consenso sobre la asignación de pesos.
- Por otra parte este estudio solo hace énfasis en la fatiga por huellas a pavimentos y no tiene en cuenta la fatiga de la capa de rodadura por efectos de deslizamiento, que es mucho más pronunciado en curvas cerradas o de baja velocidad, cuanto más ancho el neumático. En resumen, a mayor ancho, mayor desgaste por arrastre.
- Como solución podría eventualmente crearse un nuevo segmento de neumáticos que sean aún más anchos que los súper anchos Hiper anchos que se usan en el mercado Uruguayo, digase los similares a 457mm a los que eventualmente se les podría asignar un peso de entre 7 u 8 toneladas.



INFOME

Neumáticos superanchos y su asignación de peso en la República Oriental del Uruguay

Autor

Area ingeniería de transporte - DNT

11/07/2024

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1. Introducción

El motivo de este estudio es el pedido de parte de los distintos actores en el transporte de mercancías en el Uruguay, de aumentar el peso que se asigna a los ejes y conjuntos de ejes que utilizan neumáticos **supersingle** o super anchos como se denominaran de aquí en adelante (En Uruguay, según Decreto N° 311 del 2007, se consideran super ancho a partir de 385mm).

En Uruguay existen reglamentos que establecen los criterios de asignación de pesos para ejes y conjuntos de ejes. En adelante eje simple sera la denominación para un eje simple de 4 neumáticos.

2. Ventajas y Desventajas

La industria del transporte por camión está fomentando el uso de neumáticos de nueva generación de base ancha (NGWB, por sus siglas en inglés) debido a los percibidos beneficios económicos, de seguridad y ambientales. NGWB se consideran a partir de 445/50R22.5 455/55R22.5 De principal interés para muchas organizaciones de transporte por camión es el potencial de ahorro de costos.

La mayoría de los camiones de combinación utilizan ensamblajes de neumáticos dobles en los ejes motrices y de remolque. La resistencia a la rodadura representa cerca del 13 por ciento del uso de energía del camión.

Un neumático de base ancha único es más ligero que dos neumáticos y ruedas estándar. Un neumático de base ancha único, en comparación con una configuración estándar de neumáticos dobles, reduciría el peso y la resistencia a la rodadura.

Un ahorro de peso típico en un camión de combinación que reemplace cinco ejes de neumáticos dobles con neumáticos de base ancha únicos oscila entre 800 y 1,000 libras (360 a 450 kg), lo que se traduciría en un incremento en la capacidad de carga.

La Asociación Americana de Transporte por Camión (ATA) reportó un potencial de ahorro de combustible como resultado de la mejorada resistencia a la rodadura y la reducción de peso que en promedio varía entre un 2 y un 3 por ciento, y posiblemente hasta un 8 por ciento.

Un estudio de la Agencia de Protección Ambiental (EPA) mostró una reducción en el uso de combustible del 6 por ciento a 55 mph (90 kph), del 12 por ciento a 65 mph (105 kph), y del 10 por ciento en un entorno suburbano.

La carga y la presión deben estar equilibradas en las configuraciones de neumáticos dobles, pero frecuentemente es difícil monitorear el neumático interior debido a su ubicación. Los neumáticos de base ancha tienen solo una válvula externa y pueden ser verificados visualmente por baja presión. Además, los neumáticos de base ancha proporcionan un centro de gravedad más bajo y se ha informado que mejoran la calidad del viaje. Además de aumentar la eficiencia del combustible, los neumáticos de base ancha han sido promovidos para reducir las emisiones del vehículo que están relacionadas con la potencia del motor. Por lo tanto, las reducciones en los requisitos de potencia debido a la mejora en la eficiencia también deberían resultar en una disminución de las emisiones, especialmente para las emisiones de óxidos de nitrógeno (NOx) en lugar de materia particulada.

Un estudio de la EPA midió reducciones en las emisiones de NOx del 36 por ciento a 55

mph (89 kph), del 30 por ciento a 65 mph (105 kph), y del 13 por ciento en un entorno suburbano.

Finalmente, los neumáticos NGWB parecen generar menos desperdicio ya que contienen menos área de pared lateral en comparación con los neumáticos dobles. Cabe destacar que también existen posibles desventajas en el uso de neumáticos de base ancha. Parece que el desgaste de la banda de rodamiento puede aumentar en operaciones locales y urbanas. La ATA ha reportado que las millas hasta el desgaste han disminuido entre un 25 y un 35 por ciento para los neumáticos NGWB en comparación con los dobles, y también ha habido informes de un aumento en las tasas de falla de recauchutado que pueden resultar en daños al vehículo. Además, se debe mantener dos juegos de ruedas hasta que todos los camiones de una flota sean convertidos a neumáticos de base ancha.

Et al Greene-Toros-Kim-Byron-Choubane - Impact of wide base single tires on pavement damage.

3. Pesos actuales en la normativa Uruguaya

3.1. CONTROL DE PESO POR EJES Y GRUPOS DE EJES

Los límites de peso en los ejes y grupos de ejes de todos los vehículos surgen de las siguientes dos fuentes:

- En vehículos registrados ante DNT, se toman los límites que el vehículo tiene ingresados en su registro ante el Ministerio, los mismo que figuran en su Permiso Nacional de Circulación. Grupos de ejes triple y cuádruple que circulan fuera de corredores de 25,5 toneladas tienen su peso máximo topeado en 22 toneladas cuando el tipo de suspensión registrado para el vehículo es mecánica, y 22,9 toneladas cuando su suspensión es neumática.
- Si DNT no cuenta con información sobre pesos máximos admisibles para el vehículo, el peso máximo de los ejes y grupos de ejes se topea de acuerdo a la cantidad de ejes y neumáticos según lo que muestra la figura [1](#)

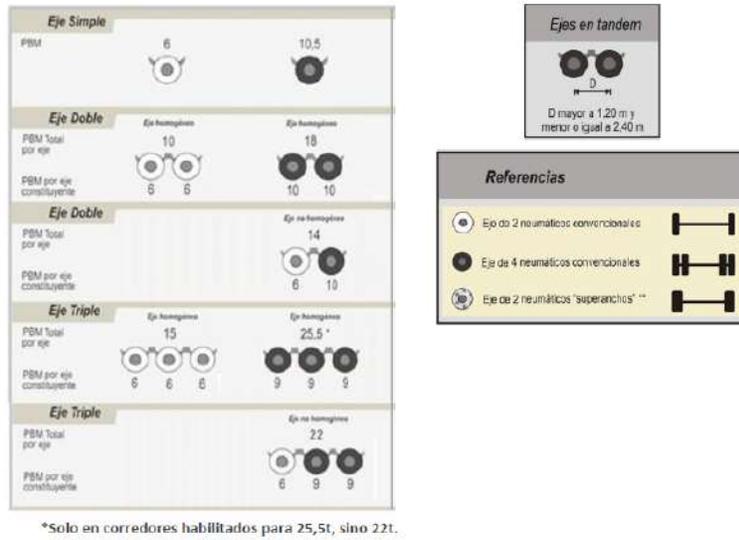


Figura 1: Límites de peso por grupos y ejes individuales para vehículos con suspensión mecánica



Figura 2: Límites de peso por grupos y ejes individuales para vehículos con suspensión Neumática o Mecánica amigable

Claramente en los conjuntos de ejes con 4 neumáticos sus pesos normativos no son la suma de sus ejes individuales, no pasando así con los conjuntos de ejes con neumáticos superanchos. Para ilustrar mejor veamos la figura 2, un eje simple tiene como máximo 10,9t, pero el tandem (2 ejes simples separados a menos de 2,4m) el límite es de 18,7t, que es distinto a sus sumas directas. En cambio, el límite en un eje simple superancho es 7t, y en el tandem es de 14t.

$$10,9 + 10,9 = 21,8 \neq 18,7 \quad (1)$$

La razón de esta minoración es por el efecto de solapamiento de los bulbos de presión de cada eje.

4. Comparativa con los pesos otorgados a ejes con superanchos en la región

Si miramos a la región, en cuanto al límite de pesos asignados a ejes superanchos tenemos que Argentina según el decreto 32/18:

- En todos los casos serán montados con suspensión neumática
- Eje simple: Con ruedas individuales 8t
- Eje doble: 14t totales, 7 por eje
- Eje triple: 19.5t.

En el caso de Brasil está solo autorizado en el caso de transporte de pasajeros en los ejes direccionales, otorgando a estos 7000 kg.

Al día de generación de este informe se encuentran trabajando en un documento, para autorizar dichos ejes para transporte de mercancías. Esta en etapa de estudio empírico.

En el caso de Chile estos no están autorizados y Paraguay los autorizó de forma experimental en ejes delantero de ómnibus con un peso de 7t.

4.1. Conclusiones

Si tomamos estos ejemplos, vemos que no hay un consenso en cuanto a

5. Estudio Americano

En el estudio hecho por "National Cooperative Highway Research Program" que se titula: "Determination of Pavement Damage From Super-single and Singled-out Dual Truck Tires" de 1997, se hace un estudio exhaustivo sobre el desgaste a distintos tipos de pavimentos comparando entre los ejes con neumáticos super anchos y los ejes de 4 neumáticos convencionales.

5.1. Introducción a los ejes equivalentes

el método de los ejes equivalentes utilizado en ingeniería de transporte, particularmente en el diseño de pavimentos según las normativas de la AASHTO (American Association of State Highway and Transportation Officials). Este método se utiliza para convertir cargas de vehículos de diferentes tipos y pesos en un número equivalente de repeticiones de un eje estándar (18 kips) para evaluar el daño potencial a los pavimentos.

En términos básicos, el método de los ejes equivalentes considera que diferentes vehículos ejercen diferentes niveles de daño a los pavimentos debido a su peso, configuración de ejes y distribución de carga. Por lo tanto, se utiliza una fórmula específica para calcular el número de ejes equivalentes (NEE) que representa el daño de un vehículo en particular en términos

de repeticiones de un eje estándar.

Este enfoque es crucial para el diseño y la evaluación de la resistencia de los pavimentos, ya que permite estimar de manera más precisa cómo diferentes tipos de vehículos contribuyen al deterioro de la superficie de la carretera a lo largo del tiempo.

5.2. Rotura de pavimentos

Según un análisis presentado en el antedicho informe, teniendo en cuenta que AC layer refiere a la capa de rodadura en mezcla asfáltica, y que, se analiza en dos distintos espesores:

Tire Type Axle Load 84 kN (18.9 kip)	AC layer 79 mm (3.1") Damage ratio	AC layer 150 mm (5.9") Damage ratio
12R22.5 Duals	0.33	0.35
265/70R19.5	0.87	0.58
445/65R22.5 Super single	1.23	1.14
385/65R22.5 Super single	2.34	1.22
350/75R22.5 Super single	2.37	1.28

Figura 3: Factor de equivalencia de fatiga para diferente configuraciones de neumáticos

Tire Type	AC Layer 79 mm (3.1") Equivalent Axle Load	AC layer 150 mm (5.9") Equivalent Axle Load
12R22.5 Duals	100 kN (22.5 kip)	100 kN (22.5 kip)
265/70R19.5 Duals	86 kN (19.3 kip)	93 kN (20.9 kip)
445/65R22.5 Super single	81 kN (18.2 kip)	81 kN (18.2 kip)
385/65R22.5 Super single	65 kN (14.6 kip)	78 kN (17.5 kip)
350/75R22.5 Super single	61 kN (13.7 kip)	75 kN (16.9 kip)

Figura 4: Carga equivalente para dañar el pavimento en la misma medida que un eje estándar

Nosotros tomaremos como válido la columna con un espesor de 3,1" que equivale a una capa entre 7 y 8 cm de mezcla asfáltica, lo que se asemeja mas a la enorme mayoría de las carreteras en de mezcla asfálticas en Uruguay.

Podemos ver en la figura 3 muestra los factores de equivalencia para las cinco configuraciones diferentes de neumáticos, mientras que la figura 4 presenta los datos basados en cargas equivalentes por eje para producir el mismo daño que el eje estándar. Los resultados muestran que los neumáticos super anchos son más dañinos que los neumáticos dobles. Dentro de los

neumáticos super anchos, los neumáticos más anchos son menos dañinos que los neumáticos más estrechos. Los neumáticos superanchos causan más daño en pavimentos delgados que en pavimentos gruesos.

5.3. Equivalencia entre ejes con distintos neumáticos

Se pueden calcular factores de equivalencia de fatiga, para un pavimento con numero estructural fijo (SN=4), teniendo en cuenta las deformaciones por huella y fatiga hasta la falla del pavimento con un eje estandar de 80 kN o 18 kips. La siguiente tabla se calcula a partir de una relación teórica entre estas magnitudes.

Equivalent 80 kN Dual Tire, Single Axle Loads					
Axle Load (kN)	Single Tire Width (mm)				
	254	305	356	406	457
44.5	0.631	0.479	0.373	0.297	0.241
53.4	1.029	0.781	0.608	0.484	0.392
62.3	1.555	1.181	0.919	0.732	0.593
71.2	2.224	1.689	1.315	1.047	0.848
80.1	3.050	2.316	1.804	1.435	1.163
89.0	4.046	3.072	2.393	1.904	1.542
97.9	5.223	3.966	3.089	2.458	1.991
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151.2	16.782	12.741	9.924	7.897	6.397
160.1	19.561	14.851	11.568	9.205	7.457
169.0	22.612	17.167	13.372	10.640	8.620
177.9	25.946	19.698	15.343	12.209	9.891

Figura 5: Equivalencia para un eje simple con 80 kN de carga

La tabla muestra los factores de equivalencia para distintos anchos de neumático con respectivas cargas, en ejes simples duales.

Teniendo en cuenta que el neumático de 305mm sería similar al neumático estándar en Uruguay, que es 295mm, que neumáticos super anchos en Uruguay son considerados a partir de 385mm, según Decreto N° 311 del 2007 y que la aproximación de que "1t=10kn":

Si realizamos una aproximación de polinomios de segundo grado con los primeros 5 términos de carga para los neumáticos 305, 356, 406 y 457, podríamos calcular el factor de fatiga que tendría con un neumático 305mm (el más parecido al neumático convencional 295 utilizado en nuestro país) bajo una carga de 6t, dando como resultado:

$$f = 1,06 \tag{2}$$

Con este input, reemplazamos por x en las ecuaciones y obtenemos que para obtener el mismo factor de fatiga la carga para los distintos anchos de neumáticos sería:

- **356** carga de 64.6 kN
- **406** carga de 72 kN
- **457** carga de 77.7 kN

Cabe aclarar que no se interpolan los anchos de neumáticos ya que esto sería una aproximación demasiado grosera, la impronta no es una función lineal, además de depender de

la presión en los neumáticos, la carga aplicada, etc.

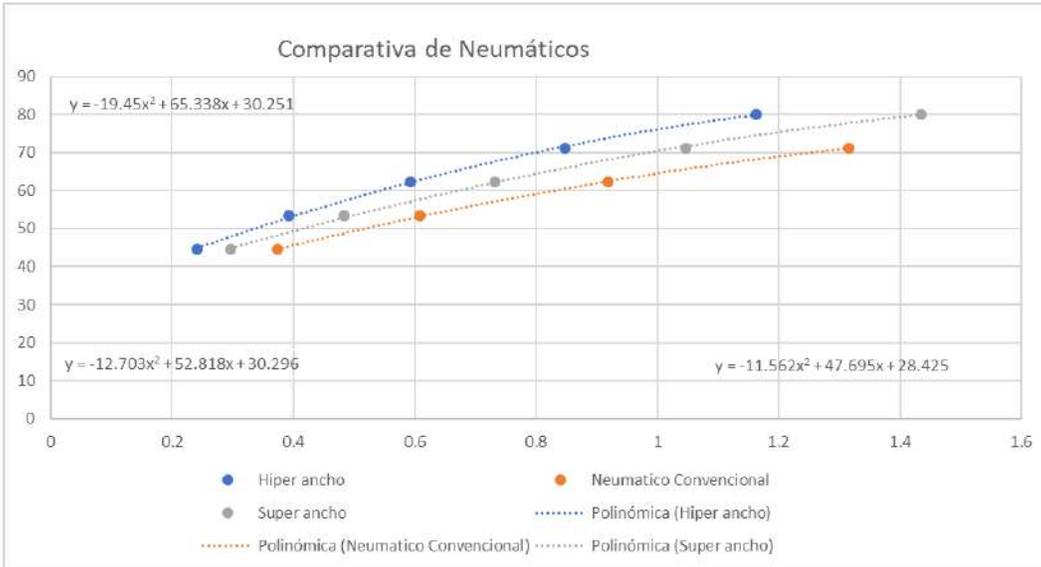


Figura 6: Factor de deformación y carga para distintos tipos de neumáticos

En el gráfico [6](#) podemos ver las líneas de tendencia polinómica y su ecuación. Los neumáticos **Hiper anchos** serían los de 457mm en adelante, los **super ancho** son los neumáticos 405mm (anchos más parecido a un super ancho en Uruguay) y finalmente **Neumático Convencional** son los de 305mm.

Se puede ver una clara tendencia que cuanto más ancho el neumático, más carga es capaz de soportar generando el mismo desgaste.

5.4. Conjunto de ejes

El antedicho informe norteamericano es muy claro en las mediciones de fatiga de un conjunto de ejes simples, pero, no es así en conjuntos de ejes de dos o más ejes.

Es de interés mencionar que los bulbos de presión de los ejes con neumáticos superanchos son grandes que los de neumáticos convencionales, por lo que deberíamos penalizar aún más el peso asignado a los conjuntos de ejes superanchos, ver 3.1 para entender estos criterios de asignación de pesos.

6. Conclusiones

Se sugiere no acceder a lo solicitado sobre el aumento de pesos a conjuntos de ejes superanchos, debido a que la evidencia marca que 7 toneladas por eje simple es un valor correcto. Tampoco en la región está extendido su uso y, mucho menos, un consenso sobre la asignación de pesos.

Por otra parte este estudio solo hace énfasis en la fatiga por huellas a pavimentos y no tiene en cuenta la fatiga de la capa de rodadura por efectos de deslizamiento, que es mucho

mas pronunciado en curvas cerradas o de baja velocidad, cuanto más ancho el neumático. En resumen, a mayor ancho, mayor desgaste por arrastre.

Como solución podría eventualmente crearse un nuevo segmentos de neumáticos que sean aun mas anchos que los supe anchos (**Hiper anchos**) que se usan en el mercado Uruguayo, dígase los similares a 457mm a los que eventualmente se les podría asignar un peso de entre 7 u 8 toneladas, se sugiere el valor de 7,5t y, en este informe el nombre que le damos es .

STATE OF FLORIDA



IMPACT OF WIDE-BASE SINGLE TIRES ON PAVEMENT DAMAGE

Research Report

FL/DOT/SMO/09-528

James Greene
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December 2009

STATE MATERIALS OFFICE

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EXECUTIVE SUMMARY

Dual tires have traditionally been used to limit pavement damage by efficiently distributing axle loads over a larger contact area than single tires. However, in recent years the trucking industry has promoted the use of wide-base single tires stating economical and safety benefits. The Super Single tire, an early type of wide-base tire, proved inadequate and induced excessive pavement damage. In contrast, the new generation wide-base tires have contact areas that approach those of dual tires and offer the potential for improved performance.

The Florida Department of Transportation (FDOT) investigated the pavement damage potential of four tire types including a conventional dual tire (11R22.5), a Super Single (425/65R22.5), and two newly-designed wide-base single tires (445/50R22.5 and 455/55R22.5, respectively). A controlled accelerated pavement testing program in addition to theoretical modeling was performed to determine critical pavement response parameters. Pavement damage was measured in terms of rutting and fatigue cracking (bottom-up or top-down), the predominant distresses in Florida. The investigation revealed the 455-mm wide-base tire performed as well as the dual tire. In comparison, the 445-mm wide-base tire was shown to create more rut damage on a dense-graded pavement surface and was also predicted to create more bottom-up cracking than a dual tire. As expected, the Super Single induced the most damage to the pavement.

This paper presents a description of the test program, the data collection efforts, and the subsequent analysis and findings.

INTRODUCTION

There have been a number of innovations in tire technology to address the evolving needs of the trucking industry for efficiency. Recently, a new generation of wide-base tires with greater tread widths has been introduced. These tire developments directly impact pavement damage. Pavement damage from tires can be controlled by adequately distributing the load over a larger area of the pavement surface to minimize critical stresses and strains. Dual tires have traditionally provided the largest footprint to adequately distribute the axle load onto the pavement surface. As the name implies, wide-base single tires provide a wider footprint than conventional single tires and attempt to distribute the load over a contact area similar to that of standard dual tires. The first generation of wide-base tires (385/65R22.5 and 425/65R22.5) was introduced in the early 1980's (1). These tires ultimately proved to cause an increase in pavement contact stress and in turn generated even greater pavement damage (2). A new generation of wide-base (NGWB) tires (445/50R22.5 and 455/55R22.5) became available after 2000 (1). The trucking industry has encouraged their use due to their increased pavement contact area, and promise of economical and safety benefits. However, potential pavement damage induced by NGWB tires must be assessed before the wholesale adoption of their use.

WIDE-BASE TIRES

The trucking industry is encouraging the use of NGWB tires due to the perceived economic, safety, and environmental benefits. Of primary interest to many trucking organizations is the potential of cost savings. Most combination trucks use dual tire assemblies on the drive and trailer axles. Rolling resistance accounts for nearly 13 percent of truck energy use. A single wide-base tire is lighter than two standard tires and wheels. A single wide-base tire, as opposed to a standard dual tire configuration, would reduce weight and rolling resistance (3). A typical weight savings of a combination truck that replaces five axles of dual tires with single wide-base tires ranges from 800 to 1,000 pounds (360 to 450 kg) (3, 4). The American Trucking Association (ATA) reported potential fuel savings as a result of the improved rolling resistance and reduced weight range on average from 2 to 3 percent and possibly up to 8 percent (4). An Environmental Protection Agency (EPA) study showed reduction in fuel use of 6 percent at 55 mph (90 kph), 12 percent at 65 mph (105 kph), and 10 percent in a suburban environment (5).

Load and pressure must be balanced on dual tire configurations, but it is often difficult to monitor the inner tire due to its location. Wide-base tires only have one outside valve and can be visually checked for low pressure. Furthermore, wide-base tires provide a lower center of gravity and have been reported to improve ride quality (4).

In addition to increasing fuel efficiency, wide-base tires have been promoted to reduce vehicle emissions which are related to engine power output. Therefore, reductions in power requirements due to improved efficiency should also result in a decrease in emissions, particularly for emissions of oxides of nitrogen (NO_x) as opposed to particulate matter. An EPA study measured NO_x emission reductions of 36 percent at 55 mph (89 kph), 30 percent at 65 mph (105 kph), and 13 percent in a suburban environment (5). Finally, NGWB tires appear to generate less scrap since they contain less sidewall area compared to dual tires (4).

It should be noted that there are potential disadvantages to the use of wide-base tires as well. It appears that tread wear may be increased for local and urban operations. The ATA has reported that miles to removal have decreased 25 to 35 percent for NGWB tires as compared to duals and there have also been reports of increased retread failure rates which may result in vehicle damage (4). Also, two sets of wheel hardware must be maintained until all trucks in a fleet are converted to wide-base tires.

PAVEMENT DAMAGE POTENTIAL

There are two primary failure mechanisms observed on flexible pavements in Florida. These failure mechanisms include permanent deformation (rutting) and fatigue cracking of the hot mix asphalt structure. Many models, including the Mechanistic-Empirical Pavement Design Guide (MEPDG), recognize that permanent deformation may take place in both bound and unbound layers, and that fatigue cracking can initiate from the bottom or top of an asphalt layer. However, permanent deformation of the base is uncommon in Florida pavements while the top-down cracking is a prevalent distress on Florida roadways.

Recent studies have shown that NGWB tires generate similar rut depths as dual tires but induce greater longitudinal strains at the bottom of the asphalt layer which will accelerate bottom-up fatigue cracking damage (6, 7, 8, 9). Furthermore, NGWB tires often generated similar or less surface shear strains than dual tires (6, 7, 8, 9). The first generation wide-base tires, often referred to as Super Singles, were shown to clearly decrease the tire contact area and, therefore, increase the pavement contact stresses. The increase in vertical and lateral stresses induced by the Super Single tires significantly increased the likelihood of top-down cracking and near-surface rutting of asphalt pavements (2).

RESEARCH OBJECTIVES

As previously stated, the primary objective of this research was to assess the impact on pavement performance of different tire designs including (1) a conventional dual tire configuration, (2) two types of NGWB tires, and (3) a first generation wide-base tire. The four tire systems are described below:

1. Goodyear Unisteel G149 RSA, 11R22.5 (Dual Tire)
2. Goodyear G286 A SS, 425/65R22.5 (Super Single)
3. Michelin X One XDA-HT Plus, 445/50R22.5 (NGWB 445-mm)
4. Michelin X One XDA-HT Plus, 455/55R22.5 (NGWB 455-mm)



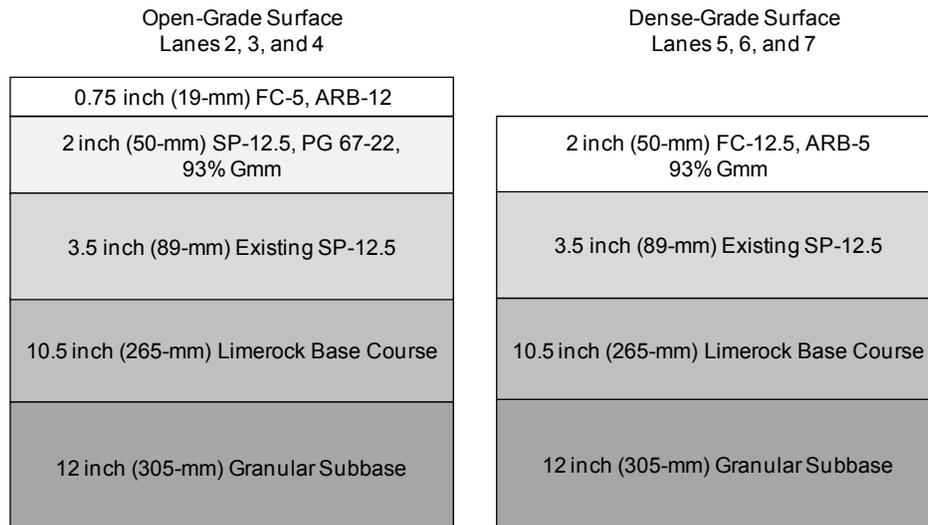
FIGURE 1 Photograph of tire used in the study.

To allow for a faster and a more practical assessment under closely simulated in-service conditions, accelerated pavement testing (APT) was considered to address the objectives of this study. APT is generally defined as a controlled application of a realistic wheel loading to a pavement system simulating long-term, in-service loading conditions. This allows the monitoring of a pavement system's performance and response to accumulation of damage within a much shorter time frame. In Florida's APT program, the accelerated loading is performed using a Heavy Vehicle Simulator (HVS), Mark IV model. The HVS is electrically powered (using an external electric power source or electricity from an on-board diesel

generator), fully automated, and mobile. A complete description of the test facility has been presented elsewhere (10, 11). The APT empirical approach was also supplemented by rigorous theoretical procedures to further quantify the critical pavement response parameters.

EXPERIMENT DESIGN

In order to better understand the pavement damage induced by each tire, several aspects of the tire and pavement interaction were investigated. As part of the APT portion of this study, a total of six test lanes (numbered 2 through 7) were constructed considering both open and dense-graded asphalt surface textures while complying with all the standard FDOT construction, materials, and in-place (as constructed) methods and specifications. For all pavement test sections, the supporting layers consisted of a 10.5 inch limerock base over a 12 inch limerock stabilized subgrade. Two different pavement structures, comprised of three asphalt mixtures, were tested. The asphalt mixtures consisted namely of (1) a fine-graded Superpave with a 12.5-mm nominal aggregate size and a PG67-22 binder (SP-12.5), (2) a fine-graded friction course mixture with a 12.5-mm nominal aggregate size and a binder with 5 percent asphalt rubber (FC-12.5), and (3) an open-graded friction course mixture and a binder with 12 percent asphalt rubber (FC-5). The SP-12.5 and FC-12.5 mixtures were similar with the exception of the binder type. The pavement structures are shown in FIGURE 2. Each test lane was divided into three pavement sections (identified as A, B and C), with each pavement section being approximately 50 feet (15.2-m) long and 12 feet (3.7-m) wide. In order to account for construction variability, the order of test sections and tire types were randomly selected. At least three replicate tests were conducted for each tire and pavement structure combination.



Note: ARB-12 represents 12% asphalt rubber binder.

FIGURE 2 Pavement structure.

Accelerated loading was performed uni-directionally with a 5 inch (127-mm) wheel wander in 1 inch (25-mm) increments. The reasoning for such a loading configuration was provided elsewhere (10). All tires except for the Super Single were inflated to 100 psi (689 kPa). The recommended inflation pressure for the Super Single tire is 115 psi (772 kPa). A 9,000 pound (40 kN) load was applied to all wheels at a speed of 8 mph (13 kph). The temperature was held constant at 122 ° F (50° C) by installing insulated panels and employing a heater system integrated into the HVS. Each lane was trafficked until a rut depth of approximately 0.50 inch (12.5-mm) was measured. Trafficking of some lanes was discontinued before reaching a 0.5 inch (12.5-mm) rut depth if the rate of rutting appeared to be constant.

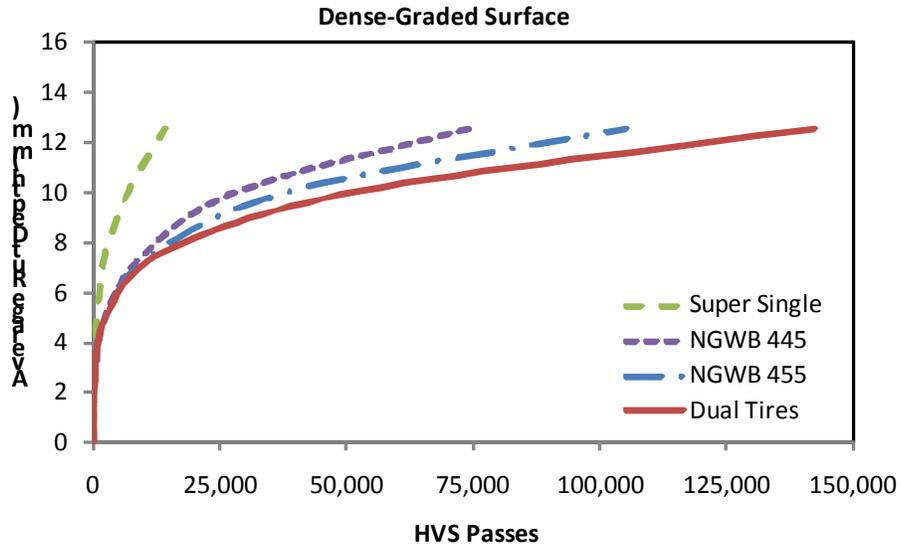
Lane 1, which was constructed similarly as Lanes 2 through 4, was used to measure surface strain caused by each tire. Finally, the dense-graded pavement structure and tire interaction was modeled using finite element analysis (FEA) to determine the theoretical pavement response to the different tires. Loaded tire geometry and contact area was measured to determine a more accurate modeling approach.

PERMANENT DEFORMATION THROUGH ACCELERATED PAVEMENT TESTING

For both pavement types, the dual tire configuration allowed a greater number of passes before reaching the critical rut depth while the Super Single tire resulted in the least number of passes. In general, the NGWB 455-mm tire required a similar number of passes on the open-graded surface and slightly less for the dense-graded surface (when considering the variability in tests) as compared to the dual tires. The NGWB 445-mm tire reached the critical rut depth with less passes than the dual for both surface types, particularly for the dense-graded surface. The Super Single tire reached the critical rut depth with significantly less number of passes than the duals for both asphalt mixtures.

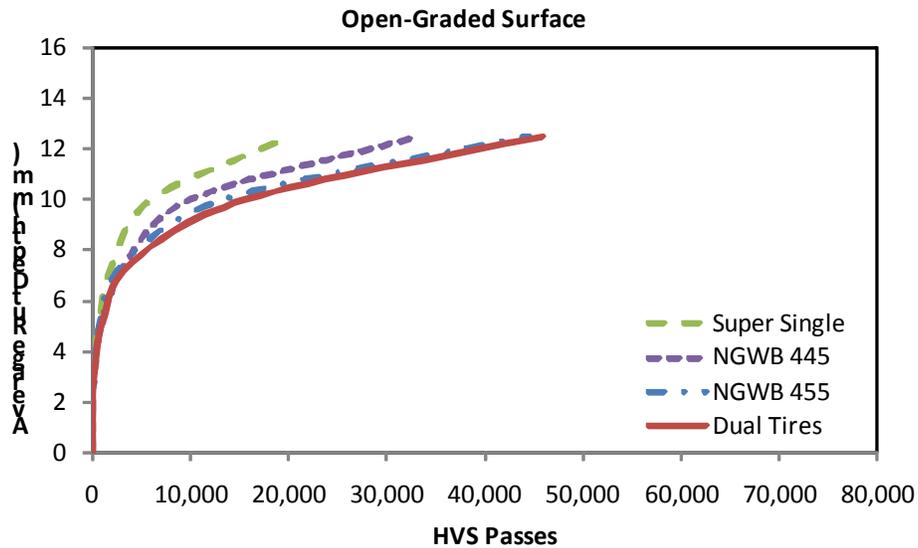
FIGURE 3 reports the rut depth and the rut damage ratio. The rut damage ratio is simply the ratio of the average number of passes required for a standard tire (in this case, the dual tires) to that of the other respective tires tested to achieve an approximate rut depth of 0.5 inch (12.5-mm).

It is believed that the large difference in rate of rutting between the dense-graded pavement and open-graded pavement is likely due to the lower modulus of the open-graded friction course and effects from the accelerated nature of the test. While not measured in this study, literature indicates that the modulus of an open-graded pavement is approximately 50 to 80 percent lower than conventional dense-graded mixtures (12). Furthermore, a previous FDOT funded study showed that open-graded friction courses tend to rut faster during accelerated testing than typically observed in the field (13). This study indicated that the open-graded aggregate structure was not allowed time to stabilize due to the increased loading frequency and shortened evaluation period during testing with the asphalt pavement analyzer.



Statistic	Passes Required for a 12.5-mm Rut Depth			
	Dual Tires	Super Single	NGWB 445	NGWB 455
Average	169,000	16,000	72,000	133,000
Rut Damage Ratio	1.0	10.6	2.3	1.3

A.) Dense-graded surface rut depth measurements.



Statistic	Passes Required for a 12.5-mm Rut Depth			
	Dual Tires	Super Single	NGWB 445	NGWB 455
Average	46,000	20,000	33,000	44,000
Rut Damage Ratio	1.0	2.3	1.4	1.0

B.) Open-graded surface rut measurements.

FIGURE 3 Rut depth summary.

SURFACE STRAIN INVESTIGATION

Top-down cracking is one of the primary distresses observed on Florida pavements. Top-down cracks are thought to form due to tensile and shear stresses generated by repeated loading in combination with stiffness gradients from aging and thermal effects. In order to determine the potential for top-down cracking, tensile strain measurements were made on the dense-graded surfaced pavement. Two transverse 1.2 inch (30-mm) foil surface strain gauges were placed 5 inches (127-mm) from the tire edge, a location where it was thought tensile strain would dominate. Five HVS wheel passes were made with each tire at 2 mph (3 kph) and 7 mph (11 kph). Strain measurements were not corrected for temperature, since the pavement surface temperature at the time of testing was $78 \pm 2^\circ \text{F}$ for all tire and speed combinations.

A representative strain profile made 5 inches (127-mm) from the dual tire edge is shown in FIGURE 4. In general, the strain measurements exhibited slight compressive strain as the wheel approached the gauge and tensile strain and reversal as the wheel moved away from the gauge. The strain magnitudes for each tire and speed are shown in FIGURE 5. The dual and Super Single generated the greatest transverse strain. As expected, transverse strain was reduced when the speed increased. While the magnitudes of measured strain are not likely to induce top-down cracking on a new pavement, these strains may be enough to generate cracks on older pavements subjected to aging and repeated loading. Additionally, some researchers suggest that load location in combination with asphalt stiffness gradients are critical to crack propagation (14).

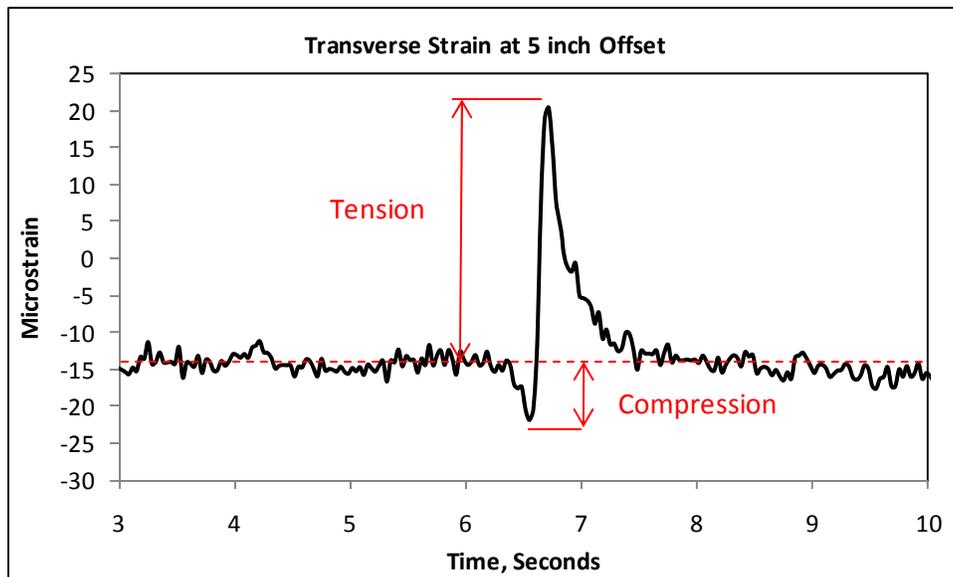
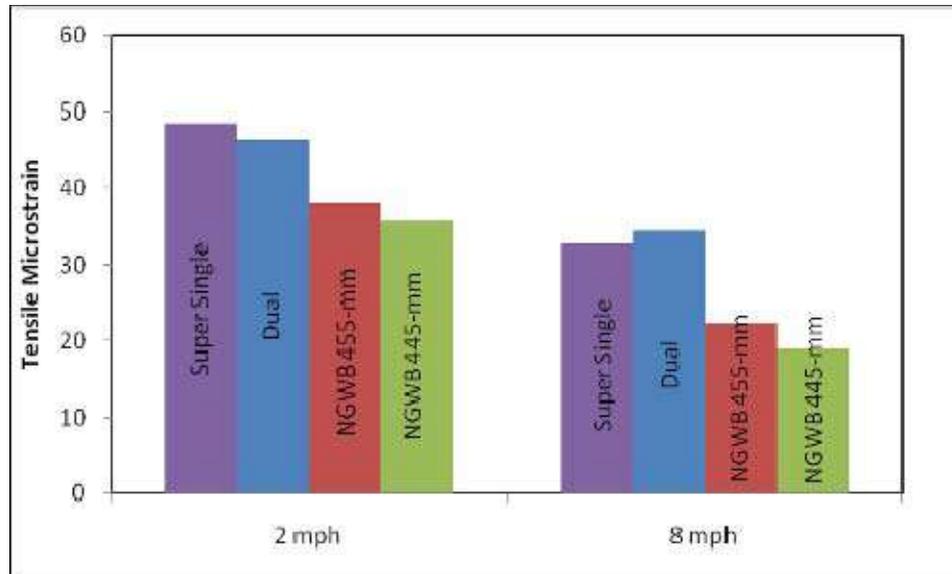


FIGURE 4 Typical dual tire strain profile at 8 mph (13 kph).



Tire Type	Measured Tensile Microstrain				Strain Ratio	
	2 mph	% COV	8 mph	COV	2 mph	8 mph
Dual	46	2.6	35	5.6	1.0	1.0
Super Single	49	3.5	33	5.5	1.0	1.0
NGWB 455	38	3.9	22	6.8	0.8	0.6
NGWB 445	36	5.7	19	10.5	0.8	0.5

FIGURE 5 Surface transverse strain measurement on dense graded surface.

FINITE ELEMENT ANALYSIS

The commercial software ADINA was used for finite element (FE) modeling of the pavement structure and tire loads. In general, a finer mesh is recommended for more detailed results. However, it is not always preferable if computation times and storage capacity become excessive. Therefore, to reduce the number of elements for a 3D model without compromising the analysis, a symmetrical geometry about the x-axis (perpendicular to the wheel path) was used. To minimize the effect of boundary conditions, the model dimensions were 200 inches (5080-mm) wide by 100 inches (2540-mm) in length. A 3D element with 10 nodes was used as the element type. A finer mesh at the center of the y-axis near the loaded area and the x-axis was achieved by the Delaunay technique. A relatively coarser mesh was used at the boundaries. Fixed support was used along the z-axis at the bottom of the subgrade layer and the x-axis along the model boundary. The modeled pavement structure was based on the dense-graded surfaced section. Material properties were determined through nondestructive deflection and seismic testing as well as laboratory analysis. The open-graded surface was not modeled since it was difficult to accurately measure the properties of the FC-5 with a falling weight deflectometer or other nondestructive means. The pavement structure and corresponding model are shown in FIGURE 6.

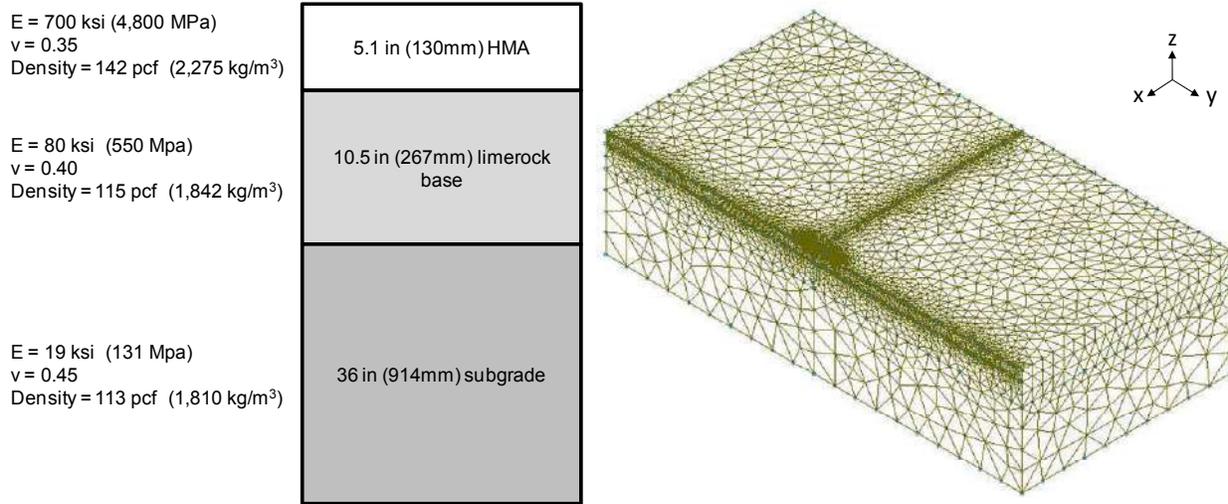


FIGURE 6 Pavement structure and model for FE analysis.

In order to more accurately model the true tire contact area, the imprint of each tire tread was measured at the recommended inflation pressure. Each imprint was converted into a digital image and pixels were counted and converted to an area measurement using an imaging software application. TABLE 1 summarizes the tire contact areas measured at various inflation pressures and loads. In general, the contact area decreased for a given load as the inflation pressure was increased. Conversely, the tire contact area increased for a given inflation pressure as the load was increased. Due to the high lateral stiffness of the tire, the tread width remained relatively constant (1.3 to 1.7 inches or 33 to 43-mm) while the length increased with increasing load and decreasing inflation pressure. Diagrams of the modeled geometry and contact pressure are shown in FIGURE 7. Tread contact pressures for the dual tire, NGWB 455 mm, and NGWB 445 mm were taken from a study by Al-Qadi et. al (15). The Super Single tire was not modeled since accurate contact pressure was not available.

TABLE 1 Tire Contact Area

Tire	Inflation Pressure, psi	Measured Contact Area, square inch			
		9 kip	12 kip	15 kip	18 kip
Dual	80	124	150	173	174
Dual	100	119	145	165	NA
Dual	125	103	133	152	NA
Super Single	80	97	120	138	142
Super Single	115	75	103	116	137
Super Single	125	77	96	120	137
NGWB 445	80	100	121	140	NA
NGWB 445	100	101	125	138	NA
NGWB 445	125	82	108	129	142
NGWB 455	80	113	135	153	NA
NGWB 455	100	96	114	140	NA
NGWB 455	125	81	114	122	142

Note: 1 inch = 6.45 cm²
 1 kip = 4.45 kN
 1 psi = 6.89 kPa

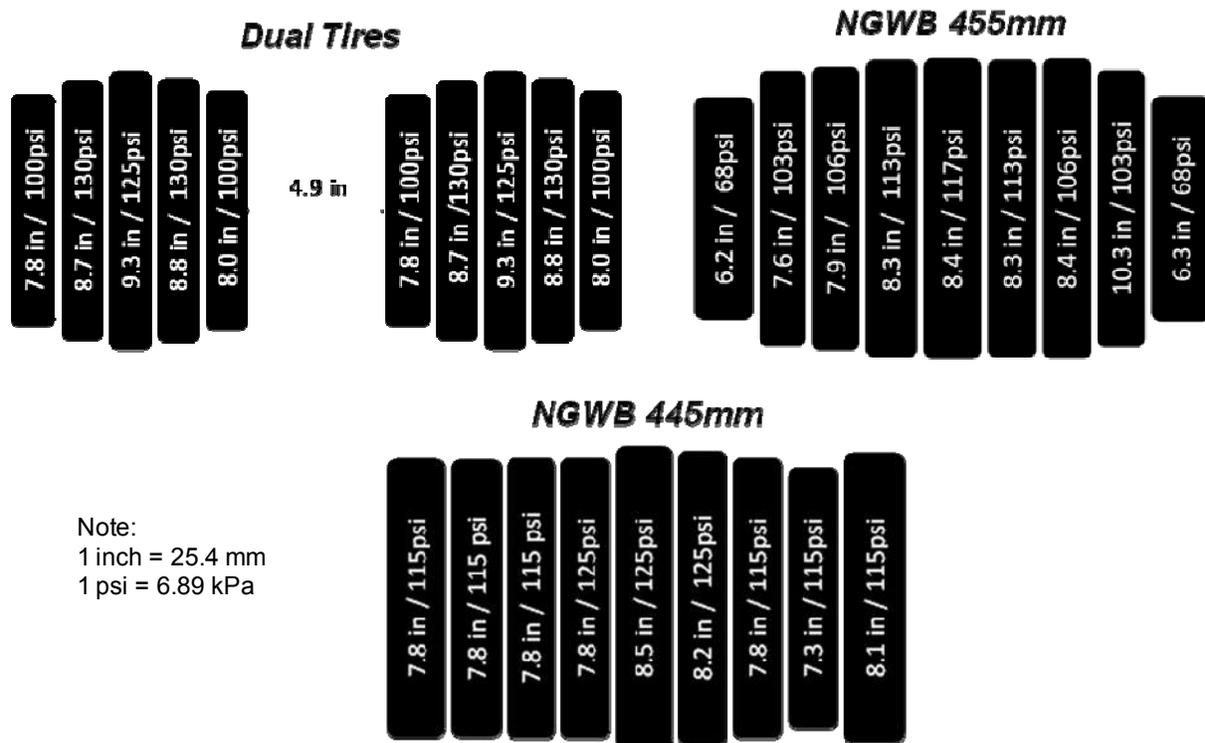


FIGURE 7 Tire geometry and contact pressure used in FE analysis.

The following four parameters were investigated using the FE model and analysis:

1. Vertical strain in the asphalt layer to indicate rutting potential.
2. Horizontal surface strain to indicate top-down cracking potential.
3. Shear strain below the tire edge to indicate top-down cracking potential.
4. Horizontal tensile strain at the bottom of the asphalt layer to indicate bottom-up fatigue cracking potential.

The stress distributions along the symmetrical transverse face for each tire are shown in FIGURE 8. As expected, the greatest tensile stress was predicted at the bottom of asphalt layer (shown in red) even with non-uniform tire pressures. On the pavement surface, the greatest compressive stress occurred below the tire treads. . A more detailed description of each investigated parameter is included in the following paragraphs.

Vertical tensile stresses developed near the surface due to lateral compressive stresses induced by the treads. The dual tire induced a greater tensile stress at the surface between the tires due to a more dominant effect from shear stresses. As found in the FE models reviewed in the literature, similar vertical compressive strains were predicted for each of the modeled tires. However, the 445-mm wide-base tire produced rut damage much quicker than the 455-mm and dual tires for the dense-graded pavement surface in the APT experiment. This indicates that a simple elastic model may not provide an accurate method to evaluate rutting potential. Viscoelastic parameters, loading frequency, and deformation accumulation should be accounted for as well.

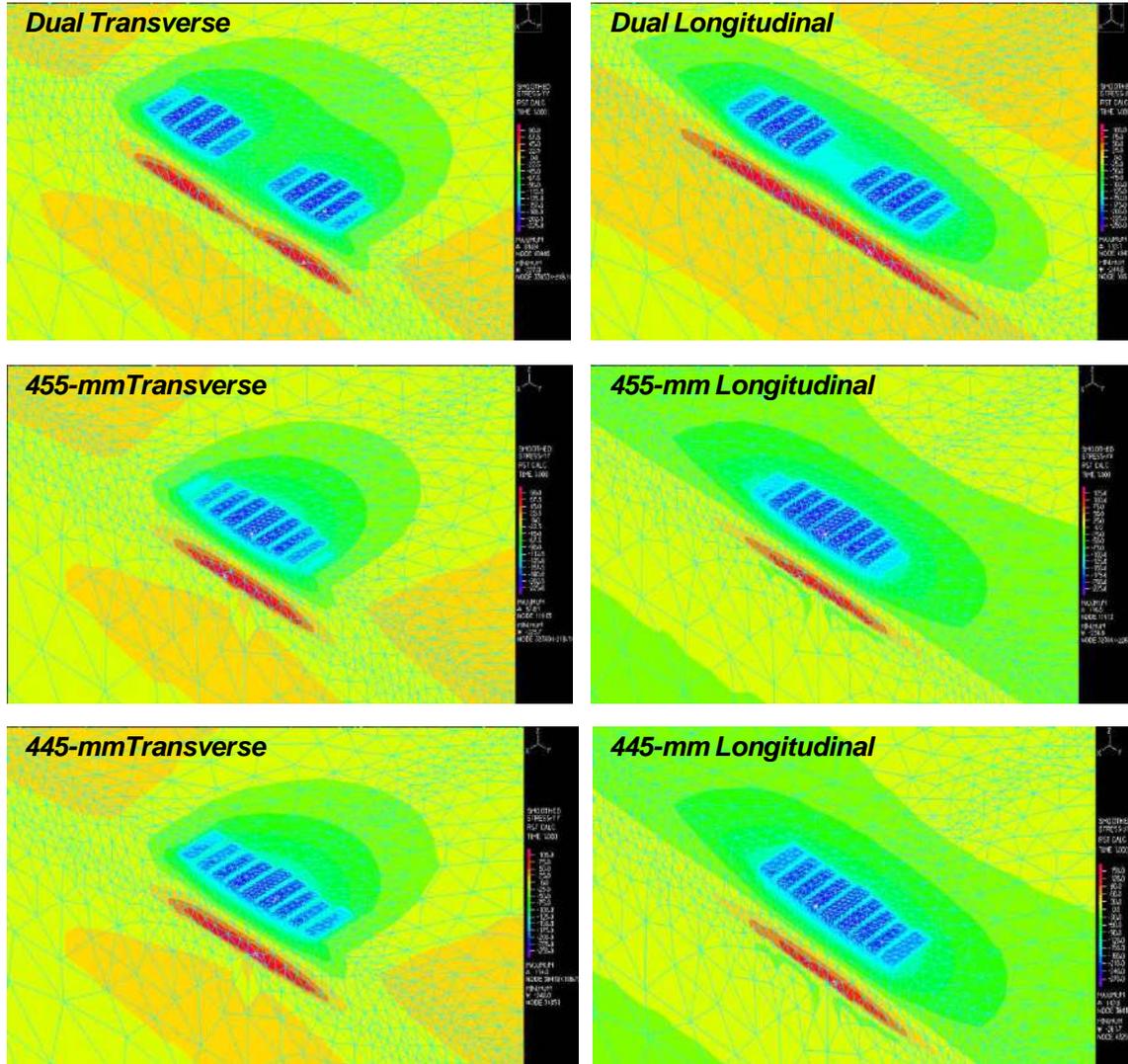


FIGURE 8 Predicted stress distributions.

Top-down cracking in Florida is primarily observed as longitudinal cracks inside or just outside the wheel path. As with the measured surface strains presented earlier, the dual tire was predicted to induce the greatest surface strain. The maximum transverse tensile strain was predicted to occur approximately 9 to 10 inches (230-mm to 255-mm) from the tire edge regardless of tire type. The magnitudes of the predicted strain were smaller than those measured. However, the predicted strain values and predicted locations of maximum tensile strain were not necessarily expected to match since a greater load was used in the HVS experiments. A recent FDOT study also indicated that the maximum surface strain would occur approximately 10 inches (250-mm) from the tire edge (16). The 455-mm wide-base tire was predicted to generate the least amount of shear strain below the tire edge. The dual and the 445-mm wide-base tire generated similar shear strains. The maximum shear strain for all of the tires was determined to occur at a depth of approximately 2 inches. However, the shear strains at shallower depths were still greater than the surface tensile strain. The actual critical location for top-down cracking found

on in-service pavements most likely corresponds to a combination of critical shear and tensile stresses due to tire induced stresses, environmental aging effects, and other surface distresses such as rutting.

Tensile strain measured at the bottom of the asphalt was used to indicate bottom-up fatigue cracking potential. The NGWB 445-mm tire was predicted to induce slightly more tensile strain and create more bottom-up fatigue cracking damage. The NGWB 455-mm tire and the dual tire produced similar tensile strains and could be expected to produce similar bottom-up fatigue crack damage. TABLE 2 summarizes the FE model predicted strains

TABLE 2 Summary of Predicted Strains

Tire Type	Maximum Predicted Strain, Microstrain				Strain Ratios			
	Rutting	Top-Down Cracking		Bottom-Up Cracking	Rutting	Top-Down Cracking		Bottom-Up Cracking
	Compressive Strain	Transverse Strain	Shear Strain	Tensile Strain	Compressive Strain	Transverse Strain	Shear Strain	Tensile Strain
Dual	353	31	180	162	1.0	1.0	1.0	1.0
NGWB 455	373	28	139	156	1.1	0.9	0.8	1.0
NGWB 445	390	24	178	187	1.1	0.8	1.0	1.2

IMPACT ON FLORIDA ROADWAYS

Dual tires have been predominantly used on Florida roadways. Pavement damage on Florida roadways is documented through annual surveys conducted by the State Materials Office (SMO). Crack and rut damage is determined on a scale of 1 to 10, with 10 representing a pavement with no damage. A rating of 6 or less indicates a deficient pavement that is eligible for rehabilitation. A rating of 7 may be considered borderline deficient. In 2008, more than 30,000 miles were surveyed statewide. A summary of the 2008 survey is shown in FIGURE 9 (17). Cracking is the predominant distress and in general, is more widespread in South Florida (Districts 4 and 6). Rutting is more common in the Panhandle (District 3).

Based on the results of this study, the pavement damage induced by the 455-mm wide-base tire could be considered similar to that of the dual tire in terms of rutting and bottom-up cracking and slightly improved in terms of top-down cracking. On the contrary, the 445-mm tire was shown to rut dense-graded pavement surfaces more than twice as fast as a standard dual. The 445-mm tire was also predicted to create slightly more bottom-up cracking damage than a dual tire, but less or similar surface cracking damage. The pavement damage trends shown in 2008, particularly rutting damage on dense-graded surfaces, would likely increase if the 445-mm tire is included in the future.

This research is important to FDOT and the trucking industry. It is important that new technology be thoroughly evaluated in terms of cost benefit and performance to both the transportation industry and the highway infrastructure where it will be applied. This research showed that by increasing the tire contact area, pavement damage can be decreased.

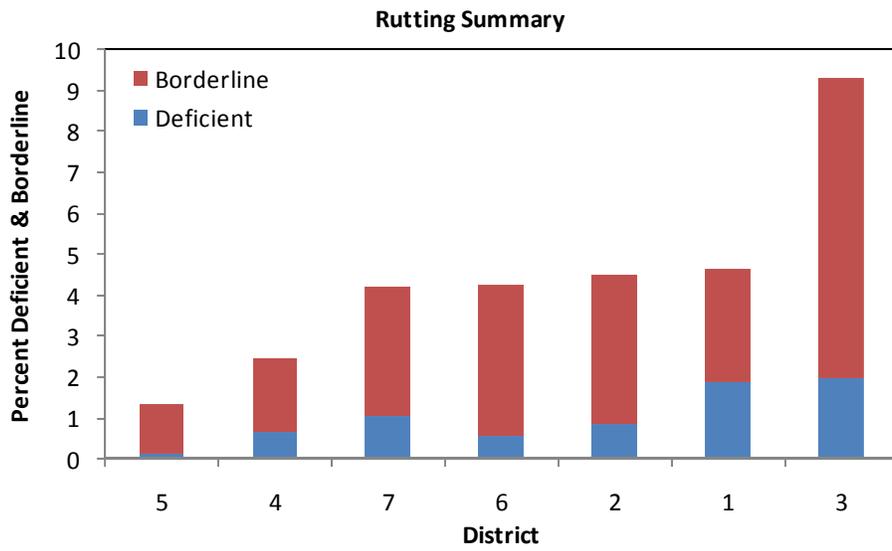
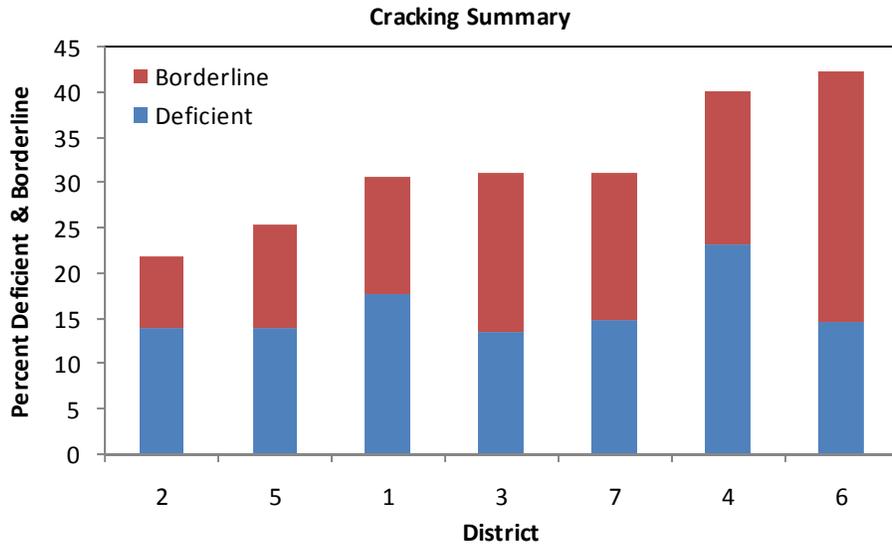


FIGURE 9 2008 Pavement Condition Survey Summary.

ACKNOWLEDGEMENTS

The work represented herein was the result of a team effort. The authors would like to acknowledge Kyle Sheppard, Lance Denmark, and Jason White for their diligent efforts and contributing knowledge.

DISCLAIMER

The content of this paper reflects the views of the authors who are solely responsible for the facts and accuracy of the data as well as for the opinions, findings and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Florida Department of Transportation. This paper does not constitute a standard, specification, or regulation. In addition, the above listed agency assumes no liability for its contents or use thereof.

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**Determination of Pavement Damage
From Super-Single and Singled-out Dual Truck Tires**

**PRELIMINARY DRAFT
INTERIM REPORT**

**Prepared for
National Cooperative Highway Research Program
Transportation Research Board
National Research Council**

TRANSPORTATION RESEARCH BOARD

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This report, not released for publication, is furnished only for review to members of or participants in the work of the National Cooperative Highway Research Program (NCHRP). It is to be regarded as fully privileged, and dissemination of the information included herein must be approved by the NCHRP.

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ACKNOWLEDGEMENT OF SPONSORSHIP

This work was sponsored by the American Association of State Highway and Transportation Officials, in cooperation with the Federal Highway Administration, and was conducted through the national Cooperative Highway Research Program, which is administered by the Transportation Research Board of the National Research Council.

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ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 1-36 by the Pavements/Materials Program, Department of Civil Engineering at the University of Nevada, ERES Consultants, Inc., and the Nevada Automotive Center (NATC). The work undertaken at ERES and NATC was under subcontracts with the University of Nevada.

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The work was done under the general supervision of Dr. Peter Sebaaly. The work at ERES was done under the supervision of Dr. Tayabji with the assistance of Yan Jiang, Staff Engineer. The work at NATC was done by Colin Ashmore.

CHAPTER 1

INTRODUCTION

The use of "super-single" tires and the practice of removing one tire from a conventional dual tire configuration, known as "singled-out dual" tires, have increased in recent years, primarily because of their favorable effects on a truck's tare weight and rolling resistance. In comparison to trucks equipped with conventional dual-tire configurations, trucks equipped with such single-tire configurations allow a higher pay load and increased fuel efficiency. However, single-tire configurations have different tire widths, pressures, and footprint dimensions than do conventional dual tires.

Research has been performed on the effects of super-single and singled-out dual tire configurations on pavement performance and damage. Although this research has shown that pavement deflections caused by single-tire configurations were higher than those caused by conventional dual-tire configurations, it has not provided clear conclusions concerning the extent of pavement damage or the measures needed to limit such damage. Further research is needed to address the effects of using single-tire configurations on pavement damage and to identify possible approaches for controlling pavement damage that will yield reduced life-cycle costs, improved ride quality, and other economic and environmental benefits.

The primary objective of the research is to develop a procedure to estimate pavement damage associated with the use of single-tire configurations compared with that of conventional dual-tire configurations. The research will also seek to identify technical and regulatory approaches for controlling pavement damage from single-tire use on both flexible and rigid pavements.

CHAPTER 2

LITERATURE REVIEW

SINGLE TIRES DAMAGE ON FLEXIBLE PAVEMENTS

Numerous studies have been conducted to evaluate flexible pavement damages due to super-single and singled-out tires. Some studies used theoretical analyses while others conducted field experiments to evaluate the relative pavement damage caused by single tires as compared to dual tires configurations. In order to facilitate the review and summary process, the identified studies were grouped into four different categories based on the procedure that they used to evaluate the relative damage: a) theoretical-response, b) theoretical-performance, c) experimental-response, and d) experimental-performance.

Prior to presenting the methodologies and findings of the various studies, it would be beneficial to define certain common terminology which will be used throughout the report.

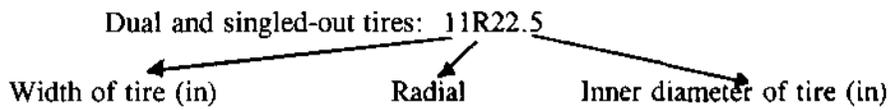
Tire Configuration:

- a. Dual tires: a set of two tires fitted to each side of an axle in a dual wheel configuration.
- b. Singled-out tire: one of the dual tires has been removed and one tire is left on each side of the axle.
- c. Super-single tire: a wider tire than the conventional dual tire that is fitted on each side of an axle in a single wheel configuration.

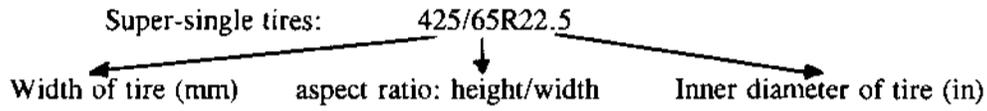
At various occasions, the report may refer to the singled-out and super-single tires simply as "single tires," except when a direct comparison between the two types of tires is being presented.

Tire Size:

The following convention is used to identify tire sizes:



****The same convention is used for bias tires except that the R is eliminated****



Pavement Performance:

- Fatigue: alligator cracking of the pavement surface.
- Rutting: permanent deformation in the wheel tracks.
- Roughness: Waviness of the pavement surface.

Theoretical-Response

This group of studies used theoretical analyses to evaluate pavement responses under single and dual tires configurations. The calculated pavement responses were then used to evaluate the relative pavement damage caused by single tires as compared to dual tires. For example, the multi-layer elastic theory is used to calculate tensile strain at the bottom of the asphalt concrete (AC) layer under single and dual tires configurations. The relative pavement damage caused by single tires as compared to dual tires is then calculated as the ratio of the strains calculated under the single tires over the strains under dual tires. Only one study was identified under this category which is summarized below.

Perdomo and Nokes (1) used the multi-layer elastic theory with surface shear stresses to evaluate the impact of super-single tires on flexible pavements. Two loading cases were considered: (1) Non-uniform vertical stress, (2) Non-uniform vertical stress with non-uniform inward surface shear stress. The pavement section analyzed had a 168 mm (6.6”) dense graded AC layer, 76 mm (3”) asphalt base,

and 427 mm (16.8") aggregate base. The evaluated axle loads consisted of 89 kN (20 kips) for single axle, 151 kN (34 kips) for tandem axle, and 151 kN (34 kips) for tridem axle. The tensile strains and strain energy of distortion at the bottom of the AC layer were used as the pavement response parameters. The strain energy (SED) of distortion was evaluated through the following equation:

$$\text{SED/volume} = 1/2(\sigma_x \epsilon_x + \sigma_y \epsilon_y + \sigma_z \epsilon_z + \tau_{xy} \gamma_{xy} + \tau_{yz} \gamma_{yz} + \tau_{xz} \gamma_{xz}) - [(1-2\nu)/6E \{(\sigma_x + \sigma_y + \sigma_z)^2\}]$$

Tables 1, 2, and 3 give the values of critical tensile strains and strain energy of distortion for the two loading conditions on single, tandem, and tridem axles respectively. This study concluded that the critical tensile strain and strain energy of distortion are higher under super-single tires than dual tires. Also the inclusion of the surface shear stresses significantly increased the magnitude of both the tensile strain and strain energy of distortion. The study, however, failed to relate the strain energy of distortion to any mode of pavement failure.

Theoretical-Performance:

This category used theoretical analyses to evaluate pavement responses under single and dual tires configurations and used the calculated responses in performance prediction models to evaluate the relative damage caused by single tires as compared to dual tires. For example, the multi-layer elastic theory is used to calculate the tensile strains while a fatigue performance model is used to calculate the number of load repetitions to fatigue failure. The following represents a summary of the studies that fit under this category.

Deacon (2) derived theoretical load equivalency factors based on the strain at the bottom of the AC layer using the multi-layer elastic theory. A variety of axles, tire configurations, and pavement structures were analyzed with circular tire contact area and uniform contact pressure. Load equivalencies

Table 1: Pavement responses under 89 kN single axle load. (1)

Tire Type	Loading Stresses	Max. Tensile Strain	Max SED
Super single Tire	Vertical only	-320	24
	Vertical + Shear	-2140	132
Dual Tires	Vertical only	-230	11
	Vertical + Shear	-1880	102

Table 2: Pavement responses under 151 kN tandem axle load. (1)

Tire Type	Loading Stresses	Max. Tensile Strain	Max SED
Super single Tire	Vertical only	-340	22
	Vertical + Shear	-2110	129
Dual Tires	Vertical only	-250	11
	Vertical + Shear	-1870	101

Table 3: Pavement responses under 151 kN tridem axle load. (3)

Tire Type	Loading Stresses	Max. Tensile Strain	Max SED
Super single Tire	Vertical only	-360	22
	Vertical + Shear	-2190	123
Dual Tires	Vertical only	-290	11
	Vertical + Shear	-1900	97

F, were derived as a function of the exponential strain ratios. The exponential represents the conversion from strains into fatigue life.

$$F_i = [\epsilon_i / \epsilon_b]^{5.5}$$

where, ϵ_i and ϵ_b are the calculated tensile strains at the bottom of AC layer under the load in question and the reference load of 80 kN (18,000 lb) on a single axle with dual tires, respectively. Figure 1 shows a summary of the results in terms of the pavement structure number (SN). The SN is based on the definition of the AASHTO Design of Pavement Structures. It can be seen that an 80 kN (18,000 lb) single axle load on dual tires is equivalent to a 52-64 kN, (11,700-14,400 lb) axle load on singled-out tires depending on the pavement structure. The equivalent load on a singled-out tired axle becomes smaller as the SN value decreases which indicates that singled-out tires are more damaging on weaker and/or thinner pavement structures. For example, an 80 kN (18,000 lb) single axle load with dual tires is equivalent to a single axle load of 52 kN (11,700 lb) and 64kN (14,400 lb) with singled-out tires on pavements with SN value of 2 and 6, respectively.

Southgate and Deen (3) presented a theoretical study to evaluate the effects of load distribution, axle type, and tire configuration on the fatigue of flexible pavements. They used the strain energy concept which they defined as the work done internally by the body and is equal and opposite in direction to work done upon the body by an external force. The multi-layer elastic solution was used to compute the work strain. Different tire loads were analyzed ranging from 24.5 kN (5.5 kips) to 42.3 kN (9.5 kips). The tire pressures investigated in this study were 552 kPa (80 psi), 793 kPa (115 psi), 1030 kPa (150 psi), and 1380 kPa (200 psi). The calculated work strains were then used to evaluate the number of load repetitions to fatigue failure through the following equation.

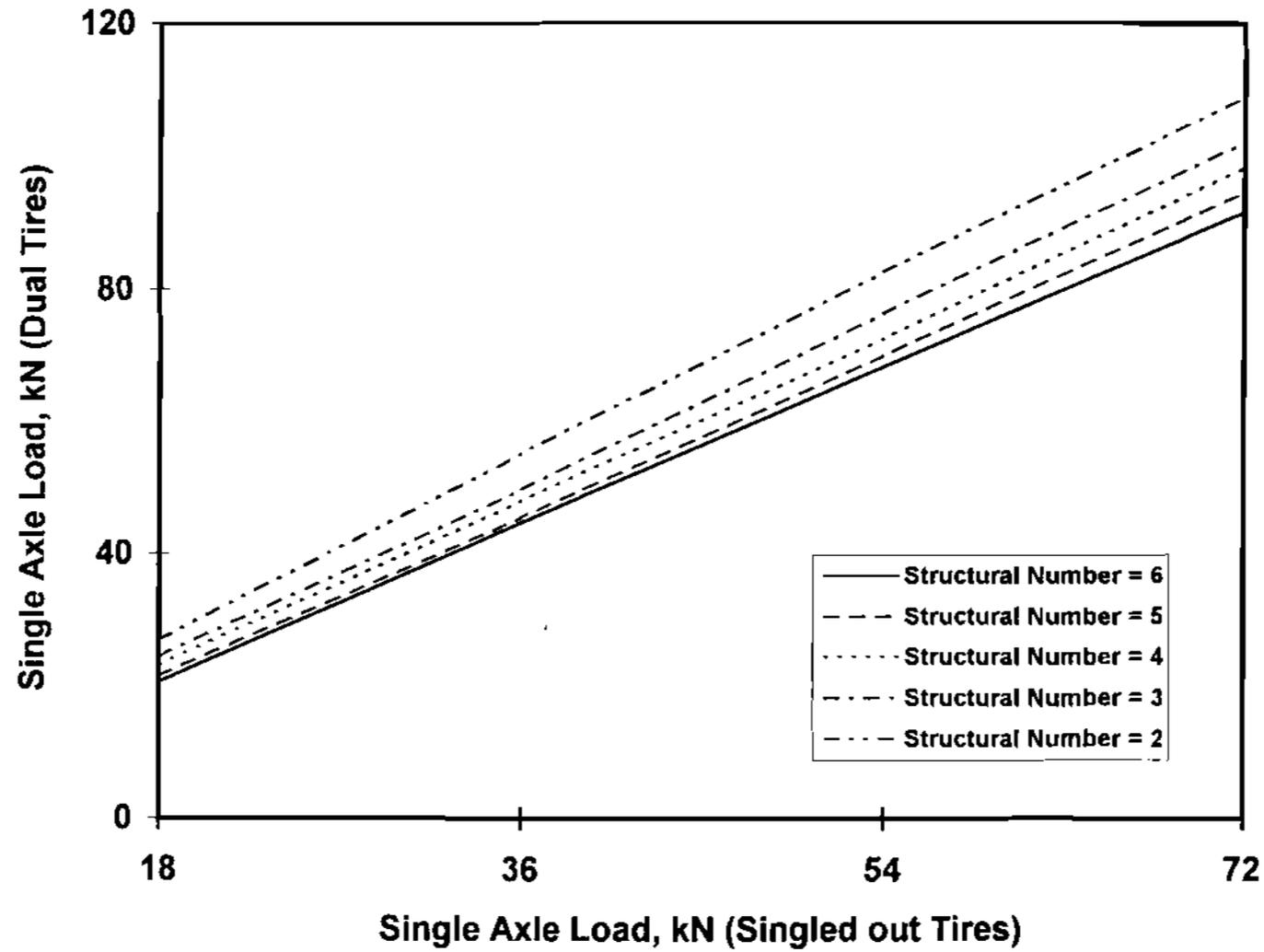


Figure 1. Equivalent single axle loads when using singled-out tires. (2)

$$\log (N) = -6.4636 \log (e_w) - 17.3081$$

where: e_w is the work strain.

The damage factors were evaluated as the ratio of the number of load repetitions to failure under the standard 80 kN (18,000 lb) single axle load with dual tires over the number of repetitions of the axle and tire configurations in question. Figure 2 compares damage factors for tandem and tridem axles using super-single and dual tires configurations. The results from this study indicated that super-single tires are more damaging to flexible pavements than dual tires. However, the damage factors approached equality at higher loads of 222 kN (50 kips) for tandem axle and 311 kN (70 kips) for tridem axles. These load levels are above the legal load limits throughout the U.S.

Hallin et al (4) used the tensile strain at the bottom of the AC layer to evaluate the impact of tires configurations on flexible pavements. A nonlinear multi-layer elastic solution was used to model the response of flexible pavements. Different axle loads were analyzed ranging from 44.5 kN to 180 kN (10 kips to 40 kips) with tire widths of 254 mm, 381 mm, 457 mm (10", 15", and 18"). Different pavement sections were included in the analysis: 76 mm, 152 mm, and 241 mm (3", 6", and 9.5") of asphalt concrete over 203 mm (8") of crushed aggregate base. The relative damage was assessed using equivalency factors. The load equivalency factors were calculated according to the following equation:

$$\text{Equivalency Factor} = N_{18} / N_i$$

where N_{18} is the number of load repetitions to fatigue failure for 80 kN (18 kip) single axle load with dual tires and N_i is the number of load repetitions to fatigue failure for the axle load/tire configuration being evaluated. The number of load repetitions was calculated according to the following equation:

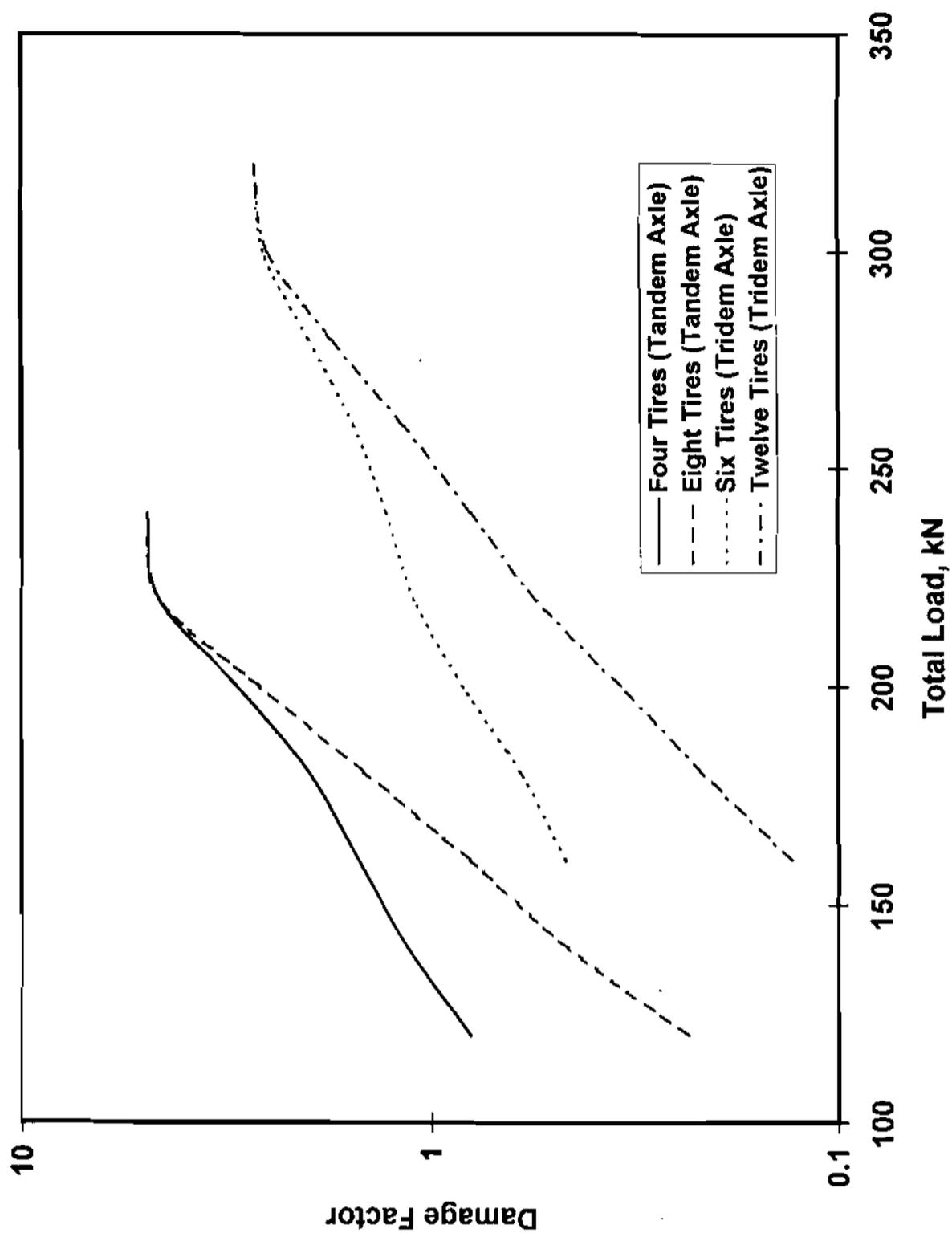


Figure 2. Pavement damage created by single tires as compared to dual tires. (3)

$$\log N_r = 15.947 - 3.291 \log (\epsilon) - 0.854 \log (E/10^3)$$

where ϵ is the tensile strain at the bottom of the asphalt concrete layer and E is the resilient modulus of the asphalt concrete layer. Table 4 summarizes a typical set of the equivalency factors for single axles with single tires, for an asphalt concrete pavement with a structural number of 4.

This study concluded that, for the same axle load, as the width of the single tire decreases, the equivalency factor increases which indicates more damage. As the axle load increases, the equivalency factor also increases. The data from this study showed that single tires can be as much as 25 times more damaging than dual tires as the axle load increases and the tire width decreases.

Bell and Randhawa (5) used the multi-layer elastic theory to evaluate the effects of singled-out tires on pavement damage. Three different types of trucks were studied 3-S2, 3-S3, and 2-S1-2. Two sets of pavement thicknesses were analyzed. Thick section with 178 mm (7") asphalt concrete over 305 mm (12") granular base and thin section with 89 mm (3.5") asphalt concrete over 305 mm (12") granular base.

Equivalency factors were used to assess the relative damage. The equivalency factors were calculated by dividing the fatigue and rutting lives produced by the application of a standard 80 kN (18,000 lb) by the lives produced by the axle under consideration. The following equation was used to estimate the number of load applications to fatigue failure (N) associated with each level of calculated tensile strain (ϵ).

$$N = 18.4 (C) (0.00432 \times \epsilon_t^{-3.29} \times E^{-0.854})$$

Table 4: Equivalency factors For single axles with single tires and SN = 4. (4)

Equivalent 80 kN Dual Tire, Single Axle Loads					
Axle Load (kN)	Single Tire Width (mm)				
	254	305	356	406	457
44.5	0.631	0.479	0.373	0.297	0.241
53.4	1.029	0.781	0.608	0.484	0.392
62.3	1.555	1.181	0.919	0.732	0.593
71.2	2.224	1.689	1.315	1.047	0.848
80.1	3.050	2.316	1.804	1.435	1.163
89.0	4.046	3.072	2.393	1.904	1.542
97.9	5.223	3.966	3.089	2.458	1.991
106.8	6.596	5.001	3.901	3.104	2.515
115.7	8.175	6.206	4.834	3.847	3.116
124.6	9.972	7.571	5.897	4.692	3.801
133.4	11.998	9.109	7.096	5.646	4.573
142.3	14.264	10.829	8.435	6.712	5.438
151.2	16.782	12.741	9.924	7.897	6.397
160.1	19.561	14.851	11.568	9.205	7.457
169.0	22.612	17.167	13.372	10.640	8.620
177.9	25.946	19.698	15.343	12.209	9.891

where:

C reflects the mix components: $C = 10^M$

$M = 4.84 (A - 0.69)$

$A = V_b / (V_v + V_b)$

$V_b = \text{Volume of Asphalt}$

$V_v = \text{Volume of Air}$

The following equation was used to estimate the number of load repetitions to rutting failure (N) associated with each level of compressive strain (ϵ_c).

$$N = 1.36 \times 10^9 \times \epsilon_c^{-4.48}$$

ϵ_t , ϵ_c and E represent the tensile strain at the bottom of the AC layer, the compressive strain on top of the subgrade and the resilient modulus of the AC layer, respectively.

Tables 5 and 6 show the equivalency factors for fatigue and rutting for thick and thin pavements. The data showed that the load/tire has the most significant impact on the fatigue damage while the total axle load has the most significant impact on the rutting damage. The data showed that singled-out tires can cause as high as 100% more damage than dual tires. Also the location of the singled-out axles within the axle group significantly impact the magnitude of the damage.

Gillipsie et al (6) used analytical methods to analyze the mechanics of vehicle-pavement interaction and to evaluate pavement damage. This study used VESYS-DYN to compute the primary responses of flexible pavement structures to applied tire loads. The program handles elastic and viscoelastic analysis of any number of pavement layers. Several thicknesses of the AC layer were analyzed. The evaluated tires included: conventional 11R22.5, low profile 215/75R17.5, low profile

Table 5. Equivalency factors For thin pavement. (5)

Case	Axle Group	Axle Load kN	Load/Tire kN	Tire Pressure (kPa)	LEF Fatigue	LEF Rut
1	Single Axle (4 tires)	80	20	703	1.00	1.00
2	Tandem Axle (8 tires)	151	18.9	703	0.87	0.72
3	Tandem Axle (6 tires) one axle singled out	151	25.2	703	1.66	2.64
4	Tandem axle 4 tires (both axles singled out)	117	29.4	724	1.25	0.63
5	Tridem axle (12 tires)	187	15.6	703	0.57	0.30
6	Tridem axle (10 tires) one axle singled out (mid axle)	187	18.7	703	0.86	0.70
7	Tridem axle (10 tires) one axle singled out (outer axle)	187	18.7	703	0.85	0.69
8	Tridem axle (8 tires) two axles singled out (outer axles)	187	23.4	703	1.37	1.86
9	Tridem axle (8 tires) two axles singled out (outer and inside axles)	187	23.4	703	1.34	1.82
10	Tridem axle (6 tires) three axles singled out	176	29.4	724	1.26	0.63
11	Tridem axle (6 tires) three axles singled out	187	31.1	724	1.40	0.82

Table 6. Equivalency Factors for thick pavement. (5)

Case	Axle Group	Axle Load kN	Load/Tire kN	Tire Pressure (kPa)	LEF Fatigue	LEF Rutting
1	Single Axle (4 tires)	80	20	703	1.00	1.00
2	Tandem Axle (8 tires)	151	18.9	703	0.63	0.83
3	Tandem Axle (6 tires) one axle singled out	151	25.2	703	1.72	2.87
4	Tandem axle 4 tires (both axles singled out)	117	29.4	724	1.02	0.37
5	Tridem axle (12 tires)	187	15.6	703	0.33	0.38
6	Tridem axle (10 tires) one axle singled out (mid axle)	187	18.7	703	0.66	0.72
7	Tridem axle (10 tires) one axle singled out (outer axle)	187	18.7	703	0.58	0.82
8	Tridem axle (8 tires) two axles singled out (outer axles)	187	23.4	703	1.33	1.99
9	Tridem axle (8 tires) two axles singled out (outer and inside axles)	187	23.4	703	1.16	2.12
10	Tridem axle (6 tires) three axles singled out	176	29.4	724	1.14	0.40
11	Tridem axle (6 tires) three axles singled out	187	31.1	724	1.33	0.52

245/75R19.5, super-single 15R22.5, and super-single 18R22.5. The 11R22.5, 15R22.5, and 18R22.5 were considered to represent the nominal sizes required to carry front axle loads of 53, 71, and 89 kN (12,000, 16,000, and 20,000 lb), respectively, in a single tire configuration. The 11R22.5 was also suited for dual tire applications on 89 kN (20,000 lb) single axle and 151 kN (34,000 lb) tandem axles. The 15R22.5 was selected as the tire size typically used on axles intended to carry 71 kN (16,000 lb) and the 18R22.5 was selected for axles rated at 89 kN (20,000 lb). The tire inflation pressure varied between 517 kPa and 827 kPa (75 and 120 psi).

The horizontal tensile strain at the bottom of the AC layer was used as an indicator of fatigue cracking. The vertical compressive strains on top of each layer were used as indicators of rutting. The relative damage was assessed using the equivalency factors approach. The equivalency factors for fatigue damage were defined as the ratio of number of passes of an 80 kN (18-kip) single axle fitted with dual tires 11R22.5 required to consume the same amount of fatigue life in the AC layer as an axle with single tires at their rated load. Table 7 shows the equivalency factors for low profile duals and single tires over a range of tire sizes.

The study also developed rut depth equivalency factors which are defined as the ratio of the number of passes of an 80 kN (18 kip) axle fitted with dual tires required to cause the same rut depth as an axle with singled-out or super-single tires. Tables 8 and 9 show the equivalence factors for a range of AC thickness and two pavement surface temperatures.

The data show that single tires are more damaging than dual tires. However, the damage created by single tires increases as the thickness of the AC layer increases. The increase in the equivalency factors as a function of the AC layer thickness is the most

Table 7. Fatigue equivalency factors for various sizes of tires (6).

AC Thickness mm	LP Duals 215/75R17.5 Axle Load 76 kN	11R22.5 Axle Load 53 kN	15R22.5 Axle Load 71 kN	18R22.5 Axle Load 89 kN
51	1.95	1.81	0.81	0.51
76	1.61	1.81	1.23	0.95
102	1.29	1.67	1.52	1.43
127	1.17	1.44	1.67	1.86
165	1.04	1.13	1.7	2.28

Table 8. Rutting equivalency factors for various sizes of tires, AC temperature 25 °C. (6)

AC Thickness mm.	11R22.5 Axle Load 53 kN	15R22.5 Axle Load 71 kN	18R22.5 Axle Load 89 kN
51	1.05	1.21	1.39
76	1.11	1.24	1.38
102	1.20	1.32	1.45
127	1.28	1.38	1.5
165	1.38	1.47	1.6

Table 9. Rutting equivalency factors for various sizes of tires, AC temperature 49 °C. (6)

AC Thickness mm.	11R22.5 Axle Load 53 kN	15R22.5 Axle Load 71 kN	18R22.5 Axle Load 89 kN
51	1.5	1.4	1.38
76	1.57	1.53	1.55
102	1.51	1.41	1.40
127	1.50	1.43	1.44
165	1.59	1.5	1.53

contradicting conclusion of this study. This finding contradicts the fundamental principles of flexible pavement design. Therefore, the validity of the approach used to calculate the equivalency factors is highly questionable.

Experimental-Response

This group of studies conducted field experiments to measure the relative pavement damage caused by single tires as compared to dual tires configurations. The studies in this category measured the pavement responses under different tire configurations but they did not monitor the actual performance of the pavements as being loaded by single and dual tires configurations. However, most of the studies in this group used the measured pavement responses in pavement performance models to estimate the relative damage. The following represents a summary of the studies in this group.

One of the earliest efforts to evaluate pavement damage from super-single tires relative to conventional dual tires was done by Zube et al (7). Pavement surface deflections were used as indicators of relative damage. Surface deflections were measured with a Benkelman-Beam and LVDT's embedded into the pavement. Testing took place on 8 sites surfaced with 50-70 mm (2" - 2.8") thick asphalt concrete layer.

Pavement responses were compared under single axles on single bias tires 18.00x19.50 and dual bias tires 10.00X20.00 inflated at 517 kPa (75 psi) and 482 kPa (70 psi), respectively. On the average, a 57 kN (12,814 lb) load on a single tired axle was equivalent, in terms of pavement surface deflection, to an 80 kN (18,000 lb) single axle load with dual tires. Therefore, this early observation indicated that bias single tires could be 30% more damaging

than dual bias tires.

Christison (8) conducted a field study at the Alberta Research Council's instrumented flexible pavement site to evaluate the relative damage caused by single tires as compared to dual tires. The longitudinal strains at the bottom of the asphalt concrete layer, pavement surface deflections, and pavement temperatures at various depths within the pavement structure were recorded under moving vehicle loads. Equivalency factors were calculated on the basis of the measured pavement responses as follows:

$$F_i = [\epsilon_i / \epsilon_b]^{5.5}$$

where, ϵ_i and ϵ_b are tensile strains under the load in question and the reference load of 80 kN (18,000 lb) on a single axle with dual tires, respectively. Pavement response parameters were found to depend on temperature, and vehicle speed. In order to eliminate the effect of temperature and vehicle speed, each pass of the axle load to be evaluated was followed by the reference axle load at the same speed. All tested tires were bias type tires. The axle load varied from 56 to 117 kN (12,600 to 26,302 lb) for single axle with dual tires, 9 to 53 kN (2,023 to 11,914 lb) for single axle with singled-out tires, and 62.7 to 86.4 kN (14,100 to 19,400 lb) for single axle with super-single tires.

Table 10 shows the equivalency factors for singled-out tires. Unfortunately, most of the load levels were kept low which generated equivalency factors less than 1.0 in most cases. However, the data showed that for singled-out tires, an axle load of 51.6 kN (11,610 lb) could be equivalent to 80 kN (18,000 lb) single axle load on dual tires. Table 11 shows the equivalency factors for super-single tires which indicate that a single axle load of 76 kN (17,100 lb) with super-single tires is equivalent to 80 kN (18,000 lb) single axle load with

Table 10. Equivalency factors for singled-out bias tires based on tensile strains and surface deflections. (8)

Bias Tire Size	Axle Load kN	Average AC Temperature	$e_{ten}(L)/e_{ten}(80 \text{ kN})$	$d(L)/d(80 \text{ kN})$
10.00 x 20	28	22	0.44	0.57
10.00 x 20	28.5	19	0.52	0.57
10.00 x 20	29.4	20	0.55	0.58
10.00 x 20	30.7	22	0.62	0.67
10.00 x 20	36.5	24	0.68	0.72
11.00 x 20	37.4	19	0.60	0.65
11.00 x 20	37.4	19	0.60	0.65
11.00 x 20	51.6	20	0.95	0.98
12.00 x 20	51.6	23	1.083	1.13
12.00 x 22.5	51.6	23	0.94	0.95

Table 11. Equivalency factors for super-single bias tires based on tensile strains and surface deflections. (8)

Tire Size	Axle Load kN	Average AC Temperature	$e_{ten}(L)/e_{ten}(80 \text{ kN})$	$d(L)/d(80 \text{ kN})$
18 x 22.5	62.7	16	0.86	0.99
18 x 22.5	76.0	15	1.00	1.10
18 x 22.5	85.3	14	1.11	1.17

Table 12. Equivalent axle loads for dual and single tires. (9)

Tire Type/ (inner/outer pressure)	Single Axle (t)	Tandem Axle (t)	Tridem (t)
10R20 (550/550)	8.2	13.6	18.5
10R20 (550/689)	7.4	NA	NA
15R22.5 (792)	5.9	10.5	17.0

dual tires. In summary, the data from this study indicate that singled-out tires are more damaging than both dual tires and super-single tires. The applicability of this data is diminishing as the use of bias tires on highway pavements has been significantly reduced.

Sharp et al (9) performed a field study to evaluate the relative damage of super-single tires on flexible pavements. The study measured surface deflections of a flexible pavement section (75 mm AC, 150 mm aggregate base, and 200 mm aggregate subbase). The tested tires were the 10R20 dual and the 15R22.5 super-single. The inflation pressures of the dual tires were varied between the two tires to simulate differential wearing of the tires. The relative damage was evaluated in terms of equivalent axle loads based on the ratios of the measured deflections. Table 12 summarizes the data for the single, tandem, and tridem axles. The data show that differential wearing of the dual tires can significantly impact the equivalent load that a single axle with dual tires can carry. In addition, the use of super-single tires reduces the allowable loads by 28, 22, and 8 percent for single, tandem, and tridem, respectively. This indicates that the damage from single tires decreases as the number of axles increases. In another word, the use of single tires on tridems may not significantly reduces the allowable loads while providing an economic incentive for the trucking industry.

Sebaaly and Tabatabaee (10) extensively studied the influence of tire pressure and type on the response of flexible pavements through a field experiment at the Penn State Test Track. Strain gauges were installed at the bottom of the AC layer to measure longitudinal strains and geophones were used to measure vertical surface deflections. A thermocouple tree consisting of four sensors at various depths was installed to monitor temperature variations throughout the AC layer. Six tire types were evaluated in the experiment:

- (a) dual 11x22.5 bias ply tires
- (b) dual 11R22.5 radial ply tires
- (c) dual 245/75R22.5 low profile dual radial tires
- (d) 425/65R22.5 super-single tire
- (e) 385/65R22.5 super-single tire
- (f) 350/75R22.5 super-single tire

The following axle loads were investigated: for dual tires 44.5, 75.6, 97.9 kN/axle (10, 17, 22 kips/axle) and 44.5, 75.6, 89 kN/axle (10, 17, 20 kips/axle) for single tires. Two pavement sections were evaluated: 1) thin pavement section with 152 mm (6") asphalt concrete and 203 mm (8") base course and 2) thick section with 254 mm (10") asphalt concrete and 254 mm (10") base course. Actual truck loading was used at speed of 65 km/h (40 mph). Pavement performance were evaluated using the following models:

Fatigue:

$$\log N_f (10\%) = 15.947 - 3.291 \log (\epsilon/10^{-6}) - 0.854 \log (E/10^3)$$

$$\log N_f (45\%) = 16.086 - 3.291 \log (\epsilon/10^{-6}) - 0.854 \log (E/10^3)$$

where :

N_f = Number of load applications required to cause 10 or 45 percent cracking of the wheel tracks.

ϵ = tensile strain at the bottom of asphalt concrete layer.

E = resilient modulus of asphalt concrete layer.

Rutting:

For Asphalt concrete layer less than 152.4 mm (6 in).

$$\log RR = -5.617 + 4.343 \log d - 0.16 \log (N_{18}) - 1.118 \log sc$$

For Asphalt concrete layer greater than or equal to 152.4 mm (6 in).

$$\log RR = -1.173 + 0.717 \log d - 0.658 \log (N_{18}) + 0.666 \log (sc)$$

Where :

RR = rate of rutting, micro-inches per axle-load repetition

d = surface deflection x 10^3 in

sc = Vertical compressive stress at interface of base course with AC

N_{18} = Equivalent of 18-kip single-axle load x 10^5

The relative damage was assessed using the following relationships:

$$\text{Damage Factor (Fatigue)} = N_r (11R22.5) / N_r (\text{any tire})$$

$$\text{Damage Factor (Rutting)} = RR (11R22.5) / RR (\text{any tire})$$

Tables 13 through 20 show some of the fatigue and rutting damage factors that were developed in this study. The data showed that the 11R22.5 had the smallest measured strains for both thick and thin pavement sections. The tire inflation pressure did not have any impact on the measured strains for both thin and thick pavement sections. There was a significant difference in the response between single and dual tires for the thin and thick pavement sections which resulted in a significant difference in the evaluated damage factors.

Table 13. Fatigue damage factors for the tandem-axle load of 76.5 kN/axle (17.2 kip/axle) for the thin section. (10)

Tire Type	Pressure kPa	Microstrain (70 °F)	Nf (10%) X10 ³	Damage Factor	Nf (45%) X10 ³	Damage Factor
11R22.5	827	253	700	1.00	964	1.0
	724	247	758	0.90	1,043	0.9
245/75R22.5	827	264	608	1.2	838	1.2
425/65R22.5	827	283	484	1.4	667	1.4
385/65R22.5	896	313	347	2.0	479	2.0

Table 14. Fatigue damage factors for the tandem-axle load of 76.5 kN/axle (17.2 kip/axle) for the thick section. (10)

Tire Type	Pressure kPa	Microstrain (70 °F)	Nf (10%) X10 ³	Damage Factor	Nf (45%) X10 ³	Damage Factor
11R22.5	827	133	4,227	1.00	5,821	1.0
	724	129	4,674	0.90	6,436	0.9
245/75R22.5	827	138	3,743	1.1	5,155	1.1
425/75R22.5	827	148	2,974	1.4	4,095	1.4
385/65R22.5	896	153	2,666	1.6	3,671	1.6

Table 15. Fatigue damage factors for the Single-axle load of 78.3 kN (17.6 kip) for the thin section. (10)

Tire Type	Pressure kPa	Microstrain (21.1 °C)	Nf (10%) X10 ³	Damage Factor	Nf (45%) X10 ³	Damage Factor
11R22.5	827	268	579	1.00	798	1.0
	724	258	656	0.90	904	0.9
245/75R22.5	827	270	565	1.0	778	1.0
425/65R22.5	827	302	391	1.5	538	1.5
385/65R22.5	896	315	340	1.7	469	1.7

Table 16. Fatigue damage factors for the Single-axle load of 78.3 kN (17.6 kip) for the thick section. (10)

Tire Type	Pressure kPa	Microstrain (21.1 °C)	Nf (10%) X10 ³	Damage Factor	Nf (45%) X10 ³	Damag e Factor
11R22.5	827	145	3,181	1.00	4,381	1.0
	724	139	3,655	0.90	5,034	0.9
245/75R22.5	827	156	2,500	1.3	3,444	1.3
425/75R22.5	827	159	2,349	1.5	3,234	1.5
385/65R22.5	896	164	2,121	1.5	2,921	1.5

Table 17. Rutting damage factors for the tandem-axle load of 76.5 kN/axle (17.2 kip/axle) for the thin section. (10)

Tire Type	Pressure kPa	Deflection (mils)	Compressive stress KPa	Rate of Rutting (10 ⁻⁶)	Damage Factor
11R22.5	827	16.7	47.6	10.2 mm	1.0
	724	16.3	47.6	10.2 mm	1.0
245/75R22.5	827	18.6	48.3	11.2 mm	1.1
425/75R22.5	827	23.1	63.4	15.5 mm	1.5
385/65R22.5	896	23.7	63.4	16.0 mm	1.6

Table 18. Rutting damage factors for the Tandem-axle load of 76.5 kN/axle (17.2 kip/axle) for the thick section. (10)

Tire Type	Pressure kPa	Deflection (mils)	Compressive stress KPa	Rate of Rutting (10 ⁻⁶)	Damage Factor
11R22.5	827	4.4	30.34	2.8 mm	1.0
	724	4.1	30.34	2.8 mm	1.0
245/75R22.5	827	4.4	31.03	3.1 mm	1.1
425/75R22.5	827	5.0	37.9	3.8 mm	1.4
385/65R22.5	896	5.2	37.9	3.8 mm	1.4

Table 19. Rutting damage factors for the single-axle load of 78.3 kN (17.6 kip) for the thin section. (10)

Tire Type	Pressure kPa	Deflection (mils)	Compressive stress KPa	Rate of Rutting (10 ⁻⁶)	Damage Factor
11R22.5	827	9.4	47.6	6.9 mm	1.0
	724	8.6	47.6	6.4 mm	0.9
245/75R22.5	827	10.6	49	7.6 mm	1.1
425/75R22.5	827	10.8	64.1	9.1 mm	1.3
385/65R22.5	896	12.3	64.1	9.9 mm	1.4

Table 20. Rutting damage factors for the single-axle load of 78.3 kN (16.7 kip) for the thick section. (10)

Tire Type	Pressure kPa	Deflection (mils)	Compressive stress KPa	Rate of Rutting (10 ⁻⁶)	Damage Factor
11R22.5	827	2.9	29	2 mm	1.0
	724	2.6	29	2 mm	0.9
245/75R22.5	827	2.9	36.5	2.5 mm	1.3
425/75R22.5	827	3.1	36.5	2.5 mm	1.3
385/65R22.5	896	3.2	36.5	2.5 mm	1.3

The evaluated fatigue and rutting damage factors were similar in magnitude for all combinations of axle loads and configurations. In summary, super-single tires are more damaging than dual tires and specially when they are used on tandem axles.

Akram et al (11) presented the results of a field study designed to evaluate the damage produced by super-single tires as compared to conventional dual truck tires. Two in service pavements were instrumented with multi-depth deflectometers to measure vertical deflections at various depths. The sections chosen represented thick and thin pavements. The thin section had an AC thickness of 38 mm (1.5") over 254 mm (10") aggregate base, while the thick pavement section had an AC thickness of 178 mm (7") over 356 mm (14") aggregate base. The conventional dual truck tires were 11R22.5 with inflation pressure of 827 kPa (120 psi). The super-single tire was 425/65R22.5 with inflation pressure of 896 kPa (130 psi). Four different speeds were evaluated in this study 16, 32, 56, and 89 km/h (10, 20, 35, and 55 mph).

The first set of tests replaced the conventional dual tires on the tandem axle of the trailer with super-single tires. The second set of tests replaced the conventional dual tires on the drive axle of the tractor with super-single tires. The Asphalt Institute criterion was used to evaluate the allowable number of equivalent 80 kN (18,000 lb) single axle loads (ESALs) for the two tire configurations.

$$\epsilon_v = L (1/N)^m$$

Where

N = permissible number of ESALs

ϵ_v = Subgrade vertical strain

L = 1.05×10^{-2} and m = 0.223

The compressive strains on top of the subgrade were calculated as the slope of the vertical deflections curve measured using the MDD. Tables 21 through 24 give a summary of the results for rutting. The relative damage of single tires was expressed as the percent reduction in the allowable number of ESALs to rutting failures (i.e. reduction in pavement performance life). The data generated from this study indicated that single tires produce an average of 65 percent reduction in the rutting ESALs for the thin section and an average of 30 percent reduction for the thick section. These reductions would indicate that single tires are 2.5 and 1.5 times more damaging for thin and thick sections, respectively.

The measured surface deflections basins were converted into surface curvature index which is then related to the horizontal tensile strain. The surface curvature index is defined as the maximum deflection under a given load minus the deflection measured at a distance from the center of the load (typically 305 mm). Regression equations were developed to relate the horizontal tensile strain at the bottom of the asphalt concrete layer to the surface curvature index. The predicted horizontal tensile strain was then used to calculate the number of load repetitions to failure using the following equation:

$$\log N_f (10\%) = 15.947 - 3.291 \log (\epsilon/10^{-6}) - 0.854 \log (E/10^3)$$

Where N_f is the number of load applications required to cause 10% cracking of the wheel tracks, ϵ is the tensile strain at the bottom of AC layer, and E is the resilient modulus of asphalt concrete layer.

Table 21. Rutting ESALs for thin pavement, tandem axle load 147 kN, temp. on top of AC layer 27 °C, bottom of AC layer 26 °C. (11)

Tire	Axle	Speed-km/h	Compressive Strain on Top of SG (microns)	ESALs
Duals	Drive	16	1355	9719
Super single	Trailer	16	1690	3609 (63%) Red
Duals	Drive	32	1332	10495
Super single	Trailer	32	1665	3858 (63%) Red
Duals	Drive	56	1294	11950
Super single	Trailer	56	1623	4327 (64%) Red
Duals	Drive	89	1246	14157
Super single	Trailer	89	1570	5021 (65%) Red

Table 22. Rutting ESALs for thin pavement, tandem axle load 76 kN, temp. on top of AC layer 35 °C, bottom of AC layer 36 °C. (11)

Tire	Axle	Speed-km/h	Compressive Strain on Top of SG (Microns)	ESALs
Duals	Trailer	16	1626	4291
Super single	Drive	16	2087	1401 (67%) Red
Duals	Trailer	32	1617	4399
Super single	Drive	32	2081	1419 (68%) Red
Duals	Trailer	56	1601	4600
Super single	Drive	56	2071	1450 (68%) Red
Duals	Trailer	89	1581	4866
Super single	Drive	89	2060	1485 (69%) Red

Table 23. Rutting ESALs for thick pavement, tandem axle load 147 kN, temp. on top of AC layer 27 °C, bottom of AC layer 23 °C. (11)

Tire	Axle	Speed-km/h	Compressive Strain on Top of SG (Microns)	ESALs
Duals	Drive	16	297	8782890
Super single	Trailer	16	334	5187769 (41%) Red
Duals	Drive	32	289	9926930
Super single	Trailer	32	330	5475794 (45%) Red
Duals	Drive	56	275	12402795
Super single	Trailer	56	325	5863820 (53%) Red
Duals	Drive	89	258	16511743
Super single	Trailer	89	317	6557210 (60%) Red

Table 24. Rutting ESALs for thick pavement, tandem axle load of 147 kN, temp. on top of AC layer 39 °C, bottom of AC layer 29 °C. (11)

Tire	Axle	Speed-km/h	Compressive Strain on Top of SG (Microns)	ESALs
Duals	Trailer	16	361	3660915
Super single	Drive	16	390	2588858 (29%) Red
Duals	Trailer	32	358	3800507
Super single	Drive	32	385	2743075 (28%) Red
Duals	Trailer	56	354	3996905
Super single	Drive	56	382	2841008 (29%) Red
Duals	Trailer	89	348	4315343
Super single	Drive	89	376	3050031 (29%) Red

In the case of fatigue, the average percent reductions in ESALs were 60 percent for the thin section and 83 percent for the thick section. Vehicle speed did not impact the relative damage of single tires. The higher percent reduction in fatigue ESALs on the thick section than on the thin section could be due to the fact that the tensile strains were estimated from vertical deflections instead of direct measurement. The use of surface vertical deflection basins to estimate tensile strains at the bottom of the AC layer is an invalid approach. Therefore, the fatigue analysis part of this study should not be seriously considered.

The Road and Research Laboratory (12) in Finland completed a research program at the Virttaa test field, which is 3 km (1.9 miles) long and 40 m (130 ft) wide part of a highway that is used as a temporary airfield by the Finnish Air Force. Two flexible pavement sections with AC layer thickness of 150 mm (5.9") and 79 mm (3.1") over 399 mm (15.7") base course were used to evaluate the effects of several tire configurations.

Single axle loads varied between 71.2 kN and 106.8 kN (16,000-lb and 24,000-lb.) and tire pressures were varied between 483 kPa and 1082 kPa (70 psi and 157 psi). Five different tire configurations were compared:

- (a) 12R22.5 dual tires
- (b) 265/70R19.5 dual tires
- (c) 445/65R22.5 super-single tire
- (d) 385/65R22.5 super-single tire
- (e) 350/75R22.5 super-single tire

The horizontal tensile strains at the bottom of the AC layer were measured using strain

gauges. The strain measurements were converted to equivalent number of axle load passes required to produce fatigue failure. The concept of equivalency factors was also used. Equivalency factors were defined as the ratio of damage produced by a given axle load to the damage produced by a 89 kN (20,000 lb) single axle with 12R22.5 dual tires inflated to 703 kPa (102 psi). Damage was defined as the reciprocal of the fatigue life. Table 25 shows the equivalency factors for all five different tire configurations while Table 26 presents the data based on equivalent axle loads to produce the same damage as the standard axle.

The results show that super-single tires are more damaging than dual tires. Within super-single tires, wider tires are less damaging than narrower tires. The super-single tires are more damaging on thin pavements than on thick pavements.

The South Dakota Department of Transportation conducted a field study to estimate the pavement damage caused by singled-out dual and super-single tires (13). The pavement section tested was representative of a typical flexible pavement in South Dakota. It consisted of approximately 127 mm (5 in) of asphalt concrete surface placed over 152 mm (6 in) base course and 203 mm (8 in) subbase course. Deflection measuring devices were installed at two locations in the outer wheel track 6 m (20 ft) apart. Dual, singled-out, and super-single tires with different load magnitudes were evaluated. Table 27 shows the different tire configurations and loads. The pavement deflections were obtained for two experimental matrices with the following factors:

Table 25. Fatigue equivalency factors for different tire configurations. (12)

Tire Type Axle Load 84 kN (18.9 kip)	AC layer 79 mm (3.1") Damage ratio	AC layer 150 mm (5.9") Damage ratio
12R22.5 Duals	0.33	0.35
265/70R19.5	0.87	0.58
445/65R22.5 Super single	1.23	1.14
385/65R22.5 Super single	2.34	1.22
350/75R22.5 Super single	2.37	1.28

Table 26. Equivalent axle loads required to cause the same damage. (12)

Tire Type	AC Layer 79 mm (3.1") Equivalent Axle Load	AC layer 150 mm (5.9") Equivalent Axle Load
12R22.5 Duals	100 kN (22,5 kip)	100 kN (22,5 kip)
265/70R19.5 Duals	86 kN (19,3 kip)	93 kN (20,9 kip)
445/65R22.5 Super single	81 kN (18,2 kip)	81 kN (18,2 kip)
385/65R22.5 Super single	65 kN (14,6 kip)	78 kN (17,5 kip)
350/75R22.5 Super single	61 kN (13,7 kip)	75 kN(16,9 kip)

Table 27. Wheel configurations and wheel loads. (13)

Wheel Configuration	Tire Width (mm)	Load Intensity (N/mm)	Total Wheel Load (kN)
Dual	508	70.1	35.6
		105.1	53.4
		140.2	71.2
Singled out dual	254	70.1	17.8
		105.1	26.7
		140.2	35.6
Super single	381	70.1	26.7
		105.1	40.0
		140.2	53.4

Matrix 1

Season	4 levels (Summer, Fall, Winter, Spring)
Tire configuration	3 levels (Dual tires, super-single tires, singled-out duals)
Tire Load	3 levels (70.1, 105.1, 140.2 N/mm)

Matrix 2

Season	4 levels (Summer, Fall, Winter, Spring)
Tire configuration	3 levels (Dual tires, super-single tires, singled-out duals)
Tire Load	3 levels (26.7, 40.0, 53.4 N/mm)

Equivalency factors were used to assess the relative damage. The equivalency factors were computed according to the following equation:

$$LEF = [D_i / D_s]^{3.8}$$

where:

D_i = Deflection under a given load

D_s = Deflection under the standard load (80 kN with dual tires)

Table 28 shows a summary of the equivalency factors. The data in Table 28 show that super-single tires produced higher deflections at lower tire loads; but the singled-out dual tires were more damaging at higher loads. The singled-out dual tires produced the largest deflection during fall; the super-single tires produced the largest deflection in winter.

The data showed some significant differences between the equivalency factors calculated from the two locations along the wheel track. This indicates the impact of materials variability

Table 28. Summary of equivalency factors developed by South Dakota DOT. (13)

Season	Wheel Configuration	Load = 70.1 N/mm		Load = 105.1 N/mm		Load = 140.2 N/mm	
		Ch1	Ch2	Ch1	Ch2	Ch1	Ch2
Summer	Dual	0.566	0.617	3.188	2.365	10.11	6.573
	Singled-out	0.053	0.068	0.426	0.274	1.268	0.888
	Super-single	0.827	0.679	2.17	1.697	8.57	5.229
Fall	Dual	0.948	0.727	4.335	3.536	9.005	7.795
	Singled-out	0.351	0.145	0.876	0.665	2.758	1.457
	Super-single	0.625	0.371	2.744	2.177	7.479	5.732
Winter	Dual	0.553	0.341	1.116	2.112	2.768	5.534
	Singled-out	0.324	0.254	0.844	1.061	1.211	2.362
	Super-single	1.298	2.941	1.872	5.759	3.192	13.172
Spring	Dual	0.597	0.632	2.492	2.408	6.198	5.113
	Singled-out	0.24	0.246	0.724	0.835	1.961	1.75
	Super-single	0.813	1.026	2.962	2.369	8.802	6.105

Table 29. Predicted pavement damage by TRRL. (14)

AC Thickness (mm)	Ratio of Damage Super single / Dual
150	2.05
200	1.80
250	1.63
300	1.53

and dynamic loading on pavement response and damage. Some of these factors vary by more than 4 times. This observation emphasizes the need for pavement models which take into account the effect of materials variability and dynamic loading along the pavement longitudinal dimension.

Addis (14) conducted tests at the transport research laboratory (TRL) pavement test facility by applying super-single and dual tire loads to full scale experimental pavements. The principal strains generated in the pavement under a 40 kN (9 kip) load traveling at a speed of 20 km/h (12.4 mph) were measured. The super-single tire was found to increase the two principal strain measurements in the pavement by about 50% when compared to conventional dual tires. Addis used performance models to evaluate the damage factors as shown in Table 29.

Experimental-Performance

This type of studies conducted field experiments to measure the relative pavement damage caused by single tires through measurements of actual pavement performance. Identical pavement sections were loaded with both single and dual tires and their actual performance were compared. The following represents a summary of these studies.

Bonaquist (15) studied the effect of a super-single truck tire on pavement response and performance. The research was conducted on full-scale pavement test sections in attempt to directly compare the super-single tire with conventional dual tires. The experiment compared pavement responses and performance created by a 425/65R22.5 super-single tire with those observed under the dual 11R22.5 tire. The tires were selected on the basis of similar load

ratings of 46.7 kN (10,500 lb) for the super-single tire and 23.6 kN (5,300 lb) for each of the dual tires.

The Accelerated Loading Facility (ALF), was used to load two flexible pavement sections. The ALF is capable of loading a 12 m (40 ft) pavement section with both single and dual tires configurations at a speed of 19 km/h (12 mph). Two pavement sections were constructed at the FHWA's pavement testing facility in Mclean, Virginia. The first section consisted of 178 mm (7.0") thick AC layer over 305 mm (12.0") base course and the second section consisted of 89 mm (3.5") thick AC layer over 305 mm (12.0") base course. Both sections were used to evaluate the effects of dual and super-single tires. The axle loads varied between 41 kN and 74 kN (9,217 lb. and 16,635 lb) and the tire inflation pressure varied between 520 kPa and 959 kPa (75 psi and 139 psi). Tensile strains at the bottom of the asphalt concrete layer and average vertical compressive strains in the asphalt layer, crushed aggregate base, and the upper 152 mm (6") of the subgrade were measured.

Since the test program was conducted on outdoor pavement sections, pavement temperatures could not be controlled. The fatigue and rutting behavior of the flexible pavement sections are expected to change as the temperature varies. If measured responses produced by the super-single tire are to be compared to those associated with conventional dual tires, the pavement temperature should be the same. This was not possible for this experiment since a time period of one to two hours was required to change tire configurations. Therefore, an indirect data comparison approach was adopted.

The first phase of the study used the measured pavement responses along with selected pavement performance models to evaluate the relative damage of the single tire as compared to

the dual tire. The axle loads varied between 41 and 74 kN (9,200 and 16,600 lb) and the tire inflation pressure varied between 520 and 959 kPa (75 and 139 psi). Using the broad samples of collected data, statistical regression models were developed to predict pavement responses as a function of pavement temperature, load, and tire pressure. Figures 3 and 4 present comparisons of the strains under dual and single tires at 703 kPa (102 psi) and average pavement temperature of 14 and 23 °C (57 and 73 °F) for the 89 mm and 178 mm asphalt pavement, respectively. The relative damage was assessed using the damage ratios concept as shown below.

$$\text{The damage ratio for fatigue} = \frac{(\epsilon_t)^b \text{ Super single tire}}{(\epsilon_t)^b \text{ Dual tire}}$$

$$\text{The damage ratio for rutting} = \frac{\delta_r \text{ Super single tire}}{\delta_r \text{ Dual tire}}$$

Where ϵ_t and δ_r are the tensile strain at the bottom of the AC layer and the vertical deflection, respectively. Table 30 presents the damage ratios for the super-single tire relative to the dual tire. The data indicate that the super-single tire generates 25 to 50 percent more rutting damage than the dual tire. The rutting damage in the subgrade decreases as the thickness of AC layer increases. This observation coincides very well with the traditional concepts of pavement design. In the case of fatigue damage, the data show that the single tire generates 350 to 450 percent more damage than the dual tire. The data also show that the fatigue damage decreases as the thickness of AC layer increases.

The second phase of this study provided pavement performance data for the direct comparison of the two tire configurations. These data also allowed the statistical work previously completed with pavement responses to be checked and verified. The ALF

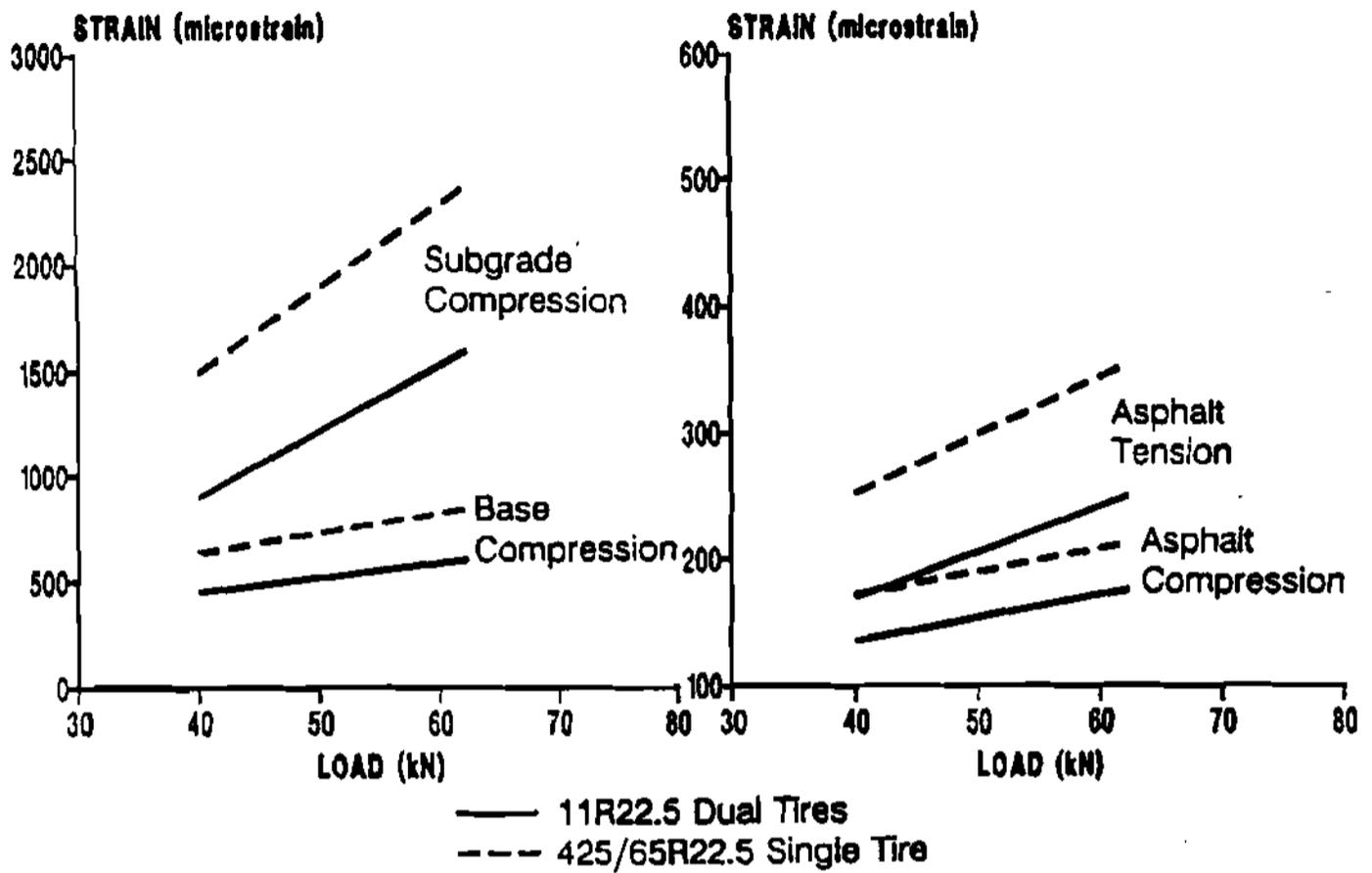


Figure 3. Comparison of pavement responses for the 89 mm AC section, tire pressure 703 kPa, pavement temp. 14 C. (15)

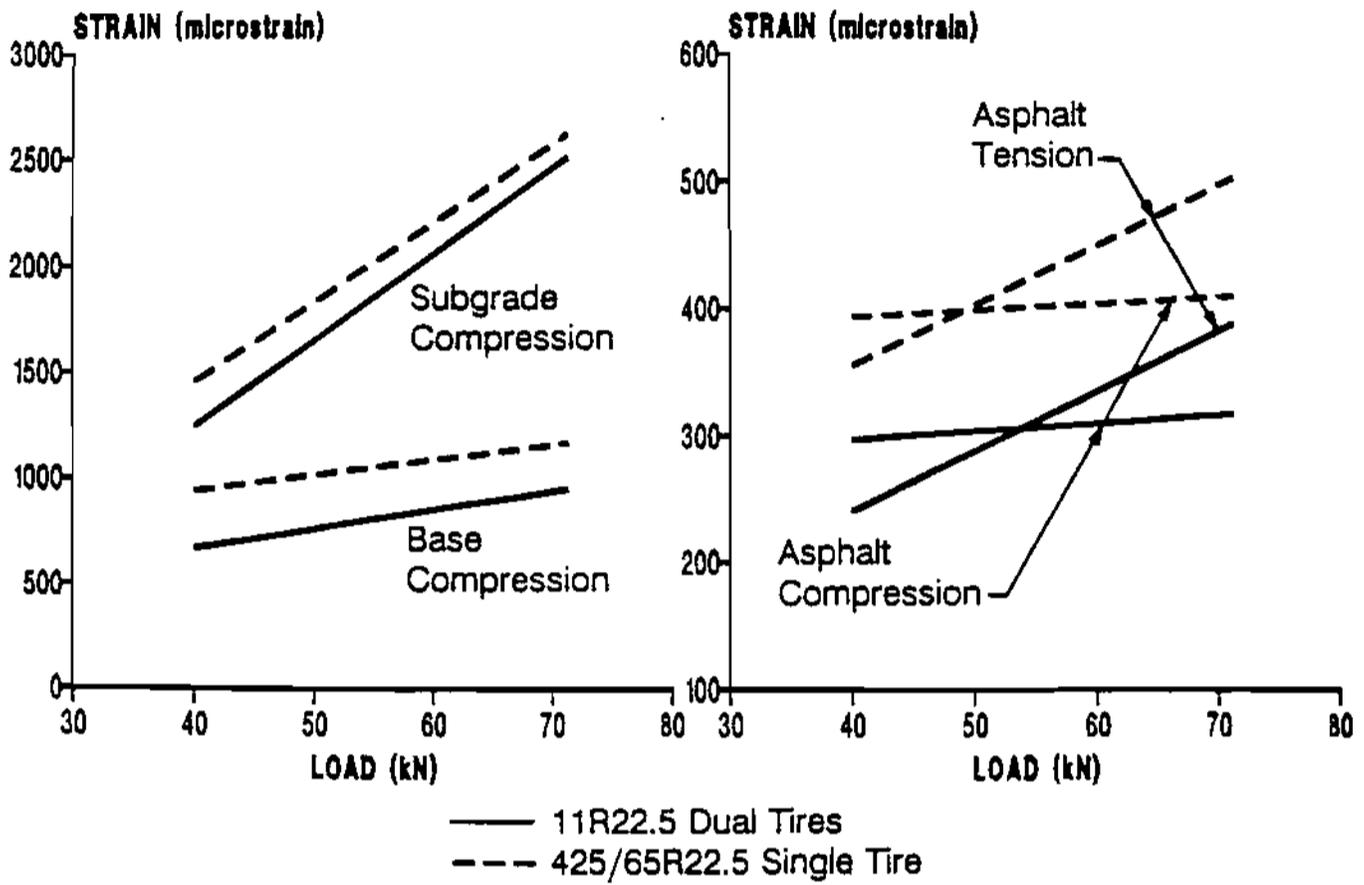


Figure 4. Comparison of pavement responses for the 178 mm AC section, tire pressure 703 kPa, pavement temp. 23 C. (15)

machine was modified to allow simultaneous testing of adjacent pavement sections. Thus, the super-single tire and conventional dual tire loadings could be directly compared under close environmental conditions. The ALF machine was used to load pavement section 1 one week with the single tire and the following week load section 2 with the dual tire and so on. Both the dual and super-single tires were loaded at 54.5 kN (12,250 lb) per tire set which translates into 109 kN/single axle (24,500 lb) and at inflation pressure of 803 kPa (102 psi). **Braquist** concluded that the results of the performance test compared well with the damage estimates from the response experiment. The observed increase in fatigue damage caused by the super-single tire was approximately 4 times and rutting damage was between 1.0 to 2.4 times relative to the dual tires. Figures 5 and 6 present a summary of the performance data.

The results of this research show that the 425/65R22.5 super-single tire is significantly more damaging to flexible pavements than the traditional 11R22.5 dual tire. For the same load and tire pressure, the super-single tire produced higher vertical compressive strains in all layers of the pavement, and higher tensile strains at the bottom of the asphalt concrete layer. These increased strains translated into greater rutting and shorter fatigue life for pavements loaded with the super-single tire.

The performance data presented in Figures 5 and 6 indicate that the relative pavement damage caused by the super-single tire can be reduced by increasing the thickness of the AC layer. Increasing the thickness of the AC layer is also equivalent to strengthening the flexible pavement structure through stronger hot mixed asphalt concrete (HMAC) mixture. Therefore, designing stronger HMAC mixtures could be an effective way to reduce the pavement damage caused by single tires relative to dual tires.

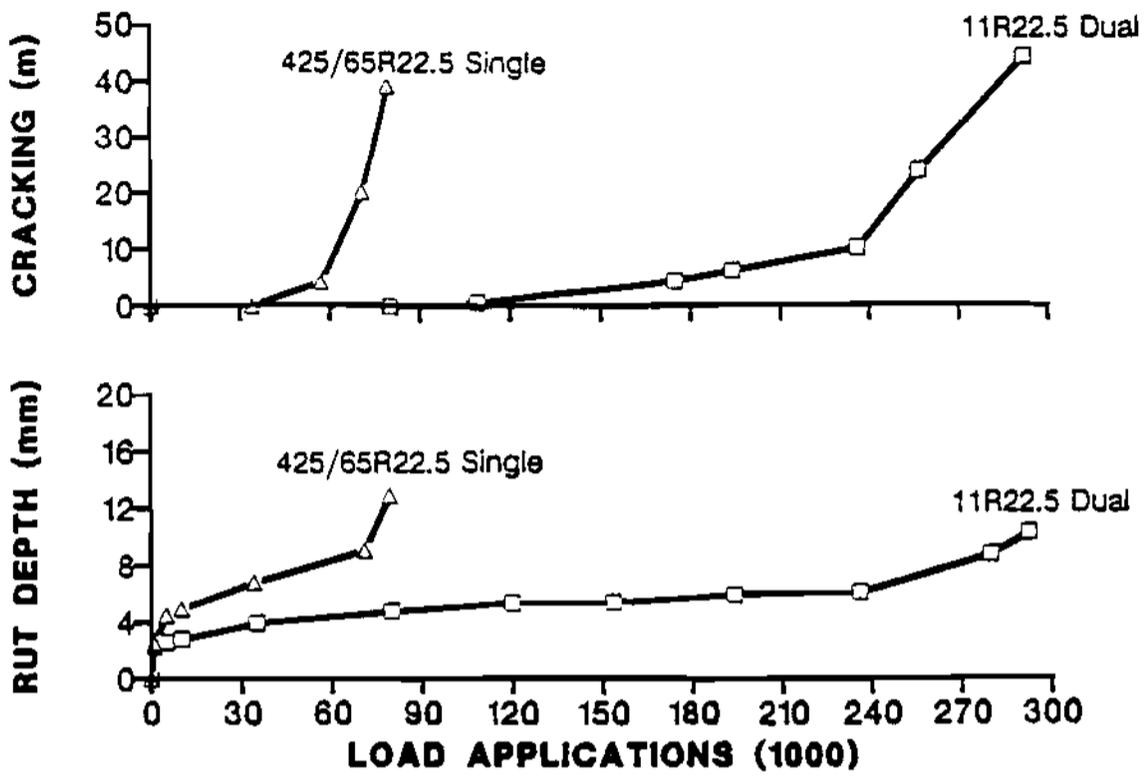


Figure 5. Summary of the 89 mm AC section performance test. (15)

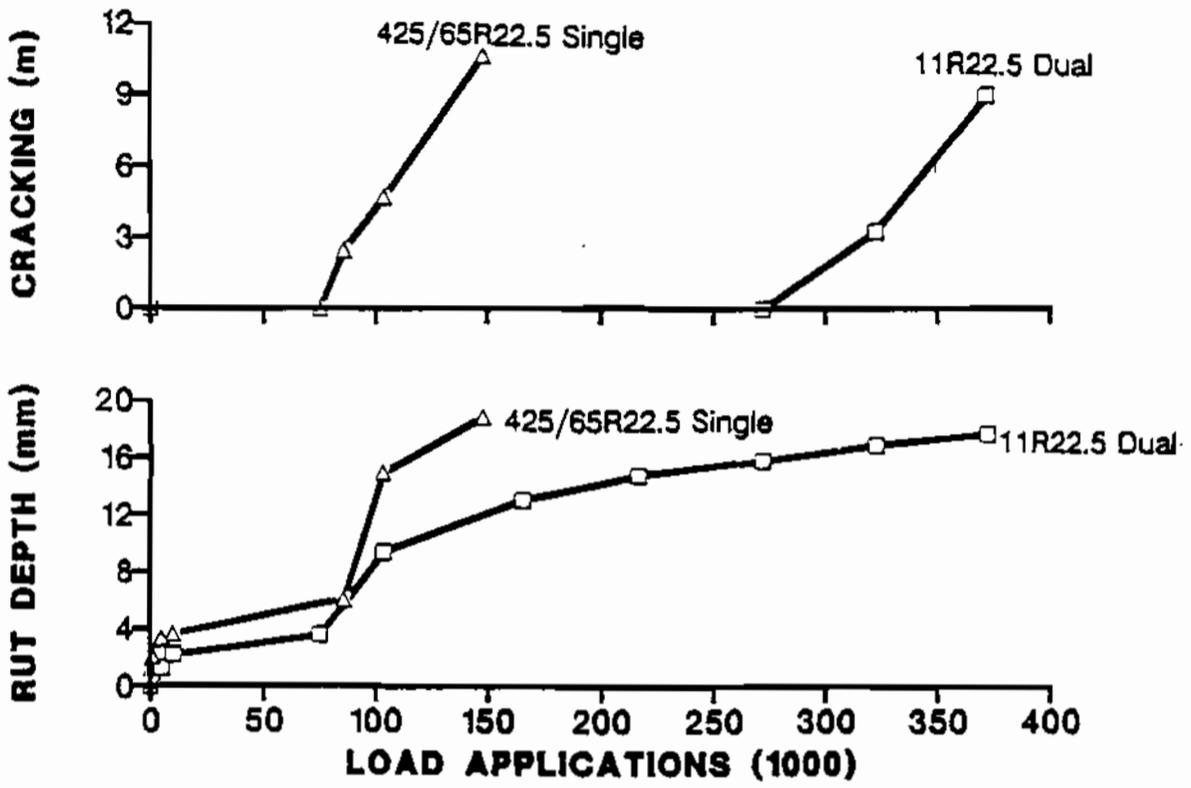


Figure 6. Summary of the 178 mm AC section performance test. (15)

Pidwerbesky and Dawe (16) conducted a field study to evaluate the rutting of flexible pavements caused by single tires relative to dual tires. The testing was conducted at the Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF) which is located in Christchurch, New Zealand. The primary feature of the facility is the dual-armed Simulated Loading and Vehicle Emulator, which is capable of applying variable loading conditions. The loading device is also capable of simulating vehicle wandering at a traveling speed varying from 1 km/h (0.6 mph) up to a maximum of 50 km/h (31 mph). The circular track is 58 m (190 ft) long, 1.5 m (4.9 ft) deep, and 4 m (13 ft) wide with a radius of 9.26 m (30.4 ft). The pavement structure consisted of 30 mm (1.2 in) AC layer over 150mm (6 in) aggregate base, and 150 mm (6 in) aggregate subbase. The section is a representative of pavement structures in New Zealand but it represents a very thin section on the U.S. road system.

The study evaluated the 356/80R20 low profile super-single tire and a 10R20 dual tire. The test section was loaded with 15,591 cycles at a standard load of 80 kN (18,000 lb) single axle load. The relative damage was assessed based on the measured rut depths under the super-single and dual tires. Figures 7 and 8 show typical rut depth formation under both the dual tires and the super-single tire configurations. The results of this study showed that the low profile super-single tire created rut depths 92% greater than the standard dual radial tires for the same loading. The average rut depth under the dual tires was 15.2 mm ($\frac{1}{2}$ in) and 29.2 mm ($\frac{1}{1}$ in) under the super single tire.

Eisenmann and Hilmer (17) presented a laboratory investigation of the impact of wheel load, tire pressure, and tire configuration on pavement rutting. The test facility used

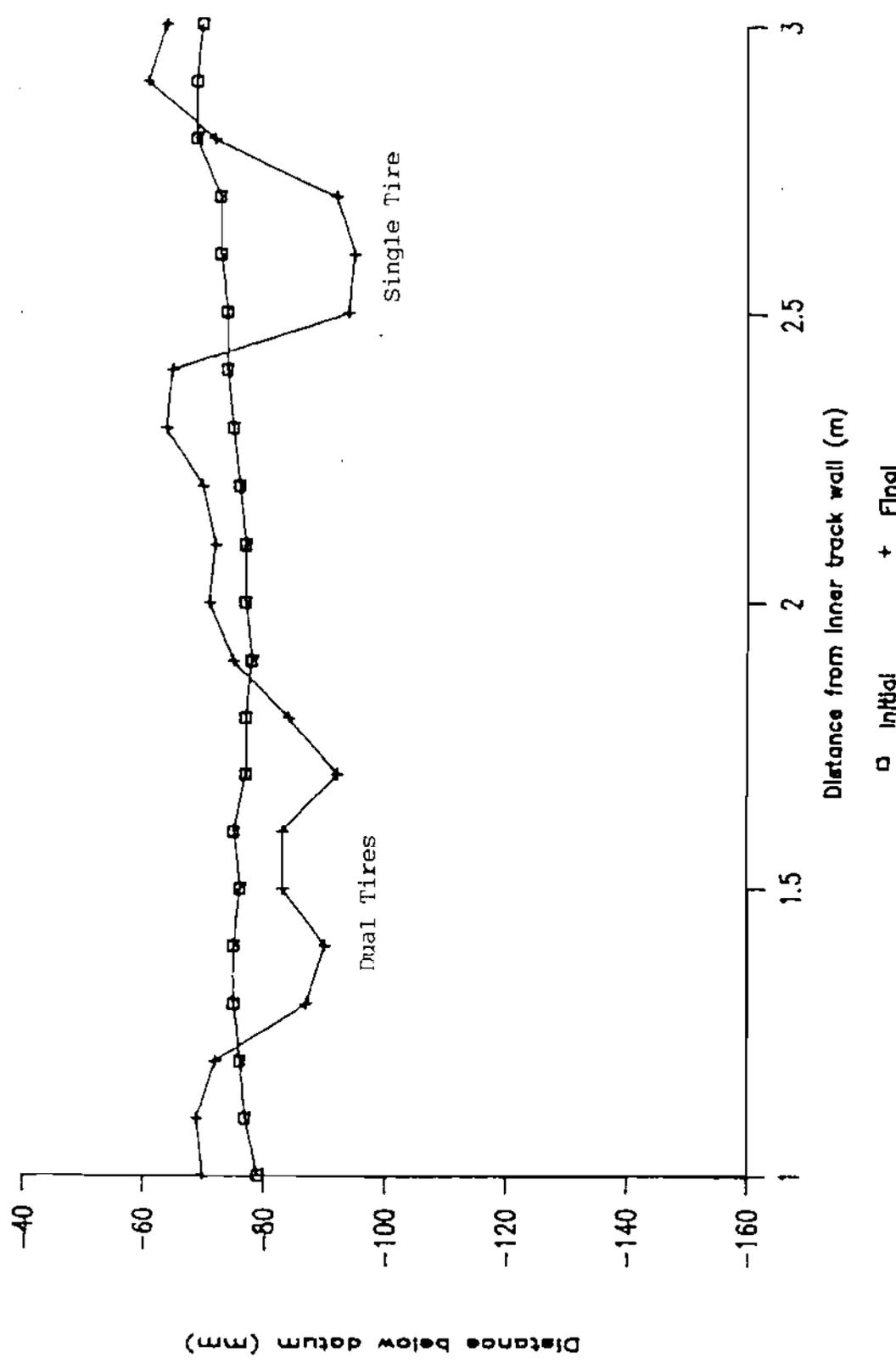


Figure 7. Typical transverse profile from the CAPTIF test. (16)

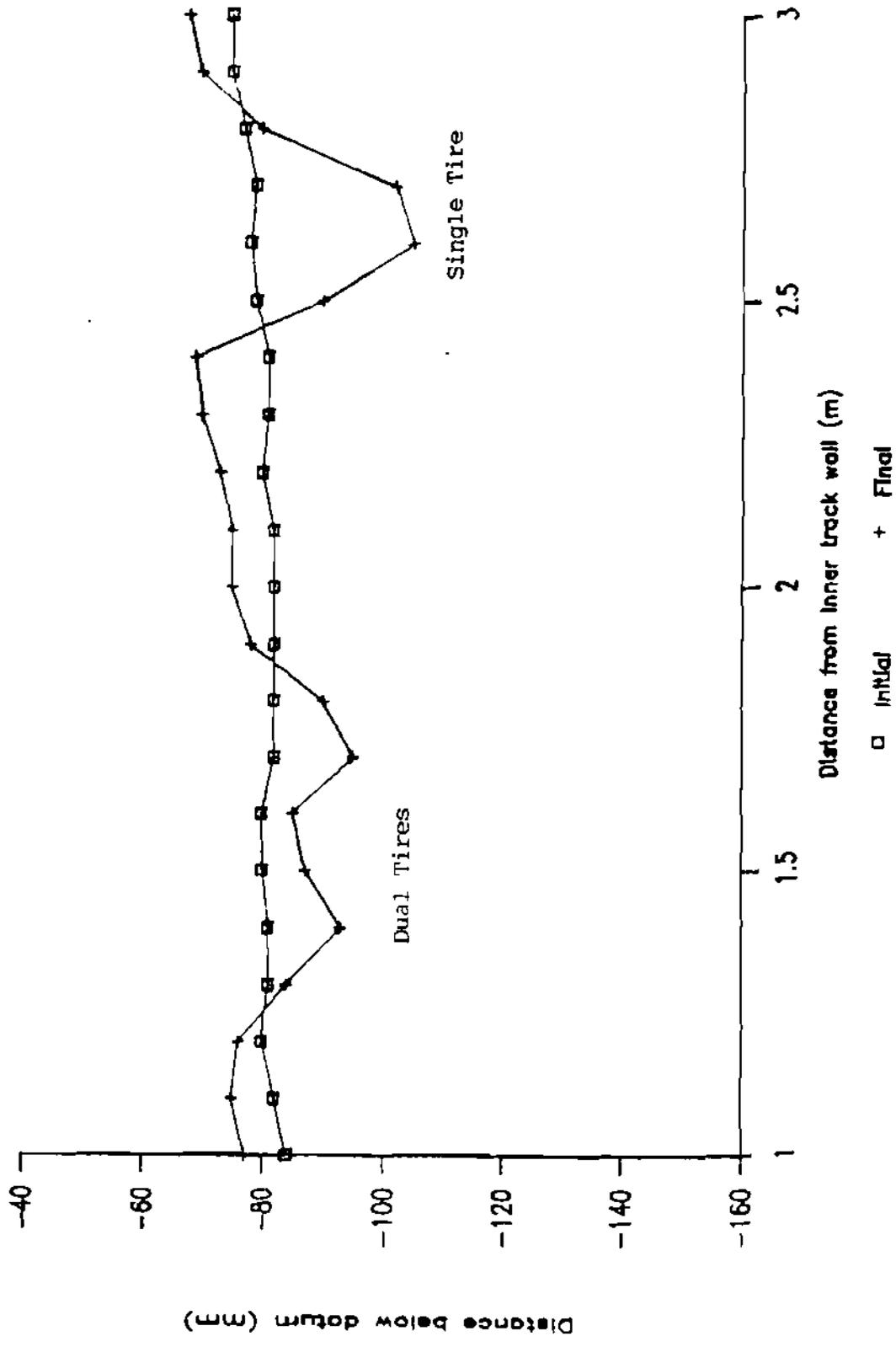


Figure 8. Typical transverse profile from the CAPTIF test. (16)

consisted of a loading frame that allows longitudinal and transverse movement of a set of wheels over an asphalt concrete layer supported by a rubber plate. The rolling speed of the applied load was about 1 km/h (0.62 mph). Dual and single tire configurations of 254x424 mm (10" x16.7") size tires were used for testing. The dual tires were inflated at pressures ranging from 800 to 1,100 kPa (116 to 160 psi) and carried loads from 31.45 to 49.7 kN (7.1 to 11.2 kip). The single tire was inflated at pressures ranging from 800 to 1,250 kPa (116 to 181 psi) and carried loads from 31.7 to 45.2 kN (7.1 to 10.2 kip).

Figures 9 and 10 show the rut depth for single tires and dual tires for different load cycles, respectively. The study concluded that the rut depth is higher under the single tire than the dual tires also the volume of deformation below the single tire is higher than dual tires.

SINGLE TIRES DAMAGE OF RIGID PAVEMENTS

An effort was exerted to identify previous studies that evaluated the damage caused by singles tires on rigid pavements. The following two studies were identified:

1. NCHRP Report 353, "Effects of Heavy-Vehicles Characteristics on Pavement Response and Performance," Transportation Research Board, 1993.
2. Ioannides, et.al., "Super-Singles- Implications for Design," Proceedings of the 3rd International Symposium on Heavy Vehicle Weights and Dimensions, Cambridge University, UK, 1992.

Both studies are based on theoretical analyses and do not include any pavement performance

Number of load cycles

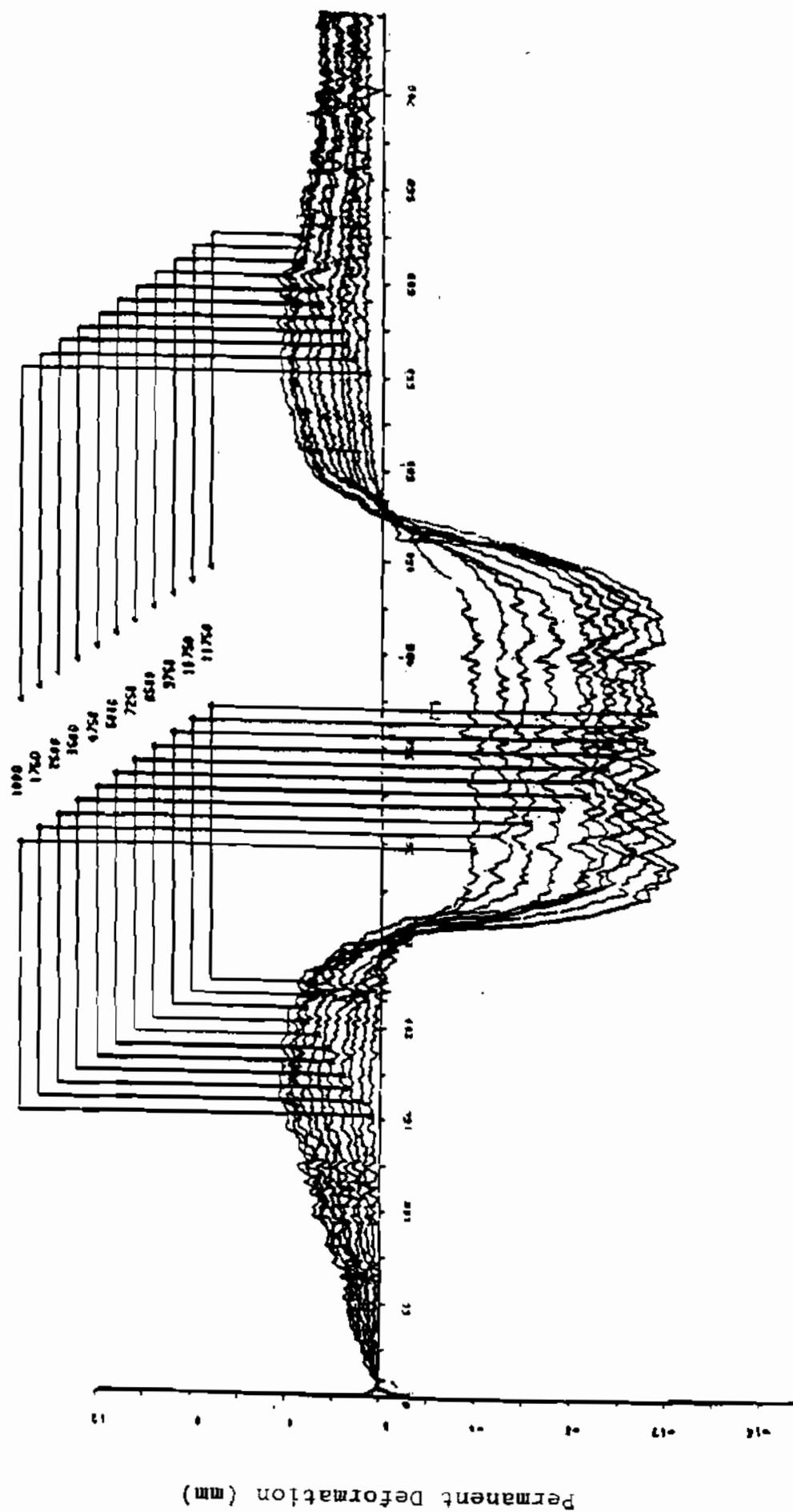


Figure 9. Development of rutting under single tire loading in the laboratory. (17)

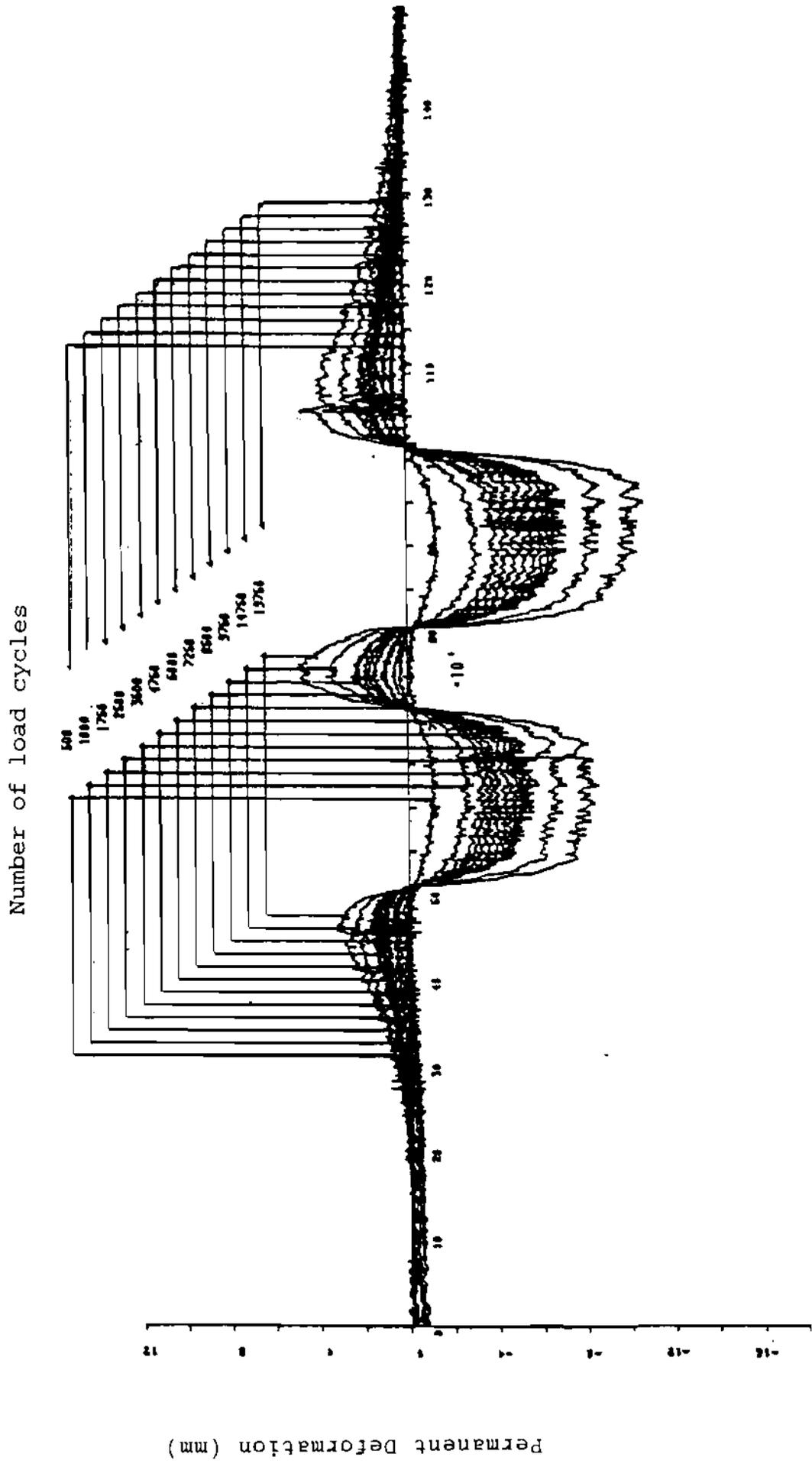


Figure 10. Development of rutting under dual tire loading in the laboratory. (17)

measurements. The following represents a summary of each of the studies. Effects of Heavy-Vehicles Characteristics on Pavement Response and Performance

This study evaluated the interaction between heavy vehicles and the pavement system. As part of the study, rigid pavement responses under heavy loadings were studied using a finite element analysis (ILLI-SLAB). With respect to the damage potential of single, dual, and super-single tires, the study concluded that: "rigid pavement fatigue is not as sensitive to tire contact conditions (area and pressure). Thus, axles with single tires are no more damaging than those with duals when operated within the rated loads of tires." The study showed that super-single tires increased the tensile stresses in the rigid pavement by 2 to 9 percent when only the axle load stresses are considered (e.g. no temperature stresses), with the stress increase becoming lower as the slab thickness increases. It was also noted that when temperature stresses are added, the increase in the combined stresses due to single tires will be very insignificant.

Super-Singles -- Implication for Design

This study used a dimensional analysis algorithm to analyze the effects of complex loading on rigid pavements edge stresses. The proposed algorithm was verified based on the 1984 PCA Concrete Pavement Design Procedure. The verified algorithm was then used to evaluate the effect of single tires on rigid pavements. The study indicated that super-single tire loadings cause a 10% increase in the calculated edge stresses over the conventional dual tires for U.S. loading conditions. It was also noted that the increase in stresses was mainly due to the increase in the inflation pressure for the super-single tires.

In summary, the literature review effort discovered that very little information is available on the relative damage of single tires of rigid pavements. The limited information that was identified indicated that rigid pavements are not sensitive to the configuration of the tires. The NCHRP 1-36 research team conducted a theoretical study to evaluate the damage caused by single tires on rigid pavements as compared to dual tires configuration.

NCHRP 1-36 Theoretical Study

The objective of this study was to evaluate the relative damage caused by single tires on rigid pavements as compared to dual tires configurations. Rigid pavement responses were calculated in terms of edge stresses as fatigue indicators and corner deflections as faulting indicators. The following combinations of tires, axle loads, and inflation pressures were used.

<u>Tire Type</u>	<u>Tire Size</u>	<u>Axle Load, kN</u>	<u>Tire Pressure, KPa</u>
Conv. Dual	11R22.5	89	690
Singled-out	11R22.5	53	690
Super-Single A	15R22.5	71	863
Super-Single B	18R22.5	89	932

The following pavement parameters were considered:

Slab thickness:	254 and 305 mm
Joint spacing:	4.9 m
Slab width:	3.7 m
Dowel Diameter:	32 mm

Dowel Spacing:	305 mm
Concrete Modulus of Elasticity:	27,600 MPa
Modulus of subgrade reaction:	5,536 g/cm ³
Concrete flexural strength:	4.8 MPa
Temperature Differential:	11°C

Edge Stresses Analysis

The edge stresses analysis was conducted using the ILLI-SLAB computer program. The first part of the analysis calculated edge stresses under axle loading alone while the second part of the analysis calculated the stresses under the combined action of axle load and environmental impact (i.e. curling). Tables 31 and 32 summarize the loading stresses and combined stresses, respectively. The percent change in stresses is defined as follows:

$$\text{Percent Change: } \frac{(\text{Stress under any tire} - \text{Stress under dual tire}) \times 100}{\text{Stress under dual tire}}$$

The data in Tables 31 and 32 indicate that the highest percent change in the edge stresses was caused by super-single tires under an axle load that is similar to the dual tires configuration. However, when the combined effect of load and temperature is considered, the maximum percent change is reduced by 65%. The evaluation of this data leads to the following conclusions:

1. Singled-out tires are more damaging than dual tires.

Table 31. Calculated edge stresses due to axle loading only.

Tire Type	Axle Load, kN	Edge Stress, Kpa	Percent Change
Slab Thickness: 254 mm			
Dual - 11R22.5	89	1,663	0
SOD - 11R22.5	53	1,304	-21
SSA - 15R22.5	71	1,684	1
SSB - 18R22.5	89	2,084	25
Slab Thickness: 305 mm			
Dual - 11R22.5	89	1,263	0
SOD - 11R22.5	53	973	-23
SSA - 15R22.5	71	1,290	2
SSB - 18R22.5	89	1,566	24

SOD: Singled-out Dual
 SSA: Super-Single A
 SSB: Super-Single B

Table 32. Calculated edge stresses due to axle loading and temperature differential.

Tire Type	Axle Load, kN	Edge Stress, Kpa	Percent Change
Slab Thickness: 254 mm			
Dual - 11R22.5	89	2,705	0
SOD - 11R22.5	53	2,381	-12
SSA - 15R22.5	71	2,677	-1
SSB - 18R22.5	89	3,029	12
Slab Thickness: 305 mm			
Dual - 11R22.5	89	2,428	0
SOD - 11R22.5	53	2,167	-11
SSA - 15R22.5	71	2,381	-2
SSB - 18R22.5	89	2,643	9

2. **Super-Single tires are more damaging than dual tires only when used under the same axle load.**
3. **The relative damage caused by single tires is significantly reduced when the combined load and temperature stresses are considered.**

Joint Faulting Analysis

Corner deflections and shear forces on dowels were used as indicators of joint faulting potential. The computer program JSLAB was used to calculate corner deflections and shear forces on dowels under the axle loading alone. Since temperature differential does not directly impact the corner deflections and shear forces on dowels, only the axle loading case was evaluated. Tables 33 and 34 summarize the results of this part of the study.

The data in Table 33 indicate that the super-single tires generate lower corner deflections than the dual tires. In other words, the super-single tires are less detrimental toward faulting than the dual tires. In the case of shear forces on the dowels (Table 34), the super-single tires showed a maximum increase of 21% in the transferred shear force. However, all shear forces are well below the expected bearing strength of the concrete which is around 14 kN (3,150 lb). Therefore, the percent increase in the shear forces on dowels becomes insignificant toward the development of faulting.

Table 33. Calculated corner deflections due to axle loading.

Tire Type	Axle Load, kN	Corner Deflection, mm	Percent Change
Slab Thickness: 254 mm			
Dual - 11R22.5	89	0.56	0
SSA - 15R22.5	71	0.48	-14
SSB - 18R22.5	89	0.53	-5
Slab Thickness: 305 mm			
Dual - 11R22.5	89	0.46	0
SSA - 15R22.5	71	0.41	-11
SSB - 18R22.5	89	0.46	0

Table 34. Calculated shear forces on dowels due to axle loading.

Tire Type	Axle Load, kN	Shear Force on Dowel, kN	Percent Change
Slab Thickness: 254 mm			
Dual - 11R22.5	89	10.7	0
SSA - 15R22.5	71	11.1	4
SSB - 18R22.5	89	12.9	21
Slab Thickness: 305 mm			
Dual - 11R22.5	89	10.2	0
SSA - 15R22.5	71	10.2	0
SSB - 18R22.5	89	12.0	18

Summary and Recommendations

In light of the lack of current information regarding the relative damage on rigid pavements caused by single tires as compared to dual tires, a theoretical analysis was conducted to support the research team's recommendations for future directions. The theoretical analysis consisted of evaluating the relative impact of single tires on edge stresses, corner deflections, and shear forces on dowels. These responses were chosen because of their direct impact on cracking and faulting potential of rigid pavements.

The analysis of the data indicated that single tires will generate slightly higher edge stresses when loaded with the same axle load level. However, the increase in edge stresses is significantly reduced when temperature stresses are superimposed to stresses generated by axle loading.

In the case of faulting, the analysis of the data showed that single tires actually reduce corner deflections which indicate that they are less detrimental toward faulting than dual tires. When looking at the shear forces on dowels, single tires showed a maximum increase of 21% in the transferred shear force as compared to dual tires. However, the maximum shear forces on dowels for all tires are well below the bearing capacity of the concrete.

Based on the review of the limited available information and the analysis of the data generated in this study, the following recommendations can be made:

1. The impact of super-single and singled-out tires on rigid pavements as compared to dual tires is insignificant.
2. It is clear that the relative damage of single tires as compared to dual tires on flexible pavements is a lot more significant than on rigid pavements.

3. No additional efforts should be expanded in this project to assess the damage of single tires on rigid pavements as compared to dual tires.
4. Any technical and regulatory approaches that will be developed to control damage on flexible pavements caused by single tires will very adequately cover the anticipated damage on rigid pavements.

COST-BENEFIT ANALYSIS OF SUPER-SINGLE TIRES

Recent trends in the Netherlands showed that new trailers and semi-trailers are fitted with super-single tires and relatively few dual tires are applied. The super-single has clearly conquered the market in the Netherlands. Figure 11 shows the percentage of axles of trailers and semi-trailers fitted with super-single tires at different locations throughout the Netherlands.

In light of this drastic increase in the use of super-single tires, the Netherlands Road Authority has conducted a cost-benefit analysis of the use of super-single tires on the axles of trailers and semi-trailers (18). The analysis used the concept of damage ratio which is expressed as follows:

$$\text{Damage Ratio} = \{k_1 * k_2 * k_3 * (P_{act}/P_o)\}^{4.0}$$

k1 is a factor which represents the influence of the axle configuration:

k1 = 1.0 for single axle

k1 = 0.6 for tandem axle

k1 = 0.45 for Triaxle

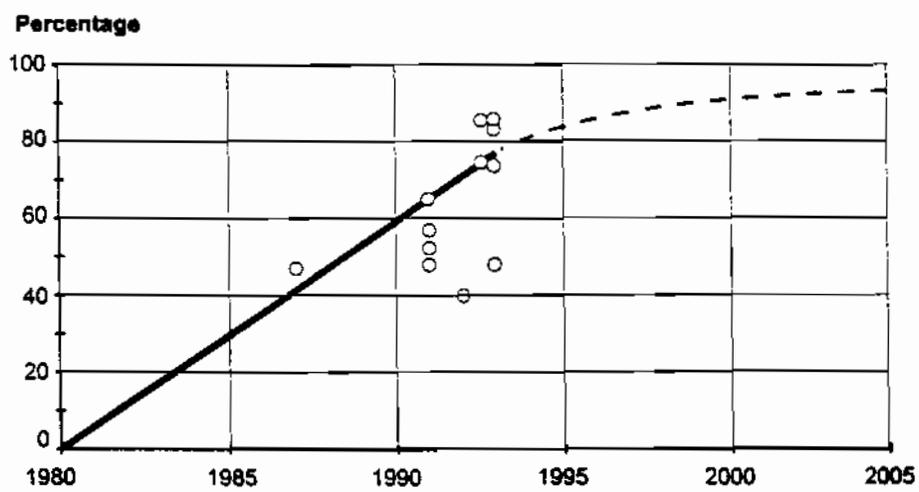


Figure 11. Percentage of axles of trailers and semi-trailers with super-single tires.

k_2 is a factor which represents the influence of tire type:

$k_2 = 1.0$ for dual tires

$k_2 = 1.3$ for singled-out tires

$k_2 = 1.2$ for super-single tires

k_3 is a factor which represents the influence of suspension:

$k_3 = 1.0$ for traditional leaf spring suspension

$k_3 = 0.95$ for air bag suspension

P_0 is the reference axle load which is 10 tonnes.

P_{act} is the magnitude of the actual axle load.

In general, it is assumed that the passage of an axle with super-single tires, with a given load, causes more damage to the pavement than the passage of an axle with dual regular tires.

The study evaluated pavement damages for the following cases:

Year 1980 with 0% super-single tires

Year 1993 with 0% and 75% super-single tires

Year 2000/2005 with 0% and 100% super-single tires

Figure 12 shows the ratio of increase in pavement damage for an average motorway in the period 1980 to 2000/2005

Costs Associated with the Use of Super-Single Tires

The study assumed that loading pavements with super-single tires on all trailer and semi-trailer axles leads to higher maintenance costs as compared with dual tires. The higher maintenance costs were calculated with the aid of the FRAME model (Forecasting Regional

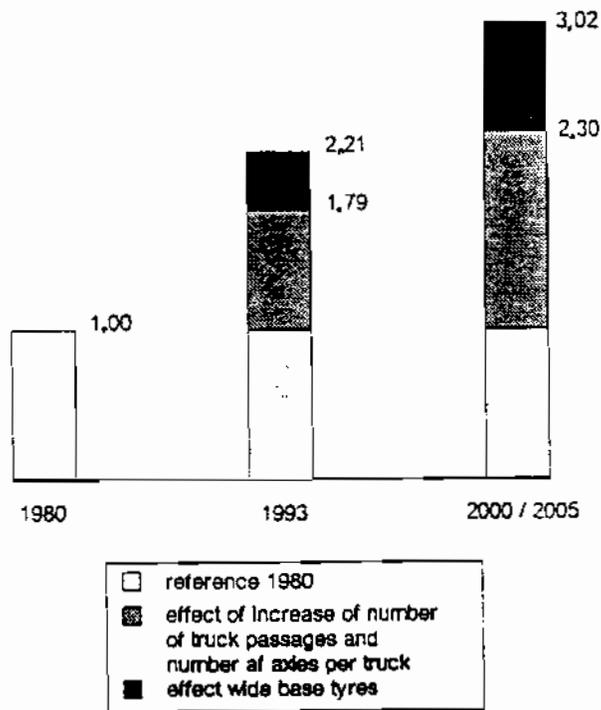


Figure 12. Ratio of increased pavement damage for a typical motorway in Netherlands.

Allocation of Means). This model has been developed by the Road and Hydraulic Division within the framework of the project Road Management 2000 for the allocation of financial means. The 30% increase in pavement damage by applying super-single tires has a cost raising effect of approximately 6%. Assuming a maintenance budget of 250 million guilders (\$480 million) per year, this represents a 15 million guilders (\$29 million) per year.

It was also assumed that using super-single tires requires higher quality of porous surface layers to resist raveling, cracking and rutting. The additional costs for modified surface layers have been estimated at approximately 7 million guilders (\$13.5 million) per year. Using super-single tires also means higher costs for the construction/widening of roads. This additional cost have been estimated at approximately 4 million guilders (\$7.7 million) per year. The total costs add up to 26 million guilders (\$50 million) per year.

Savings Associated with the Use of Super-Single Tires

The study identified three sources of savings associated with the use of super-single tires:

1. Increase in net loading capacity
2. Lower tire cost
3. Less fuel consumption

The weight advantage for the 385/65R22.5 super-single tire amounts to 120 kg (264 lb) per axle. Table 35 shows annual cost savings due to higher net loading capacity of heavy vehicles by using super-single tires on all trailer and semitrailer axles forecasted for the 1997 year.

The use of super-single tires result in lower tire costs. This is mainly because when

purchasing a new trailer or semi-trailer less tires and wheels are needed and at the end of the life span less tires need retreading or complete replacement will be required. The annual mileage was assumed at 75,000 km, with an estimated life span of 12 years. It was also assumed that the life span of the tire tread is 150,000 km for both types of tires and that during the life span of the tire the tread is renewed once. Calculations showed that the tire cost per axle for dual tires are 1.43 ct (2.75 cents) per kilometer and 0.9 ct (1.73 cents) per kilometer for super-singles. Using super-single tires results in a 37% savings. Table 36 shows the annual cost savings due to lower tire costs by using super-single tires on all trailer and semi-trailer axles forecasted for the 1997 year.

The super-single tires are used with higher tire pressure than regular dual tires. The higher contact pressure results in a contact area with the road that is smaller than regular dual tires. Because of this the super-single tire has a lower rolling resistance and that results in a decrease in fuel consumption. Savings were calculated for two groups of trucks, namely: a) articulated truck with allowable vehicle-combination weight more than 40 tonnes and b) articulated truck with allowable vehicle-combination weight less than 40 tonnes

An average value of 5% savings on fuel consumption was assumed for group one and 2.5% for group two. A lower value was used for group two because the average number of axles per vehicle fitted with super-single tires is less. Fuel savings also result in lower exhaust fume discharges. Table 37 shows annual cost savings due to lower fuel consumption

Table 35. Annual cost savings due to higher net loading capacity of heavy vehicles.

Types of Goods	Savings in Millions of Guilders*
agricultural products and livestock	3.36
food products and cattle feed	5.19
Solid mineral fuels	0.20
petroleum and petroleum products	0.6
ores, metal waste	0.3
iron, steel and non ferrous metals	1.34
crude minerals and products; building materials	4.71
fertilizers	0.5
chemical products	3.11
vehicle, machines and other goods	2.98
Total	22.3

* 1 Dollar = 0.521 Guilder

Table 36. Annual cost savings due to lower tire costs.

Truck category	Savings in millions of guilders
articulated truck allowable vehicle-combination weight more than 40 tonnes	17.8
articulated truck allowable vehicle-combination weight less than 40 tonnes	22.7
total savings	40.5

Table 37. Annual cost savings due to lower fuel consumption.

Truck category	Savings in millions of guilders
articulated truck allowable vehicle-combination weight more than 40 tonnes	25
articulated truck allowable vehicle-combination weight less than 40 tonnes	23
total savings	48

Table 38. Summary of the calculated extra costs and benefits per year for super single tires.

Costs	in millions of guilders	Benefits	in millions of guilders
MotorWay Network		Weight Saving	22
Pavement	26	Tire Cost	41
Bridges	6	Fuel Cost	48
Provincial roads			
Pavement	10 - 15		
Bridges	6		
Total	53		111

caused by lower rolling resistance when applying super-single tires on all trailer and semi-trailer axles.

Conclusions and Recommendation

Using super-single tires in the Netherlands is particularly economical for tires and fuel costs. Besides the financial aspect, there are also favorable environmental aspects, namely less energy consumption, less exhaust-fume emission, less need for raw materials (rubber) and a limit to the waste flow of old tires. Table 38 gives a summary of the calculated extra costs and benefits per year when applying super-single tires.

CHAPTER 3

PREVELANCE OF SINGLE TIRES AND ASSOCIATED DISTRESS

TRAFFIC SURVEYS

Traffic surveys are typically conducted by highway agencies to gather information on the traffic volume and composition using the highway system. The kind of traffic surveys that are of interest to this research project are the ones that include specific information regarding the distribution of tire types.

As part of this research project, a survey questionnaire was sent to the state highway agencies (SHA) requesting information concerning any traffic survey studies that they have conducted. A total of 37 responses were received. Only four SHA's have conducted traffic surveys to identify the types of tires and tires configurations that are being used on the highway system. The following represents a summary of the four SHA's traffic survey studies.

Washington DOT

In 1983, the Washington Department of Transportation conducted a limited traffic survey study to identify the distribution of tire types, tire loads, and tire inflation pressure (19). A total of 80 trucks were surveyed on the northbound of Interstate I-5 near Fife Washington. The following observations were made:

1. A total of six trucks had singled-out tires on single or tandem axles.
2. One truck exceeded the criterion of 105 N per one millimeter of tire width.
3. One truck with 419 mm (16.5 in) wide super-single tires and one truck with 457

mm (18 in) wide super-single tires.

In summary, the Washington DOT study showed that the percentage of trucks using super-single or singled-out tires is around 10 percent. Also the number of trucks violating the load/tire width regulation is extremely small. However, it should be noted that the sample size is very small which may skew the data in either directions.

Arkansas DOT

In 1988, the Arkansas DOT conducted a traffic survey study which identified the distribution of tire types on the highway system (20). The survey indicated that 72% of the tires are radial while 28% of tires are bias. A later study by Oregon DOT indicated that the percent of bias tires has been dropping significantly (1.2% in 1992) since the Arkansas study.

Oregon DOT

In 1992, The Oregon Department of Transportation Conducted a traffic survey study to identify the distribution of super-single and singled-out tires on the state highway system (21). The survey covered five Ports of Entry (POE). Table 39 summarizes the percentages of singled-out tires at the various POE's. This data showed that there the percentage of the trucks on the highway system that are using singled-out tires ranges between 1.5 and 21. It is very clear that the percentage of the trucks using singled-out tires depends on the location within the state highway system.

Table 39. Summary of data on trucks using singled-out tires based on the 1992 survey conducted by Oregon DOT. (20)

POE	March			June			September			Overall Singled-out, %
	No. of Trucks	Trucks with singled-out	%	No. of Trucks	Trucks with singled-out	%	No. of Trucks	Trucks with singled-out	%	
Ashland	196	3	1.5	169	3	1.8	218	3	1.4	1.5
Woodburn	113	8	7.1	-	-	-	88	12	14	10
Cascade Locks	85	17	20	231	48	21	100	23	23	21
Farewell Bends	132	12	9.1	49	4	8.2	36	2	5.6	8.3
Klamath Falls	108	7	6.5	115	0	0	65	1	1.5	2.8

The Oregon DOT study mentioned that the reason the Cascade Locks POE has the highest percentage is attributable to the large proportion of trucks shipping garbage to Arlington, OR. The study also indicated that: "A large proportion of the tridem axles were singled-out (40% in March and June, and 90% in September). Of these, the majority were partially singled-out. The lead axle was the axle most likely to be singled-out. A small percentage of tandems were singled-out. Of these, the tendency was for both axles to be singled-out."

Table 40 summarizes the overall distribution of tire types for all of the surveyed POE's in Oregon. The data clearly indicate that the majority of the trucks use dual tires. The percent of trucks using singled-out tires ranges between 7 and 10 percent and the percentage of trucks using super-single tires is around 1.5 percent. It should be noted that this data were collected in 1992 and some of these trends may have changed. In addition, the Oregon study indicated the following distribution of the trucks using singled-out dual tires: 40% were carrying groceries, 26% were carrying garbage and waste, and 11% were empty.

Figures 13 and 14 shows the distribution of the singled-out tires as a function of axle combinations for the March and June 1992 surveys, respectively. The data show that there are some differences between the two dates. The lead axle of the tridem group and both axles on the tandem group are among the highest in both surveys. However, the June survey (Figure 14) shows that the percent of single axles using singled-out tires has significantly increased since the March survey.

In summary, the Oregon DOT data showed that the percent of trucks using singled-

Table 40. Summary of the survey data for all the Surveyed POE's based on the 1992 survey conducted by Oregon DOT. (20)

Tire Types and Configuration	March: 635 Trucks		June: 564 Trucks		September: 511 Trucks	
	No. Trucks	Percent	No. Trucks	Percent	No. Trucks	Percent
Bias Tires on Steering	0	0	0	0	2	0.4
Bias Tires on Non-Steering	63	9.9	24	4.3	34	6.6
Dual Tires 280 mm wide	342	53.9	372	66.0	210	41.1
Other Dual Tires	227	35.7	166	29.5	258	50.5
Super-Single Tires	3	0.5	1	0.2	9	1.8
Singled-out	47	7.4	55	9.8	41	8.0

Table 41. Summary of the 1992 traffic survey data conducted by South Dakota DOT. (21)

Tire Configuration	Percent (%)	Tire Width (mm)
Dual Tires	73.0	282
Super-Single Tires	23.3	386
Singled-out Dual Tires	3.7	274

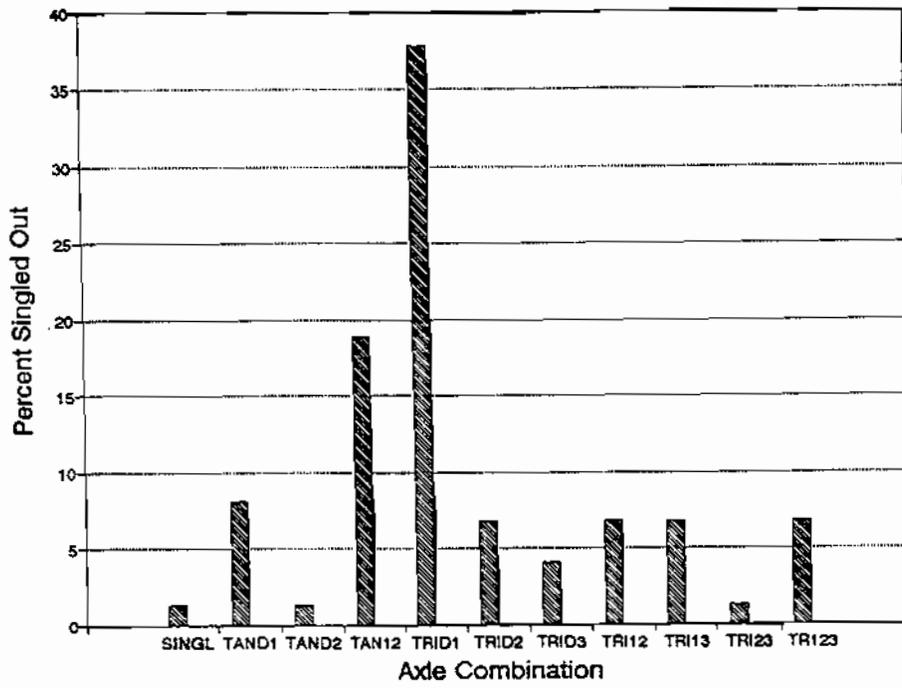


Figure 13. Percent distribution of axles using singled-out tires based on the March 1992 survey.

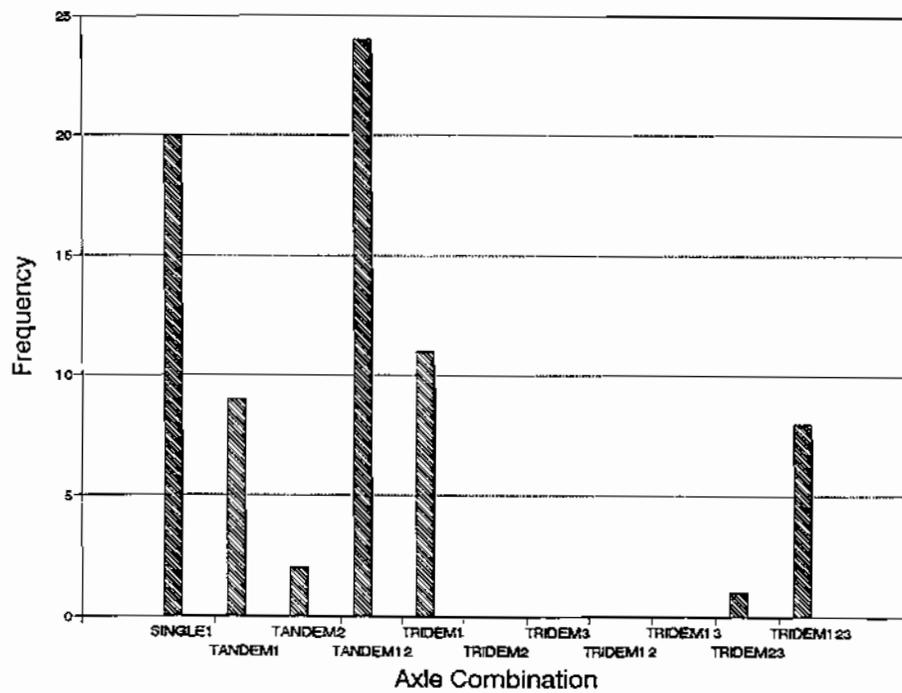


Figure 14. Frequency distribution of axles using singled-out tires based on the June 1992 survey.

out tires maybe significant depending on the location within the state highway system. The data also showed that the majority of truck tires are radial ply tires. In addition, the tendency of using singled-out tires on the lead axle of the tridem group is the highest among all other axle groups, followed by both axles of the tandem group and the single axle.

South Dakota DOT

In 1992, The South Dakota Department of Transportation conducted a traffic survey study at five locations throughout the state (22). Table 41 shows a summary of the survey data. This survey data showed that the majority of the trucks use dual tires, however, the percentage of trucks using super-single tires in South Dakota is relatively significant (e.g. 23.3 %).

In 1994-1995, the South Dakota DOT conducted another very extensive traffic survey to identify the distribution of tires configurations on the highway system (23). The survey included 36 locations on the South Dakota highway system. Figure 15 shows the distribution of dual tires, super-single, and singled-out tires. The location axis in Figure 15 shows the route number and the milepost separated by a slash (/). The data showed that the great majority of the trucks on the majority of locations use dual tires. The percent of singled-out tires is in the range of 15 to 20 percent on some locations. In fact, the percent of singled-out tires at SD 44 MP 69 exceeds the percent of dual tires. The percent of super-single tires ranges between 0 and 10 percent.

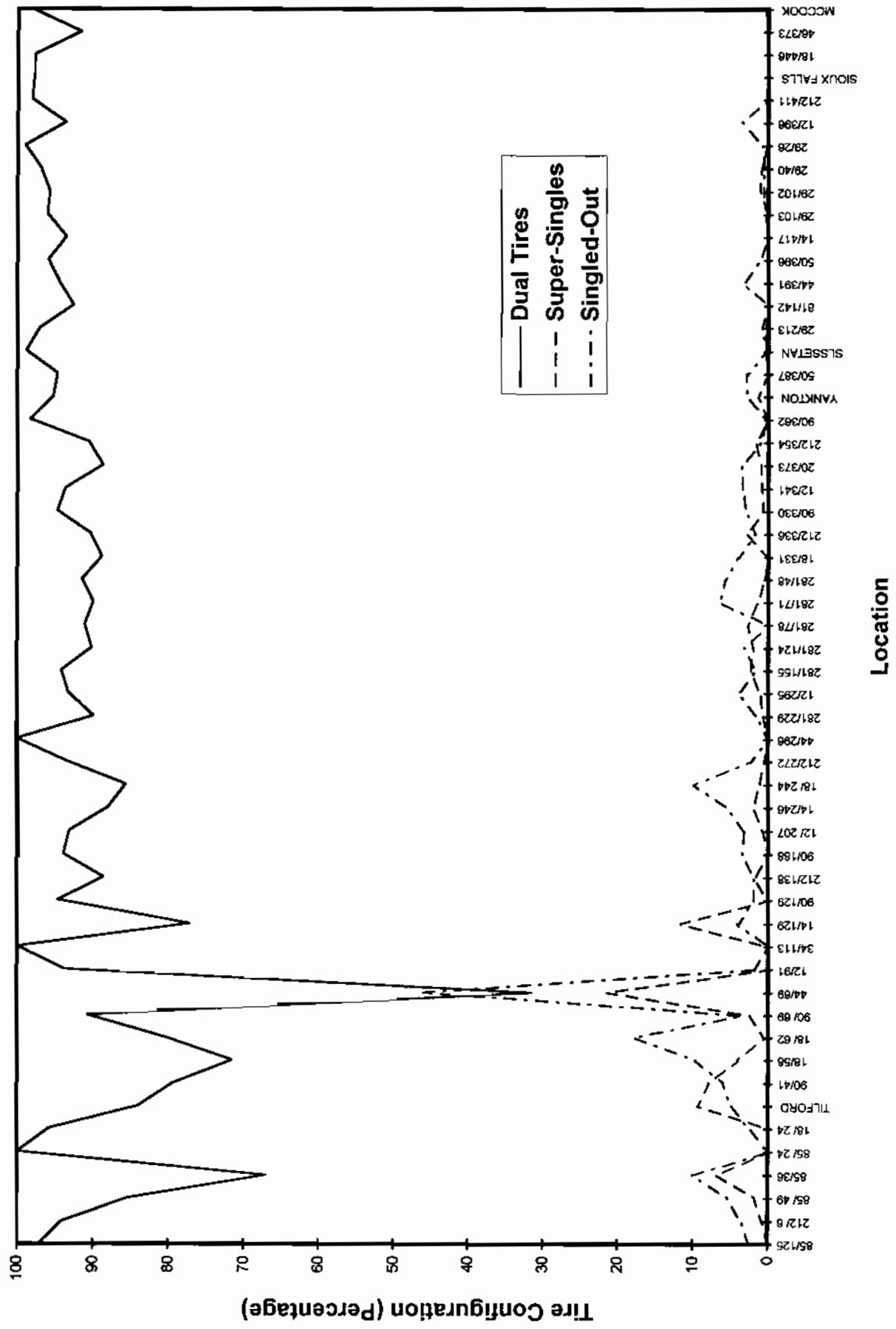


Figure 15. Distribution of tire types at various highway locations.

The South Dakota DOT surveys clearly indicate that there is an upward trend in the use of singled-out tires. The 1992 survey showed very small percentage of trucks using singled-out tires while the 1994-1995 survey showed a significant percentage of trucks using singled-out tires. However, the use of singled-out tires is highly dependent on the location throughout the state.

Summary and Recommendations

A total of four traffic surveys have been conducted throughout the U.S. to identify the prevalence of single tires on the highway system. Among the four studies, the South Dakota and Oregon studies are the most extensive ones. Based on the analysis of the data from these surveys, the following recommendations can be made:

1. The majority of truck tires are radial ply tires.
2. The majority of trucks still use dual tires configurations.
3. The use of singled-out tires is increasing at an alarming rate at some locations.
4. The increase in the use of singled-out tires seems to be highly dependent on the location within the state highway system.
5. The use of super-single tires has been holding steady within the past five years with an average percentage ranging between 5 and 10%.

TIRE MARKET DISTRIBUTION

The market shares of the various tire types were collected from the tires

manufacturers. Table 42 summarizes the market shares distribution for the various tire types. The data for the years between 1989 and 1994 are missing because most manufacturers do not keep more than three years of data.

Market shares data provides a good indication on the trends of the super-single tires, however, no indication is given on the use of the singled-out tires since the conventional and low profile duals can also be used as singled-out tires. The data in Table 42 indicate that dual tires dominates the market either in the form of conventional duals or low profiles duals. The national market has not seen any significant changes in the production and use of the super-single tires. Discussions with tire manufacturers representatives indicated that the majority of the super-single tires are being used for local short hauls such as concrete mixers and garbage trucks. In addition the tires manufactures believe that the 315/80R22.5 super-single tire is the most damaging tire on highway pavements due to its highest unit pressure. This type of tire makes up the following percentages of the market:

<u>Year</u>	<u>Percent of 315/80R22.5</u>
1994	0.8%
1995	0.9%
1996	1.1%

By looking at the above percentages, it can be seen that the 315/80R22.5 tire represents the majority of the super-single tires used in the market today. This type of tire is mainly used on the axle of garbage/waste haulers.

TIRE LOAD LIMITS

The survey data indicated that only a few state highway agencies consider the use of single tires as being a problem. Several of the surveyed agencies indicated that the percentage of single tires on their highway system is too little to be of any concern. However, the majority of them have implemented a tire load limit criterion which indirectly discourages the use of singled-out or super-single tires on highway traffic. Currently thirty states have regulatory limits on the basis of weight per unit width of the tire. These laws specify the maximum legal wheel load in newton per millimeter of tire width or as the manufacturer's recommended load whichever is less. Table 43 summarizes the regulations of the various agencies.

Table 44 shows the allowable single axle loads in KN based on the various levels of tire load limits. The majority of the states are currently allowing up to 90 kN on single axles. The data in Table 44 show that the tire load limit can be used to discourage the use of singled-out and the regular super-single (385/65R22.5) tires while the use of the wide super-single tires (i.e. 425/65R22.5) may not be affected unless the tire load limit was reduced to 105 N/mm (600 lb/in) or less. In other words, wide super-single tires can currently be used on many highways without violating neither the axle load nor the tire load limits.

PAVEMENT DISTRESS ASSOCIATED WITH TIRE TYPE

As mentioned earlier the major types of load-associated pavement distresses are the rutting and fatigue failures. Various studies have indicated that tire type significantly impact the loading mechanism at the tire/pavement interface and therefore, may change the mode of Table 42. Market shares distribution for the various tire types

Tire Type	1987 (%)	1989 (%)	1994 (%)	1995 (%)	1996 (%)
Conventional Duals	52	49	55	52	53
Low Profile Duals	47	49	44	46	45
Super-Singles	1	2	2	2	2

Table 43. Tire load limit laws for various state highway agencies.

Tire Load N/mm (lb./in)	States
96.3 (550)	Alaska, Mississippi, North Dakota, South Dakota
105.1 (600)	Connecticut, Idaho, Kentucky, Maine, Minnesota, Montana, New Hampshire, New Mexico, Nevada, Oregon, South Carolina, Utah, Vermont, Washington, Wyoming
106.0 (605)	Florida
113.8 (650)	Louisiana, Ohio, Texas, Virginia
122.6 (700)	Michigan
140.1 (800)	Indiana, Massachusetts, New Jersey, New York, Pennsylvania

Table 44. Allowable single axle loads in kN based on tire load limits.

Tire Load (N/mm)	Dual 11R22.5	Singled-out 11R22.5	Super-Single 425/65R22.5	Super-Single 385/65R22.5
96.3	108	54	82	74
105.1	118	59	89	81
113.8	127	64	97	88
122.6	137	69	104	94
140.1	156	78	119	108

pavement failure. For example, a pavement may fail in fatigue when loaded with dual tires while the predominant mode of failure for the same pavement may be rutting when loaded with single tires.

In order to check the above mentioned theory on the impact of tire type on failure mode, long term pavement performance must be available. There are two studies that could offer input data for this evaluation: the ALF study conducted by Bonaquist and the CAPTIF study conducted by Pidwerbesky. Both of these studies compared pavement performance under dual and single tires.

The results of the ALF study were presented in Figures 5 and 6. The trends in these figures show that single tires accelerates the formation of rutting and fatigue of both the thin and thick sections. The performance data presented in these figures can also be used to evaluate the impact of tire type on the failure mode of flexible pavements. This evaluation was done as follows:

1. Identify failure criteria: The following failure criteria was used.
 - a. Fatigue failure: 10m of cracking
 - b. Rutting failure: 10mm rut depth
2. Identify the number of load repetitions to cause fatigue and rutting failures under dual and super-single tires for both sections based on the performance data presented in Figures 5 and 6:

<u>Tire Type</u>	<u>89 mm Section</u>	
	<u>10m Fatigue</u>	<u>10mm Rutting</u>
425/65R22.5	60,000	75,000
11R22.5	225,000	280,000

<u>Tire Type</u>	<u>178 mm Section</u>	
	<u>10m Fatigue</u>	<u>10mm Rutting</u>
425/65R22.5	140,000	90,000
11R22.5	375,000	150,000

3. Identify the initial mode of failure under each tire for both sections. For example, the initial mode of failure of the 89mm AC section under super-single tire loading is fatigue because the number of load repetitions (60,000) to cause 10m fatigue is lower than the number of load repetitions to cause 10mm rutting (75,000). Using this approach, the following initial failure modes were identified:

<u>Section</u>	<u>Tire Type</u>	<u>Initial Failure Mode</u>
89mm AC	425/65R22.5	Fatigue
89mm AC	11R22.5	Fatigue
178mm AC	425/65R22.5	Rutting
178mm AC	11R22.5	Rutting

4. Evaluate the impact of tire type on the initial failure mode: The above data indicate that the initial failure mode is not impacted by the tire type. On the other hand, the initial failure mode is significantly impacted by the thickness of AC layer

The results of the CAPTIF study are presented in Figures 7 and 8. The data are presented in terms of typical rut depth after the 15,591 load repetitions. The actual report contains the transverse profiles for all stations along the test section. Personal discussions with the New Zealand researchers indicated that both sections failed in rutting without any significant

fatigue cracking.

Based on the very limited data available, it can be concluded that tire type, i.e. dual versus single, does not have any impact on the failure mode of the pavement section. It is very clear, however, that single tires accelerate the failure of flexible pavements but do not change the distress mode.

CHAPTER 4

EVALUATION OF ANALYTICAL PROCEDURES

An analytical procedure is defined as the overall process by which the relative pavement damage caused by single tires as compared to dual tires is evaluated. The first step in evaluating this relative damage consists of defining the modes of failure that are impacted by the use of single tires. All previous studies conducted on this topic agree that rutting and fatigue are the two modes of failure that are most significantly impacted by the use of single tires. In addition, previous studies identified the following parameters as indicators of rutting and fatigue failures:

1. Rutting:
 - a. Vertical strain on top of subgrade.
 - b. Vertical deflection at the pavement surface.
 - c. Compressive stress at the center of the base layer.
2. Fatigue:
 - a. Tensile strain at the bottom of the asphalt concrete layer.

Having identified the critical responses, the impact of single tires on the rutting and fatigue of flexible pavements can be evaluated through any of the following approaches:

1. Calculate the response parameters under dual and single tires through theoretical modeling and use performance models to predict the relative pavement damage caused by single tires.
2. Measure the response parameters under dual and single tires and use performance models to predict the relative pavement damage caused by single tires. The advantage of this approach is that the measured pavement responses would not be significantly

influenced by the assumptions of the theoretical model used to calculate the critical responses.

3. Measure the performance of flexible pavements under both dual and single tires loadings. The advantage of this approach is that the measured performance would not be impacted by the assumptions of the theoretical models nor the performance models.

It should be noted that the complexity and the cost of conducting the evaluation drastically increases as it moves from approach 1 through 3. Considering the list of pavement response parameters, it can be concluded that the following factors are critical to the evaluation of the relative pavement damage caused by single tires as compared to dual tires.

1. Vehicle factors:
 - a. Axle load
 - b. Tire pressure
 - c. Tire type
 - d. Axle configuration
 - e. Speed
2. Pavement factors:
 - a. Structure
 - b. Temperature
 - c. Stiffness

Therefore, the ideal analytical procedure is the one that measures actual pavement performance under dual and single tires while taking into consideration the impact of the above identified

factors. Table 45 summarizes all of the previous studies as they compare to the ideal evaluation plan. The data in Table 45 indicate that none of the previously conducted studies includes all of the features of an ideal analytical procedure.

SELECTION OF PROMISSING PROCEDURES

The evaluation process indicated that there are several previous studies that possess some features of an ideal analytical procedure. This group of studies included the ones that measured pavement responses or performance under full scale loading conditions. The reason for selecting this group of studies is that measuring pavement responses and/or performance under full scale loading would eliminate several limitations of the analytical procedures that are purely theoretical. These limitations include the modeling of the contact pressure at the tire/pavement interface, vehicle speed, pavement dynamics, materials variability, etc....

This section of the report takes a closer look at the results of the selected studies and compares their recommendations concerning the relative damage of single tires as compared to dual tires. The following studies were selected for this evaluation:

1. "An Assesment of the Increased Damage Potential of Wide Base Single Tires," conducted by Bonaquist (ref# 15).
2. "Relative Rutting Effects of Different Tire Types," Conducted by Pidwerbesky and Dawe (ref#16).
3. "Effect of Tire Types and Pressures on Pavement performance," conducted by Sebaaly and Tabatabaee (ref# 10).
4. "Estimating Damage Effects of Dual vs Super Single Tires with Multidepth

Table 45. Comparison of the analytical procedures used in previous studies.

Study	Vehicle Factors					Pavement Factors			Performance			
	Axle Load	Tire Pressure	Tire Type	Axle Config.	Speed	Structure	Temp	Pav. Stiff.	Rutting		Fatigue	
									Calc	Measured	Calc	Measured
Perdomo (1)	Varied at 89 and 151 kN	Varied at 1103 and 1517 kPa	Super Single and Dual	Single, Tandem Tridem	N/C	One Structure	N/C	N/C				
Deacon (2)	Varied at 18, 36, 54, 12 kN	N/C	Dual and Singled Out	Single and Tandem	N/C	5 levels of Structural Number	N/C	N/C			Yes	
Southgate (3)	Varied at 25 and 42 kN	Varied at 552, 793, 1030, 1380 kPa	Dual and Singled Out	Tandem and Tridem	N/C	One Structure	N/C	N/C			Yes	
Hallin (4)	Varied at 44.5 and 180 kN	N/C	Super Single and Dual	N/C	N/C	3 different AC layer thickness	N/C	N/C			Yes	
Bell (5)	N/C	N/C	Dual and Singled Out	N/C	N/C	2 different AC layer thickness	N/C	N/C	Yes		Yes	
Gillipsie (6)	N/C	Varied at 517 and 827 kPa	Dual, Low Profile Dual, Super Single, Singled Out	N/C	N/C	Thick and thin	25 C 49 C	N/C	Yes		Yes	
Zube (7)	N/C	N/C	Super Single and Dual Bias ply Tires	N/C	N/C	50-70 mm AC layer	N/C	N/C				
Christison (8)	Varied at 56 and 117 kN	N/C	Dual, Super Single, Singled Out Bias ply Tires	N/C	N/C	One Structure	N/C	N/C			Yes	
Sharp (9)	N/C	N/C	Super Single and Dual Radial Tires	N/C	N/C	One Structure	N/C	N/C				
Sebaaly (10)	Varied at 44.5 and 97.9 kN	Varied at 723 and 896 kPa	Dual Bias ply tire, Dual Radial ply, Super Singles Radial	Single and Tandem	65 km/h	Thick and Thin	N/C	N/C	Yes		Yes	

Table 45. Comparison of the analytical procedures used in previous studies (Continued).

Study	Vehicle Factors						Pavement Factors				Performance	
	Axle Load	Tire Pressure	Tire size	Axle Config.	Speed	Structure	Temp	Pav. Stiff	Calc	Measured	Calc	Measured
									Yes		Yes	
Akram (11)	N/C	N/C	Dual and Super Single Radial Tires	N/C	Varied at 16, 32, 56, 89 km/h	Thick and Thin	27C 39C	N/C	Yes		Yes	
Huhtala (12)	Axle Load 10 tons +/- 20%	Varied at 483 to 1082 kPa	Dual, Low Profile Dual, Super Single Radial Tires	N/C	N/A	2 different AC layer thickness		N/C			Yes	
S. Dakota (13)	Tire Load varied at 70.1, 105.1, 140.2 N/mm	N/C	Super single, Dual, Singled Out Radial Tires	N/C	30 km/h	One Structure		N/C	Yes			
Bonaquist (15)	Varied at 41, 54, 64, 74 kN	Varied at 520, 712, 959 kPa	Dual and Super Single Radial tires	N/C	19km/h	2 different AC layer thickness	Low, Moderate, high	N/C		Yes		Yes
Pidwerbesky (16)	N/C	N/C	Dual and Super Single Radial Tires	N/C	N/A	One Structure		N/C		Yes		
Eisenmann (17)	Varied at 31.7 and 49.7 kN	Varied at 800 to 1250 kPa	Dual and Singled Out	N/C	N/C	One Structure		N/C		Yes		

N/C = Not Considered

N/A = Not Available

Deflectometers," conducted by Akram et al. (Ref# 11).

5. "Effects of Tires and Tire Pressures on Road Pavements," conducted by Huhtala et al. (ref# 12).

6. "The Effects of Increased Truck Tire Loads on Pavements," conducted by Huntington/Austin Research Engineers for the S. Dakota DOT (ref# 13).

The selected analytical models used in 1 and 2 measured actual pavement performance while the models in 3-6 used a combination of measured pavement responses and performance models. The use of a combination of measured pavement responses and performance models is very attractive since a large number of variables can be evaluated within limited budget and time constraints. The objective of this evaluation will be to assess how effective the models that use pavement responses are in predicting the relative pavement damage of single tires as compared to dual tires.

The ALF study evaluated the fatigue and rutting damage factors for the super-single tire on both thin and thick sections under single axle load of 109 kN (24,500 lb) and tire pressure of 703 kPa (102 psi). The damage factors shown in Table 30 were based on the measured strains and deflections and the use of performance models. However, if the performance data shown in Figures 5 and 6 are used, performance-based damage factors can be evaluated. This analysis assumed a 10m (33 ft) cracking and 10mm (0.4 in) rut depth as failure limits for both the thin and thick sections. The corresponding numbers of load repetitions to failures were obtained from Figures 5 and 6 as follows:

<u>89 mm Section</u>		
<u>Tire Type</u>	<u>10m Fatigue</u>	<u>10mm Rutting</u>
425/65R22.5	60,000	75,000
11R22.5	225,000	280,000

<u>178 mm Section</u>		
<u>Tire Type</u>	<u>10m Fatigue</u>	<u>10mm Rutting</u>
425/65R22.5	140,000	90,000
11R22.5	375,000	150,000

Using the above data and defining the damage factor as the number of load repetitions under the dual tires (11R22.5) divided by the number of load repetitions under the super-single tire (425/65R22.5), the following damage factors can be obtained:

89 mm section: Fatigue damage factor: 3.75 Rutting damage factor: 3.73

178 mm section: Fatigue damage factor: 2.68 Rutting damage factor: 1.67

Table 46 compares the damage factors based on pavement response and pavement performance in the ALF experiment. The highest discrepancy occurred between the rutting damage factors for the 89mm pavement. The performance-based rutting factor is three times the rutting damage factor based on pavement response. The pavement-response rutting damage factor showed a lower value for the thin pavement (1.23) than the one for the thick pavement (1.31) which

Table 46. Comparison of the pavement response and pavement performance ALF damage factors.

Damage Factor/Thickness of AC (mm)	Pavement Response	Pavement Performance
Fatigue/89 mm AC	4.30	3.75
Fatigue/178 mm AC	3.52	2.68
Rutting/89 mm AC	1.23	3.73
Rutting/178 mm AC	1.31	1.67

indicates that super-single tires are more damaging on thick pavements. Again, this observation contradicts pavement design theories which makes the pavement-response rutting damage factors somewhat doubtful. It should be noted that the pavement-response rutting damage factors were calculated as a simple ratio of surface deflections generated under the single tire over the deflections under the dual tires. The fatigue response-based factors were calculated based on the ratio of number of load repetitions to failure produced from the performance models. The fatigue performance-based and response-based damage factors showed that thicker pavements are less damaged by super-single tires (i.e. lower damage factors).

The CAPTIF study presented the data in terms of rut depth under dual tires versus rut depth under a low profile super-single tire. Converting the measured rut depth into a damage factor for rutting, the CAPTIF study indicated that the low profile super-single tire would have a rutting damage factor of 1.92. It should be noted that both the pavement structure and the tire type significantly differ between the ALF and the CAPTIF studies. In addition, the methods of calculating the damage factors are also different: the ALF damage factors represent the ratios of number of load repetitions to achieve a constant level of rutting or fatigue while the CAPTIF damage factor is the ratio of rut depth under a constant number of load repetitions.

Since the pavement sections used in the ALF experiment are more representative of pavements on the U.S. road network than the pavement section in the CAPTIF experiment, the ALF performance-based damage factors will be used to evaluate the merit of the response-based damage factors.

The damage factors generated from the pavement-response based studies (3-6) have been fully discussed and presented in Chapter 2. Some of these factors can be directly compared with

the ALF's performance-based factors as will be shown in the following discussions. Efforts will be made to compare damage factors developed under as close conditions as possible.

The Sebaaly et al. study generated damage factors for a thin pavement with AC thickness of 152 mm (6 in) for the 425/65R22.5 super-single tire under single axle load of 96 kN (21,600 lb). Since the same tire type was used and relatively close pavement thickness and axle loads, the damage factors from the Sebaaly et al. study can be compared with the ALF's performance-based damage factors as follows:

	<u>Fatigue</u>	<u>Rutting</u>
Sebaaly et al.	1.40	1.40
ALF performance-based	2.68	1.67

The above comparison indicates that the fatigue damage factors vary significantly between the response-based and the performance-based studies while the rutting damage factors are relatively close.

The South Dakota study evaluated the rutting damage factors of singled-out and super-single tires relative to the dual tires. The deflection ratios reported in the South Dakota study referred to the ratio of the deflection under a given tire over the deflection under dual tires with 80 kN (18,000 lb) single axle load. In order to make the data consistent with the ALF performance-based data, it was necessary to convert the ratios in terms of deflections under the same axle load raised to the power 3.8. The converted ratios are as follows:

<u>Season</u>	<u>Damage factor under single axle load of 106.8 kN</u>
Summer	2.48
Fall	1.68
Winter	1.98
Spring	4.96

The measurement of seasonal damage factors presented another problem for the comparison of the S. Dakota data with the ALF data. The S. Dakota study showed that the season significantly impacts the magnitude of the damage factor, especially the spring season. The ALF experiment was conducted during the Summer of 1989. In addition, the pavement structure of the S. Dakota study falls in-between the thin and thick sections of the ALF study. Based on these limitations, it was decided to compare the Summer damage factors from the S. Dakota study with the damage factors from the thin and thick sections of the ALF study.

<u>Rutting damage factor</u>	
S. Dakota	2.48
ALF performance-based,	
Thin:	3.73
Thick	1.67

The only conclusion that can be drawn from the above comparison is that the S. Dakota rutting damage factor fits very well within the range of the ALF performance-based rutting damage factors. Assuming a linear relationship between damage factors and AC thickness, a linear interpolation of the ALF's factors would indicate that an AC thickness of 127 mm would

have a rutting damage factor of 2.85 which is relatively close to S. Dakota factor of 2.48.

The Akram et al. study evaluated the rutting damage factors under tandem axles with 147 kN (33,000 lb) load. The study evaluated the damage factors for a super-single tire (425/65R22.5) at four speeds (16, 32, 56n and 89 km/h). The pavement section had an AC layer of 178 mm which is exactly the same as the ALF thick section. Since the same super-single tire and AC thickness were used, it was decided to ignore the fact that the Akram et al. study evaluated the damage factors under tandem axles while the ALF used single axles and compare the 16 km/h data from Table 23 with the ALF data. The rutting damage factor was obtained as the ratio of the ESALs under the dual-drive over the super-single on the trailer.

Rutting damage factor

Akram et al.	1.69
ALF performance-based	1.67

The above comparison indicates that the rutting damage factors generated from the two approaches are very close.

The Huhtala et al. study generated fatigue damage factors for two pavement sections: 80 mm and 150 mm AC layers. The fatigue damage factors for a super-single tire equivalent to the one tested in the ALF experiment are 3.73 and 3.25 for the 80 mm and 150 mm AC, respectively. These fatigue damage factors are different from the ones shown in Table 25 since they are calculated using the same approach used in the ALF experiment. This approach calculates the damage factors based on the fatigue life under the dual and single tires loaded to

the same level. The interpolated fatigue damage factor based on the ALF data for the 150 mm AC is 3.02. These fatigue damage factors compare very well with the ALF factors of 3.75 and 2.68 for the 89 mm and 178 mm sections, respectively.

Table 47 summarizes the damage factors from the selected studies and how they compared with the ALF's performance-based damage factors. The data presented in Table 46 indicate the following:

1. Using the simple ratio of strains or deflections will not result in reliable damage factors for neither rutting nor fatigue. The measured pavement responses will have to be converted into number of ESALs to failure and then used to calculate the damage factors. This indicates that a performance model must be used.
2. The rutting damage factors can be effectively determined by using the ratio of the equivalent single axle loads determined from the vertical compressive strain on top of the subgrade or the vertical deflection at the pavement surface.
3. The fatigue damage factors can be effectively determined by using the ratio of the equivalent single axle loads determined from the tensile strain at the bottom of the asphalt concrete layer.

Table 47. Comparison of the ALF performance-based damage factors with response-based studies

Study	Rutting Damage Factors			Fatigue Damage Factors		
	Thin	127 mm AC (interpolated)	Thick	Thin	150 mm AC (interpolated)	Thick
ALF	3.73	2.85	1.67	3.75	3.02	2.68
Sebaaly et al.	NA	NA	1.40	NA	NA	1.40
S. Dakota	NA	2.48	NA	NA	NA	NA
Akram et al.	NA	NA	1.67	NA	NA	NA
Huhtala et al.	NA	NA	NA	3.73	3.25	NA

CHAPTER 5

RECOMMENDED EVALUATION PLAN

The objective of this part of the research is to recommend a plan which can be used to determine pavement damage from super-single and singled-out dual truck tires relative to dual tires. Before presenting the recommended evaluation plan, it would be beneficial to mention that the primary objective of the research is to develop a procedure to estimate pavement damage associated with the use of single tires as compared with that of conventional dual tire configurations. Therefore, the relative pavement damage caused by single tires should be the primary measure of the recommended evaluation plan.

The recommendations of the evaluation plan are based on the findings of the research tasks that have been completed which summarized below:

1. Numerous studies have evaluated the relative damage caused by single tires as compared to dual tires. The findings and recommendations of these studies vary significantly depending on the approach used in measuring the relative pavement damage caused by single tires.
2. The relative damage of single tires on rigid pavements is very minimal when compared to flexible pavements. Therefore, any technical and regulatory approaches that will be developed to control damage on flexible pavements will very adequately cover the anticipated damage on rigid pavements.
3. Traffic survey studies and market distribution data indicate that the use of super-single tires has been holding steady for the past ten years at a rate of 1-3 percent of total tires

on highway pavements. However, the use of singled-out tires has been increasing at an alarming rate.

4. The use of singled-out tires is very highly dependent on the location of the highway, the type of commodity being transported, and the axle configurations of the truck. The data showed that a high percentage of singled-out tires are being used on tandem and tridem configurations.

5. The ALF experiment offered the best data on the relative flexible pavement damage caused by super-single tires as compared to dual tires configuration. On the other hand some of the pavement-response studies have generated damage factors which are very close to the ones generated from the ALF experiment.

In light of the above observations, the following criteria were established to guide the development of the evaluation plan:

1. The evaluation plan should be capable of measuring or predicting pavement performance under single and dual tires.
2. The evaluation plan should include the evaluation of relative pavement damage under various combinations of single tires on tandem and tridem configurations. For example, the plan should include the evaluation of relative damage caused by tandem axles with singled-out tires on both the front or back axle or any combination of the two. As
3. The evaluation plan should cover a wide range of the critical parameters as identified in Chapter 4 (vehicle and pavement factors). The wider the range of the critical parameters the more applicable the results/recommendations will be.

The analysis presented in Chapter 3 identified the critical factors to be considered in the evaluation of the relative pavement damage caused by single tires as compared to dual tires. The following is a list of these factors along with their recommended levels:

1. Vehicle factors:
 - a. Axle load (3 levels)
 - b. Tire pressure (2 levels)
 - c. Tire type (3 levels)
 - d. Axle configuration (1-single, 2-tandem, and 3-tridem)
 - e. Speed (2 levels)
2. Pavement Factors:
 - a. Structure (2 levels)
 - b. Temperature (2 levels)
 - c. Stiffness (differs for each section)

The 2 and 3 levels for the tandem and tridem represents the combinations of singled-out tires on various axles (i.e. front, back, or middle). It was also indicated that the ideal analytical procedure is the one that measures actual pavement performance under dual and single tires while taking into consideration the impact of the above identified factors. The options for obtaining actual pavement performance are the following:

1. Use the Accelerated Loading Device (ALF)
2. Use the Heavy Vehicle Simulator (HVS)
3. Use a full scale test track

ALF EXPERIMENT

Conducting an ALF experiment to evaluate the relative damage of single tires as compared to dual tires will satisfy the majority but not all of the above identified critical factors. Axle configuration and speed are the two factors that could not be handled in an ALF experiment. The ALF machine can only simulate single axle at 16 km/h (10 mph) loading speed. An ALF experiment would require the construction and testing of an individual test section for each combination of the critical factors. Considering only the factors that the ALF can satisfy, this would require the construction and testing of 72 test sections. Discussions with FHWA personnel indicated that the cost of constructing a test section is around \$50,000.00 and the operational costs of the ALF machine are around \$275,000.00/year. Assuming that three sections can be tested each year, the total cost for each section will be around \$ 140,000.00.

HVS EXPERIMENT

Conducting an HVS experiment to evaluate the relative damage of single tires as compared to dual tires will satisfy the majority but not all of the above identified critical factors. Axle configuration and speed are the two factors that could not be handled in an HVS experiment. The HVS machine can only simulate single axle at 8 km/h (5 mph) loading speed.

An HVS experiment would require the construction and testing of an individual test section for each combination of the critical factors. Considering only the factors that the HVS can satisfy, this would require the construction and testing of 72 test sections. Discussions with

University of California, Berkeley personnel indicated that the cost of constructing a test section is around \$50,000.00 and the operational costs of the HVS machine are around \$80,000.00/month. Assuming that it will take four month to test a section, the total cost for each section will be around \$370,000.00.

A TEST TRACK EXPERIMENT

A test track experiment will satisfy all of the critical factors since actual trucks will be used to load the pavement which can handle variable speed and multiple axle configurations. Constructing test sections on an existing test track will also allow for multiple structural sections to be tested. The construction of pavement sections on an existing test track similar to the Westrack facility would involve milling of the existing AC layer and replacing it with the desired thickness of the new section. The cost for such activity is \$15,000 per section. The operational cost of the truck loading is around \$45,000/month.

The advantage of a test track experiment is that multiple sections can be tested at the same time which would greatly reduce the operational cost per test section. For example four or more test sections can be tested at the same time which makes the operational cost at \$11,000/month/section.

The above analysis shows that achieving the ideal evaluation plan is outside the financial capabilities of this research project. This observation coupled with the fact that pavement-response based studies compared favorably with the data generated from the ALF experiment led the research team to recommend one main evaluation plan and one alternative plan.

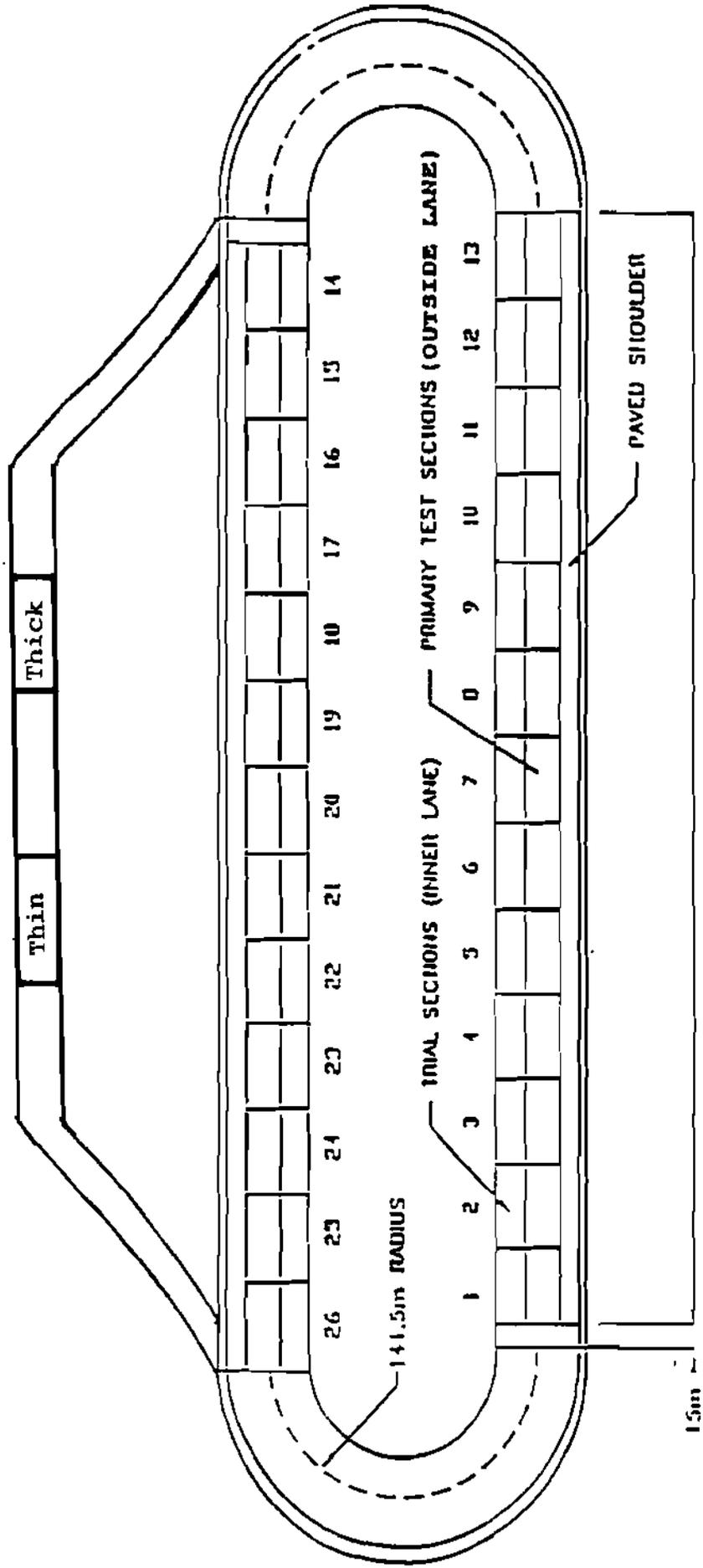
THE MAIN EVALUATION PLAN

Based on the noticeable success of some of the pavement-response type studies, it is recommended that a pavement-response experiment be conducted to evaluate the relative damage of flexible pavements caused by single tires as compared to dual tires. The concept of the proposed experimental plan consists of measuring pavement responses under a wide range of the critical factors and use performance models to predict pavement damage under both single and dual tires. Use the evaluated damages to determine the relative pavement damage caused by single tires as compared to dual tires. In addition, the measured pavement responses will be used to validate a theoretical analysis model which will be used to predict the relative damages of conditions outside the proposed experimental plan.

Experimental Program

Construct two test sections at the Westrack facility: one thin section and one thick section. Figure 16 displays the location of these test sections on the Westrack facility. Figure 17 shows the layout of the test sections. The following abbreviations are used to describe the test sections:

proposed location
of test sections



910m (13 - 70m SECTIONS)

Figure 16. Westtrack facility and proposed test sections layout.

DIRECTION OF TRUCK TRAFFIC



Existing 102 mm AC Layer	Thin Section 102 mm AC 204 mm CAB 30 m Long	Transition Zone 50 m long	Thick Section 204 mm AC 102 mm CAB 30 m Long	Existing 102 mm AC Layer
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Figure 17. Layout of the proposed flexible pavement test sections.

HMA	=	Hot Mixed Asphalt
CAB	=	Crushed Aggregate Base
SG	=	Subgrade

Pavement Structures and Materials Properties

A combination of pavement structure and properties of the HMA layer will be used to achieve a strong and a weak flexible pavement sections. The two sections will consist of the following:

<u>Section</u>	<u>Layer</u>	<u>Thickness (mm)</u>	<u>Modulus at 25°C (MPa)</u>
Thin	HMA	102	1,300 - 1,700
	CAB	204	19.3
	Comp. SG	204	9.7
	Nat. SG		5.2
Thick	HMA	204	2,400 - 2,800
	CAB	102	19.3
	Comp. SG	204	9.7
	Nat. SG		5.2

The combination of a thin section with low modulus HMA and a thick section with high modulus HMA will provide two extremely different sections with distinct responses.

Instrumentation Layout

The overall objective of this experiment is to measure the pavement responses that can be used to assess the relative damage of single tires as compared to dual tires. As mentioned earlier, the critical responses include the maximum tensile strain at the bottom of the HMA layer, the compressive strain at the top of the SG and the vertical deflection at the pavement

surface. The maximum tensile strains will be measured using longitudinal and transverse strain gauges installed at the bottom of the HMA layer while the compressive strain at the top of SG and vertical surface deflection will be measured using the multi-depth-deflectometer (MDD).

Figures 18 and 19 show the proposed instrumentation plans. The longitudinal and transverse strain gauges will be installed in groups of five (30 cm apart) at three locations throughout each of the pavement section. The MDD will be installed in the wheeltrack at the middle of each pavement section. Thermocouples will be installed throughout the depth of the HMA layer to monitor the temperature.

Field Test Program

The following combinations of the test parameters will be used in the field test program:

- Axle Load: Intermediate
Full
20% Overload
- Speed: 24 km/h
80 km/h
- Tire pressure:
 1. Manufacturer recommended
 2. 80% of manuf. recommended
 3. 120% of manuf. recommended
- Axle Configuration/
tire type:
 1. Single axle/dual tires
 2. Single axle/low profile dual tires
 3. Single axle/super-single tires
 4. Single axle/singled-out tires
 5. Tandem axle/dual tires on both axles
 6. Tandem axle/low profile dual tires on both

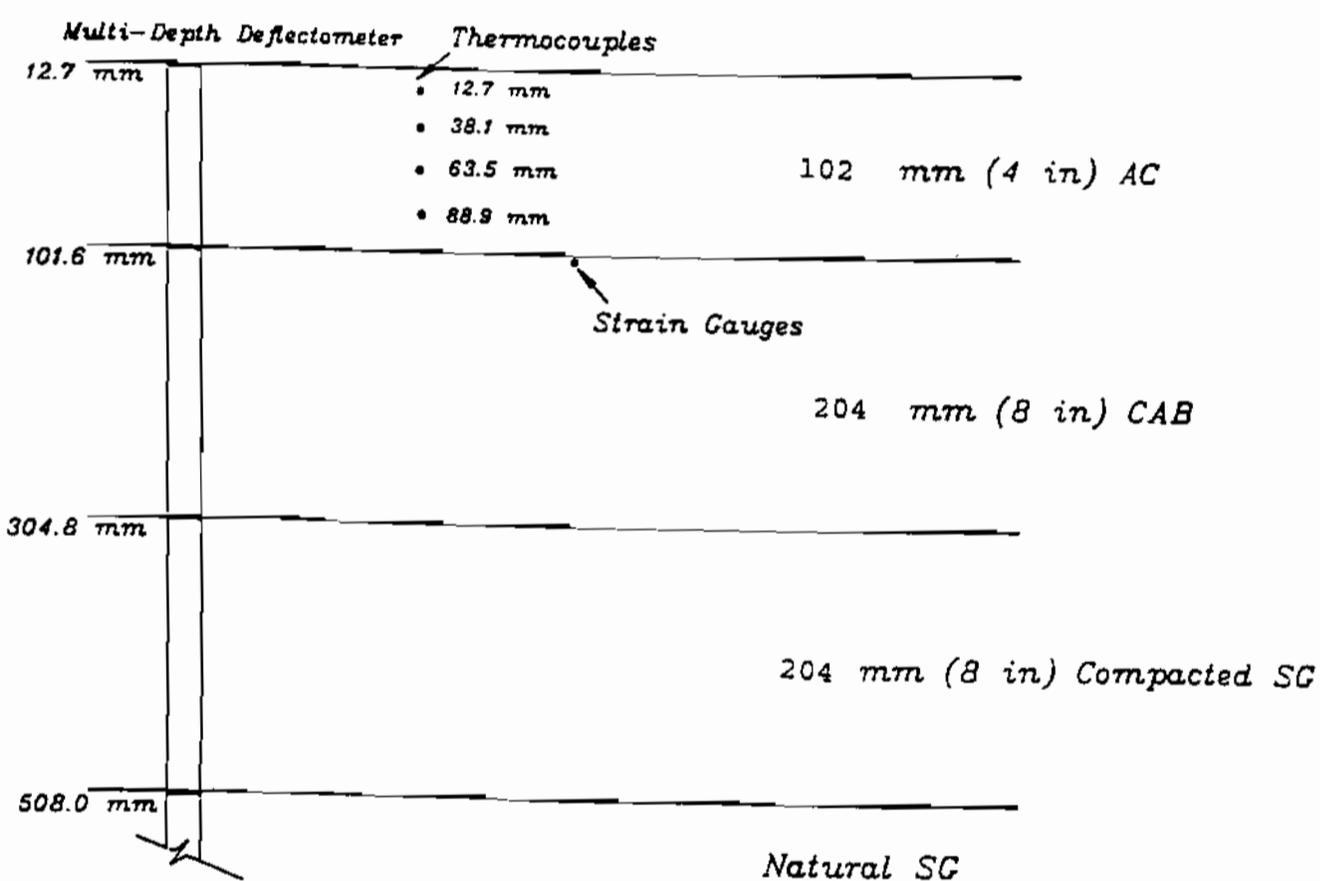


Figure 18. Instrumentation plan for the thin section.

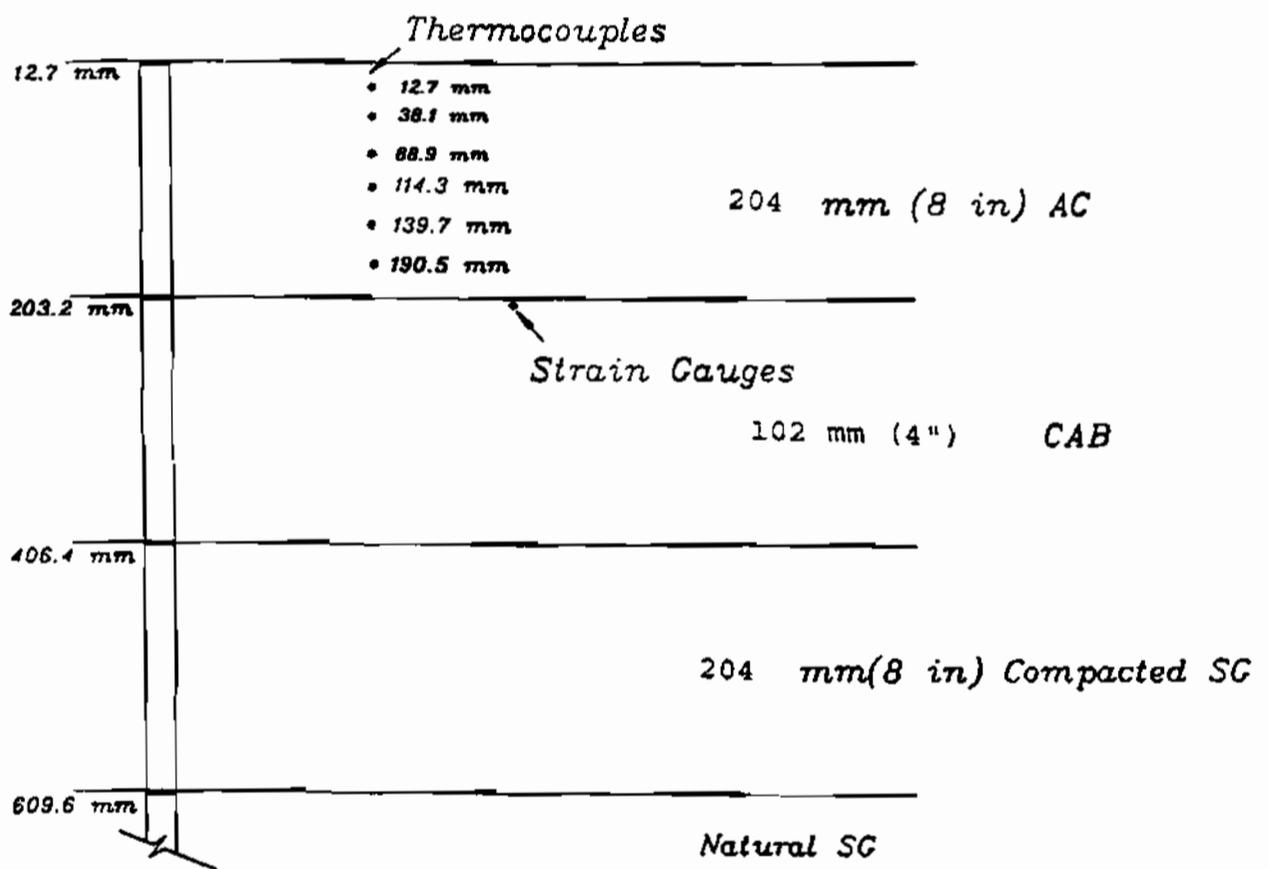


Figure 19. Instrumentation plan for the thick section.

axles

7. Tandem axle/super-single on both axles
8. Tandem axle/singled-out on both axles
9. Tandem axle/singled-out on first and duals on second
10. Tridem/dual tires on all axles
11. Tridem/low profile dual tires on all axles
12. Tridem/super-single on all axles
13. Tridem/singled-out on all axles
14. Tridem/super-single on first and duals on second and third axles
15. Tridem/Singled-out on first and duals on second and third axles
16. Tridem/singled-out on first and second and duals on third axle

- **Environment:**
 1. Conduct one field test during the Summer of 1998
 2. Conduct one field test during the fall of 1998
- **Replicates:** Three replicate measurements will be conducted for each combination of test variables.

The total number of response measurements: 3 (load) x 2 (speed) x 3(tire pressure) x 16 (axle/tire configuration) x 3 (replicates) = 864 combinations.

The responses of the strain gauges, MDD's, and thermocouples will be measured under 864 combinations of test parameters.

Field Test at The MinRoad Facility

Personnel at the MinRoad Facility have been contacted for the possibility of conducting the above described program in full or partial combinations at the main highway instrumented sections during the Summer of 1998. At the time this report was completed, the MinRoad

personnel did not give a final response. However, \$8,000.00 have been budgeted as part of the operating budget of the University of Nevada to accommodate the MinRoad Test plan if it can be conducted.

Field Data Collection

The following represents the distribution of the intrumentations:

- Flexible Section I:**
 - 30 strain gauges
 - 4 LVDT's
 - 4 thermocouples

- Flexible Section II:**
 - 30 strain gauges
 - 4 LVDT's
 - 6 thermocouples

The overall instrumentation plan includes: 60 strain gauges, 8 LVDT's, and 10 thermocouples. The output from all the strain gauges and LVDT's will be collected under each of the 864 test variables combinations using An Advantec Model PCA6147 digital data acquisition system. One 64 channel Metrabyte single ended input cards with high gain will be used to condition the signals and sample the data channels (analog-to-digital conversion). The Advantec computer has a maximum aggregate sample rate of 100,000 samples per second. This will allow an individual gauge to be sampled at a rate of 781 samples per second which is sufficient to capture a peak as narrow as 4 msec. The termocouples will be sampled manually every 30 minutes during testing using a hand-held temperature readout device (Omega Model HH21).

The location of the applied load with respect to the edge of the pavement and the location of the instruments has a significant impact on the measured pavement response. The test vehicle to be used in the field test program will be instrumented with a lateral and longitudinal positioning system. The system will consist of an antenna installed on the front bumper of the test vehicle and a 14-gauge wire placed down the middle of the test sections. Tape will secure the 14-gauge wire to the road surface. The output of the antenna with respect to the reference wire on the pavement surface will allow for lateral location of the truck with respect to the pavement edge and instrumentation to within ± 13 mm (0.5"). NATC has used this approach in several other tire studies, and it has proven to be highly reliable.

The test vehicle proposed to be used in the field test program consists of a tractor-trailer combination. NATC owns the tractor, while the trailer will be leased for this project. The tractor will have a tandem drive axle, while the trailer will have a tridem axle configuration. The field test program will collect and analyze the pavement response data under the trailer axles. The three types of axle configurations will be achieved as follows.

1. For the tridem configuration, use all three axles on the trailer.
2. For the tandem axle configuration, the tires will be removed from the tag axle of the tridem and the payload adjusted accordingly.
3. For the single axle configuration, the tires will be removed from the front two axles and the payload will be adjusted accordingly.

Data Analysis

Once the experiment is conducted, The data collected from the field test program will

be used in the following two approaches.

- I. The collected data will be used to estimate pavement damage associated with the use of single-tire configurations compared with that of conventional dual-tire configurations for the specific tire types, pavement types, axle types and environmental conditions included in the experiment. The relative damage will be estimated by using the pavement responses collected in this experiment in the selected pavement performance models. Fatigue damage will be estimated through the measured tensile strains and in situ properties of the AC layer. Permanent deformation (rutting) damage will be estimated through the measured pavement vertical deflections at various depths (using the MDD's data) and the vertical compressive strain on top of subgrade.
- II. The collected pavement response data will also be used to validate a comprehensive analytical model for flexible pavements. The comprehensive analytical model will include a dynamic load model which can predict the response of flexible pavements under dynamic loads generated by the various combinations of axle configurations, vehicle speed, tire configurations, and tire inflation pressure. The validated comprehensive analytical model will then be used to estimate pavement damage associated with the use of the single tire configuration for conditions that are beyond the ones controlled in the field test program.

As a result of these efforts, a validated comprehensive analytical model will be available for flexible pavements. With this model, the pavement damage associated with the use of single tire configurations compared with that of conventional dual tire configurations will be estimated

for conditions beyond the ones controlled in the field test program.

The proposed approach by which the pavement damage caused by single tires is compared with that of dual tires is referred to as the tire equivalency factor (TEF) and is defined as follows.

$$FTEFSS (L,S,A) = \frac{\text{Fatigue life under dual tire}}{\text{Fatigue life under super-single tire}}$$

$$FTEFSO (L,S,A) = \frac{\text{Fatigue life under dual tire}}{\text{Fatigue life under singled-out tire}} \quad \text{life under}$$

Where:

- FTEFSS= Fatigue tire equivalency factor for super-single tire
- FTEFSO= Fatigue tire equivalency factor for singled-out tire
- L = Axle load level
- S = Vehicle speed level
- A = Axle configuration (single, tandem, tridem)

$$RTEFSS (L,S,A) = \frac{\text{Rutting life under dual tire}}{\text{Rutting life under super-single tire}}$$

$$RTEFSO (L,S,A) = \frac{\text{Rutting life under dual tire}}{\text{Rutting life under singled-out tire}}$$

Where:

- RTEFSS = Rutting tire equivalency factor for super-single tires
- RTEFSO = Rutting tire equivalency factor for singled-out tires

The following example describes the proposed TEF approach.

Pavement type: Flexible

Pavement Structure:	AC 102 mm (4") CAB 152 mm (6")
Axle Configuration:	single
Axle Load:	98 kN (22,000 lbs.)
Vehicle Speed:	80 km/h (50 mph)
Tire Inflation Pressure:	690 kpa (100 psi) for both dual & single tires
Materials Properties:	medium strength pavement AC- $M_r = 1,380 \text{ Mpa}(200,000 \text{ psi})$ CAB- $M_r = 207 \text{ Mpa} (30,000 \text{ psi})$ SG- $M_r = 104 \text{ Mpa} (15,000 \text{ psi})$

Let us assume that using the data above in the comprehensive model for flexible pavement would generate the following data.

Tensile strain at the bottom of AC under dual tire configuration	=	460 microns
Tensile strain at the bottom of AC under single tire configuration	=	530 microns
Fatigue life under dual tires	=	1,620,000 ESALs
Fatigue life under single tires	=	1,040,000 ESALs

The fatigue tire equivalency factor for super-single tires is:

$$FTEFSS = \frac{1,670,000}{1,040,000} = 1.6$$

The sample calculation above indicates that, under these conditions of pavement structure, materials, axle type, and load level, the super-single tire causes 60% more pavement damage than the dual tire.

Dynamic Load Model

Based on the review of the ideal analytical procedure (described in Chapter 4) and the pavement response models that were used in the previous studies to evaluate flexible pavement damage caused by single tires as compared to dual tires, it was concluded that the recommended pavement response model should have the following capabilities:

- Simulates the dynamic nature of traffic loads,
- Incorporates the nonuniform tire print pressure distributions, and
- Predicts the dynamic response of the pavement structure.

The dynamic nature of traffic loads are influenced by axle load, gross vehicle weight, speed, pavement roughness, and axle suspension; axle load having the greatest impact on pavement deterioration. Speed and road roughness interact to increase the dynamic wheel loadings. These interactions necessitates that different levels of load, speed, and axle configurations be evaluated for each tire type and tire inflation pressure setting.

The tire-pavement interaction mechanism controls the way in which traffic loads transfer

to the pavement surface and, therefore, to the entire pavement structure. The tire inflation pressure and the tire structure are the two most important factors that influence the contact area and contact pressure at the tire-pavement interface for a given load magnitude. Most pavement analysis procedures assume a circular contact area with uniformly distributed pressure equals to the tire inflation pressure. However, several field and laboratory studies have contradicted these assumptions.

The Goodyear Tire and Rubber Company has conducted a laboratory experiment to measure the contact area and stress distributions under various types of truck tires (24). Researchers measured the contact area by inking the tread area of the inflated tire mounted on a special machine that loads it to a preset value. An imprint was left on a piece of paper between the tire and the machine's loading plate. The areas within the imprints were calculated by computer using digitized boundary points as input. Table 48 shows a typical data set of the contact area measurements for a super-single tire. It can be seen from this data that the shape of the contact area changes as a function of tire load and inflation pressure. In general, the width of the contact area remains relatively constant while its length increases as the load increases. At a constant load level, the length of the contact area decreases as the inflation pressure increases. In the case of the super-single tire, the width of the contact measures almost 1½ times its length. One thing these measurements make clear is that the assumption of a circular contact area is not valid.

The Goodyear study also measured the stress distribution within the contact area. A specially instrumented flatbed measured the contact pressures. A strain gauge located in the flatbed provided the contact stresses exerted by the loaded tire. This bed had the capability of

Table 48. Footprint data for the 425/65R22.5 single tire.

Load (lbs)	Tire Pressure (psi)	Length (in)	Width (in)	Gross Area (in ²)	Net Area (in ²)
4500	90	7.30	11.05	71.1	48.0
	105	7.05	10.90	67.7	46.6
	120	6.65	10.70	62.9	42.0
7000	90	9.00	12.65	102.2	74.0
	105	8.60	12.40	92.2	65.2
	120	8.30	11.95	87.6	60.9
8500	100	9.60	12.65	111.3	80.8
	115	9.25	12.70	103.5	75.7
	130	8.85	12.60	97.3	69.5
11000	115	10.60	12.80	124.5	93.9
	130	10.10	12.70	116.9	87.1
	145	9.60	12.60	109.8	78.5

moving with the tire as it rotated at a slow speed. Numerous points across the tire tread were tracked as they went through the length of contact to obtain an overall pressure profile. Figure 20 shows a typical stress distribution for a super-single tire. These data show that a nonuniform pressure distribution exists at the tire-pavement interface.

Researchers at the Road and Transport Technology Center in South Africa have recently developed a Vehicle-Road Surface Pressure Transducer Array (VRSPTA) system to measure tire print pressure distribution under a moving wheel load (25). The system consists of an array of strain-gauged load cell pins embedded into the pavement surface. The unique feature of this system is its ability to measure the vertical and horizontal pressures within the tire contact area. Figure 21 shows typical measurements from the South African system.

The horizontal pressures within the tire contact area have a significant impact near the surface of a flexible pavement. As recommended by the SHRP A-003 project, the rutting of flexible pavements relates directly to the maximum shear strain within the AC layer (26). Siddharthan et al. (27) evaluated the impact of horizontal pressures at the tire-pavement interface on the shear strain within the AC layer. Figure 22 shows that, as either the rough surface texture or a geometric incline generates the horizontal interface stresses, the maximum shear strain within the AC layer significantly increases.

All previous and current data indicate that the tire contact area is noncircular and that the tire print pressure distribution is nonuniform and exceeds the tire inflation pressure. Therefore, it is highly critical that the pavement response model can handle a noncircular contact area, a nonuniform pressure distribution, and horizontal pressures. Recently, the South African Device (VRSPTA) was evaluated by members of the research team under a FHWA sponsored research

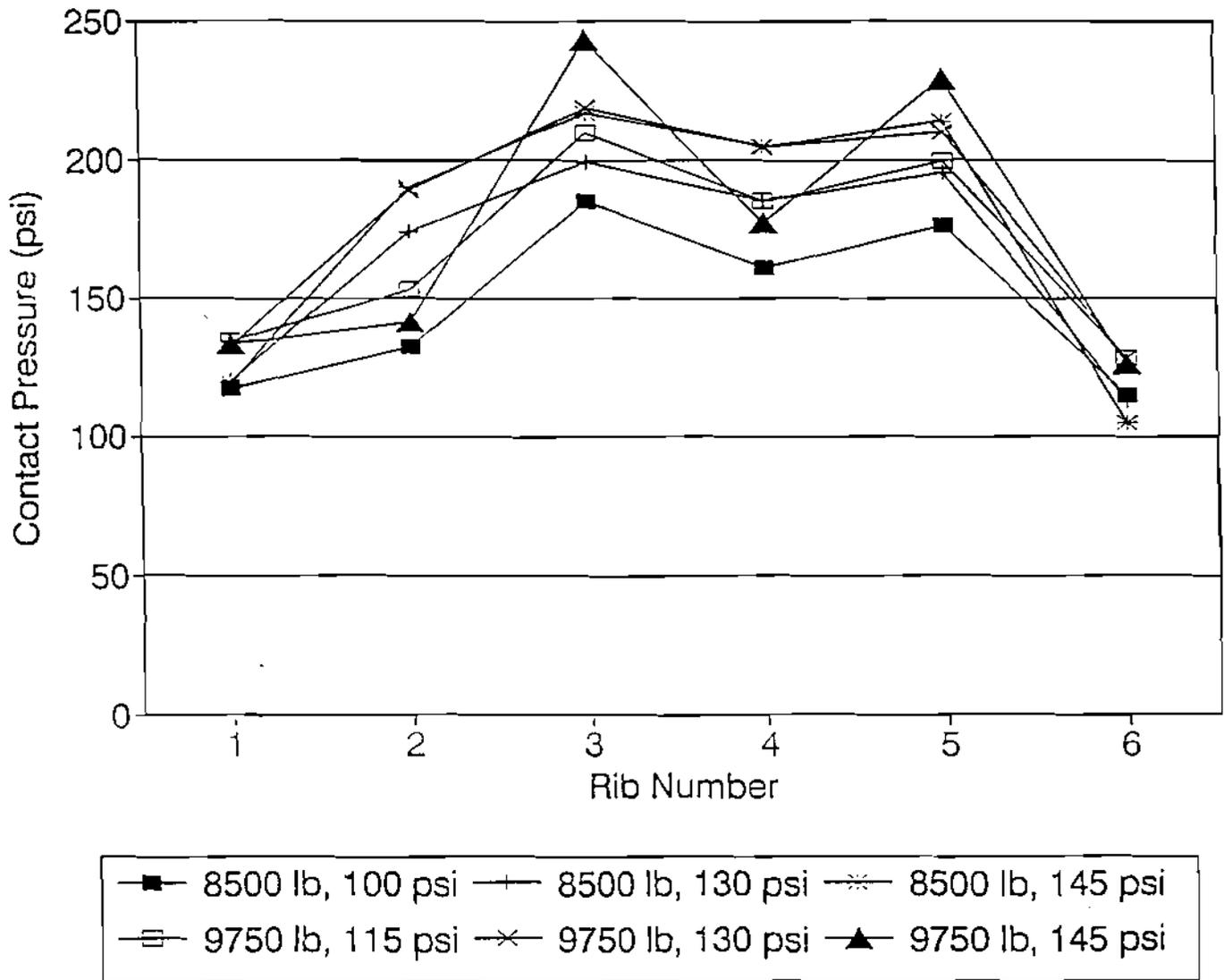


Figure 20. Contact stress distribution for the 425/65R22.5 single tire, 8500 and 9750 lb/tire load.

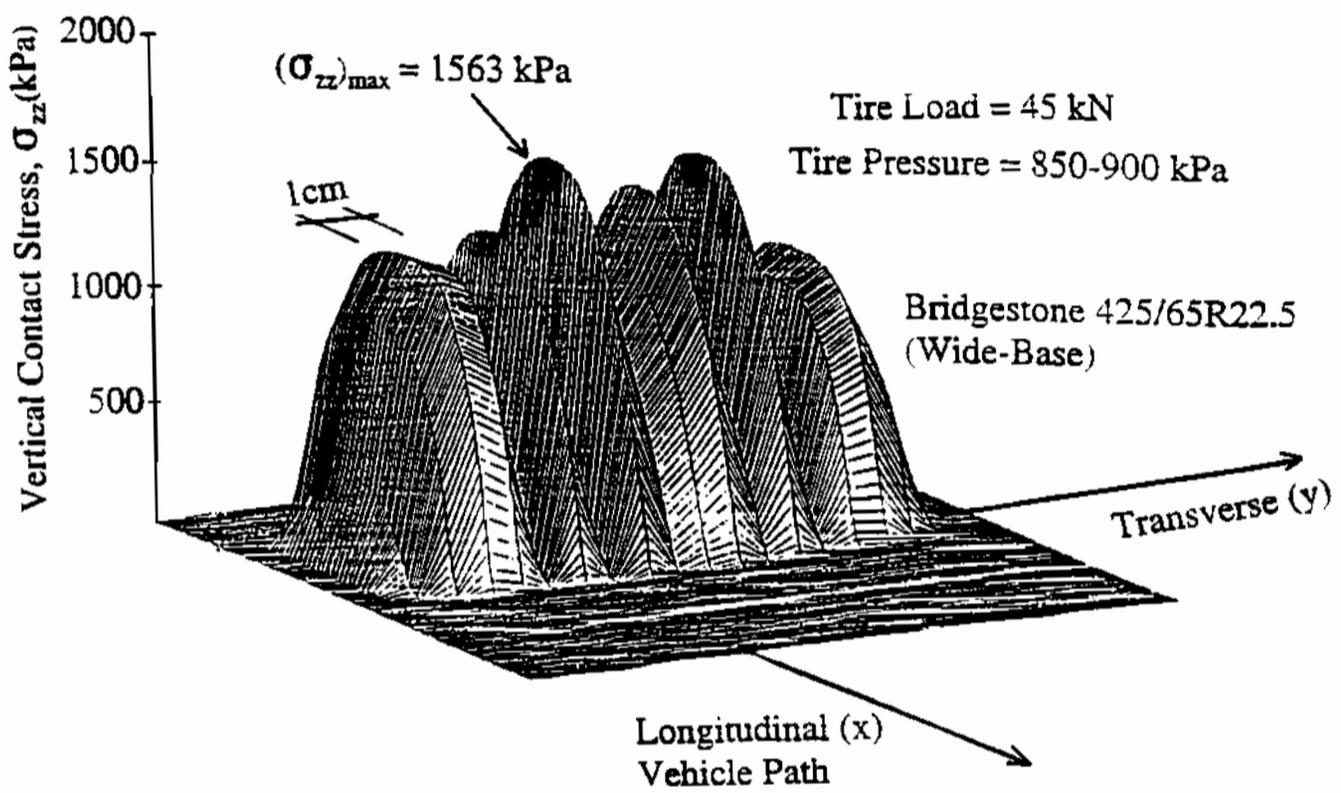


Figure 21. Vertical pressure distribution at the tire/pavement interface measured by the VRSPTA device.

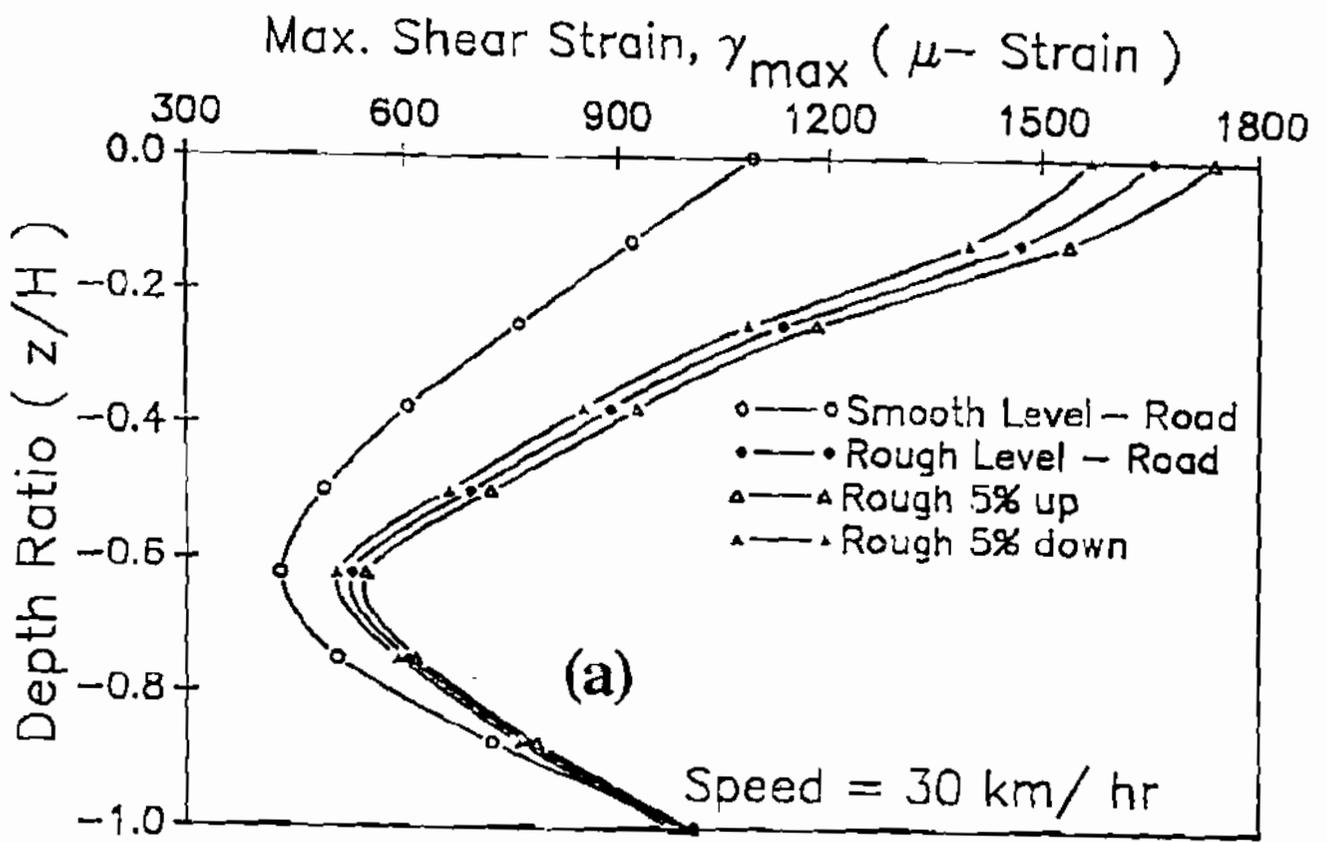


Figure 22. Distribution of maximum shear strain in the AC layer at speed of 30 km/h.

project (28). The VRSPTA device was used to measure the stress distribution at the tire/pavement interface under various levels of axle load and tire inflation pressure. With the appropriate approval from the FHWA's COTR, the measured stress distributions can be directly used in the Phase II of this research. It should be noted that the tires evaluated in the FHWA project are the same ones recommended in the test plan for this project.

It is common knowledge that the loads generate by the moving traffic are highly dynamic. The previous sections have also emphasized this fact and showed the various factors that influence the magnitude of these dynamic loads. Several field studies have shown that dynamic loads generate pavement responses which are significantly influenced by vehicle speed. Figure 23 shows the influence of truck speed on the measured surface deflections of flexible pavements at the AASHO Road Test (29). The AASHO Road Test data showed that an increase from creep speed to 48 Kph (30 mph) would reduce the surface deflection by fifty percent.

Sebaaly et al. Measured the impact of vehicle speed on the tensile strain at the bottom of the AC layer at the Penn State Test Track as part of an FHWA research project (30). Figure 24 summarizes the impact of vehicle speed on the measured tensile strains under single and tandem axles. The data in Figure 24 shows that vehicle speed has a significant impact on the measured tensile strain at the bottom of the AC layer, especially under the intermediate and full load levels for both single and tandem axles. By varying the vehicle speed from 32 to 80 km/h (20 to 50 mph), the measured strains under the intermediate and fully loaded axles decreased by 50 percent. By looking at the fatigue life-strain relationships discussed earlier, it can be seen that a 50 percent reduction in the strain can significantly increase the predicted fatigue life. Therefore, vehicle speed will play a major role in the damage caused by super-single and

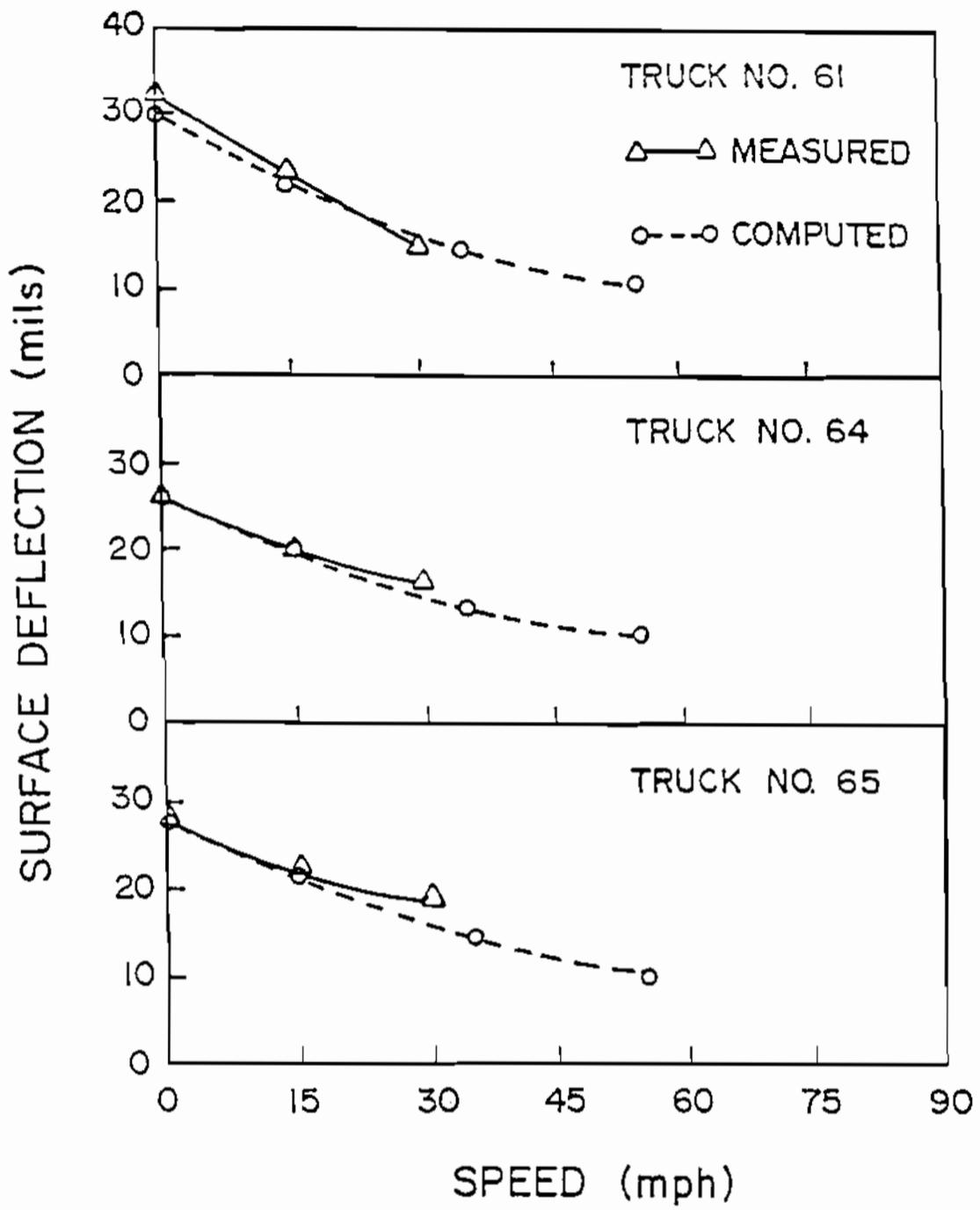


Figure 23. Measured and computed surface deflections under various speed at the AASHTO Road Test.

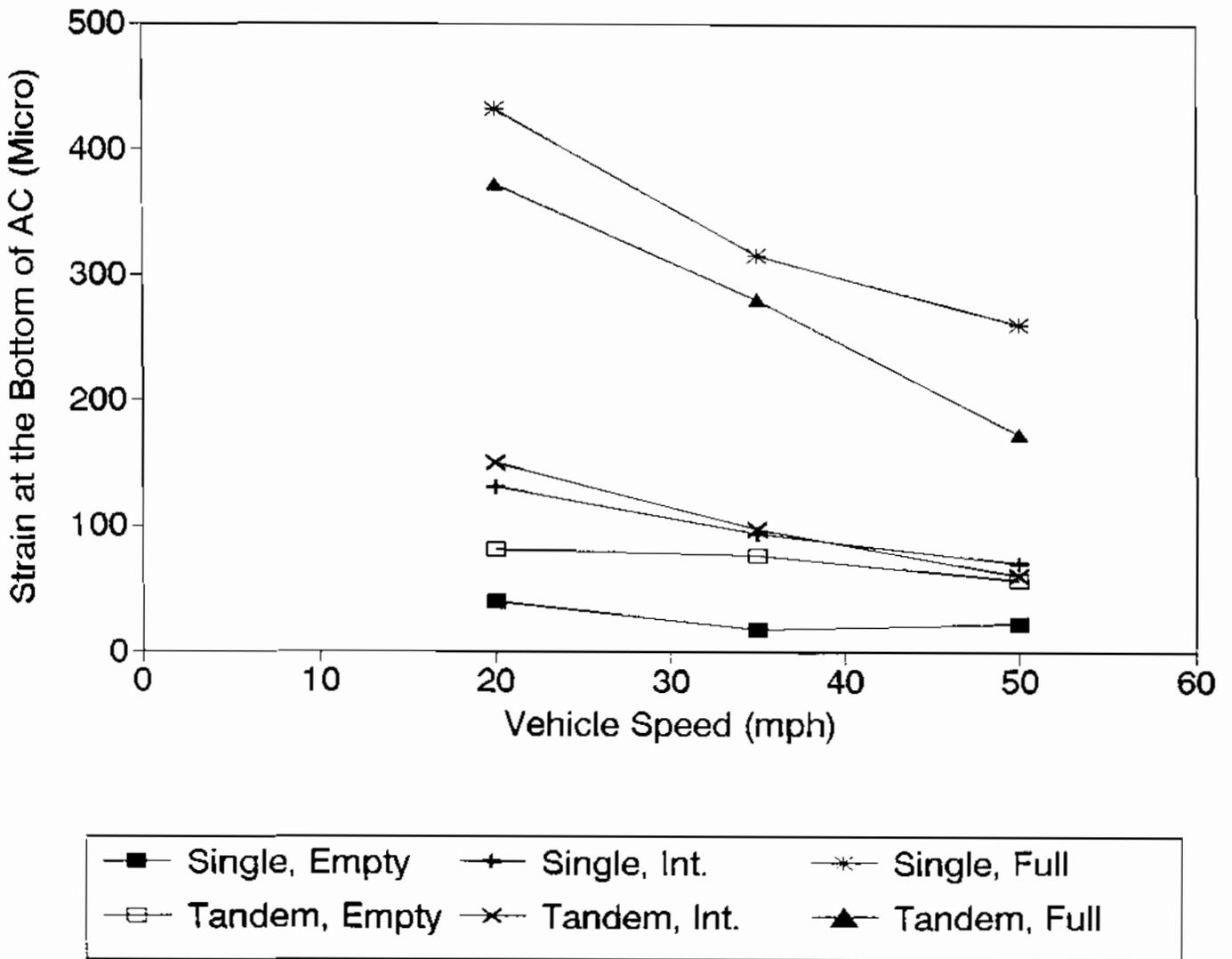


Figure 24. Effect of vehicle speed on the measured tensile strain at the bottom of AC layer.

Cement Treated Base: 100 150 200 mm
Granular Subbase : 100 150 200 mm

- Axle Configuration: Single Tandem and Tridem
- Vehicle Speed: 25, 50, 80, and 105 km/h
- Tire Inflation Pressures: Manufacturer recommended +/- 20%
- Materials Factors: Materials properties will be selected to represent weak, medium, and strong pavement structures. The type of material properties will depend on the selected pavement response model.

Once the above sensitivity analysis is conducted, the significant factors will be identified and the final analysis will be conducted using more refined levels of the critical factors.

Approaches to Control Single Tires Damage

It is anticipated that the sensitivity analysis conducted would indicate that the relative damage of single-tire configurations versus dual tire configurations is a function of the following critical factors:

1. axle load
2. tire pressure
3. thickness of structural section
4. stiffness of structural layers
 - a. material types used for subgrade, subbase, base and surface course
 - b. temperature of pavement layers
 - 1). frozen subgrade, subbase, base
 - 2). loss of stiffness of HMA at high temperatures
 - c. moisture content of pavement layers
5. joint design and load transfer across joints
6. axle configuration

This task will identify the various combinations of the above critical factors which must

be considered. A TEF for fatigue and a TEF for rutting will be evaluated for each combination of critical factors. The levels of the critical factors will be selected to represent the widest ranges possible. The research team recognizes that at least six distinct climatic zones exist in the U.S. as defined by the *AASHTO Design Guide*. These climatic zones will impact the selection of materials properties for the weak, medium, and strong pavement structures. Therefore, the database will be divided along the boundaries of the AASHTO recommended climatic zones and each zone will have its own set of TEF's. The database will include different combinations of pavement structures, i.e. pavements with and without subbases and different layers thicknesses. In the case of traffic conditions, the selection of a wide range of axle load configurations, i.e., single, tandem, and tridem, and axle load levels will ensure the applicability of the database to a wide range of road facilities.

The information in the TEF database will be analyzed to identify the various scenarios by which the pavement damage resulting from the use of single tires can be controlled. This analysis will be conducted on the following premise:

For a given pavement section located in a given climatic zone, identify the most effective way(s) to control or reduce the pavement damage resulting from the single tire use. The following suggestions or a combination of these could result.

- Recommend a better AC material to resist the added damage.
- Use thicker structural sections to resist the added damage.
- Allow single tires above a certain speed level.
- Allow single tires below a certain level of axle load.

For example, on a flexible pavement located in the wet freeze-thaw cycling zone, the TEF database showed the following:

TEF at 80 km/h = 1.02

TEF at 24 km/h = 2.00

Therefore, one of the scenarios will be to allow single tires only where the higher speed can be maintained.

THE ALTERNATIVE EVALUATION PLAN

This evaluation plan is being recommended as an alternative to the pavement-response plan that was recommended above. The objective of this alternative plan is the combine actual pavement performance with theoretical analyses to evaluate the flexible pavement damage caused by single tires as compared to dual tires. The following is a description of the major elements of the alternative plan:

- Collect field performance measurement on the Westrack pavement testing facility. The Westrack Pavement testing facility has an inside lane which has not been loaded as part of the current FHWA research project. This inside lane is a mirror image of the test lane having twenty-six sections of HMA mixtures with different volumetric properties. Table 49 summarizes the properties of the twenty-six sections and Figure 25 shows their locations. The Westrack pavement testing facility will be loaded with four tractor-trailer combination vehicles where each of the vehicles will be fitted with dual tires on one side of the axle and with super-single or singled-out tires on the other side of the axle.

Table 49. Properties of the Westrack test sections.

Section	Gradation	Mix Designation	Target %AC	Target %AV
01	Fine	MM1	M	M
02		LM	L	M
03		LH1	L	H
04		ML	M	L
14		HM	H	M
15		MM2	M	M
16		LH2	L	H
17		MH	M	H
18		HL	H	L
19		Fine Plus	MM1	M
20	MH		M	H
21	HL1		H	L
22	LM		L	M
09	HL2		H	L
10	LH		L	H
11	MM2		M	M
12	ML		M	L
13	HM		H	M
05	Coarse	MM1	M	M
06		MH	M	H
07		HM	H	M
08		LM	L	M
23		ML	M	L
24		MM2	M	M
25		HL	H	L
26		LH	L	H

L = Low, M = Medium, H = High

proposed location
of test sections

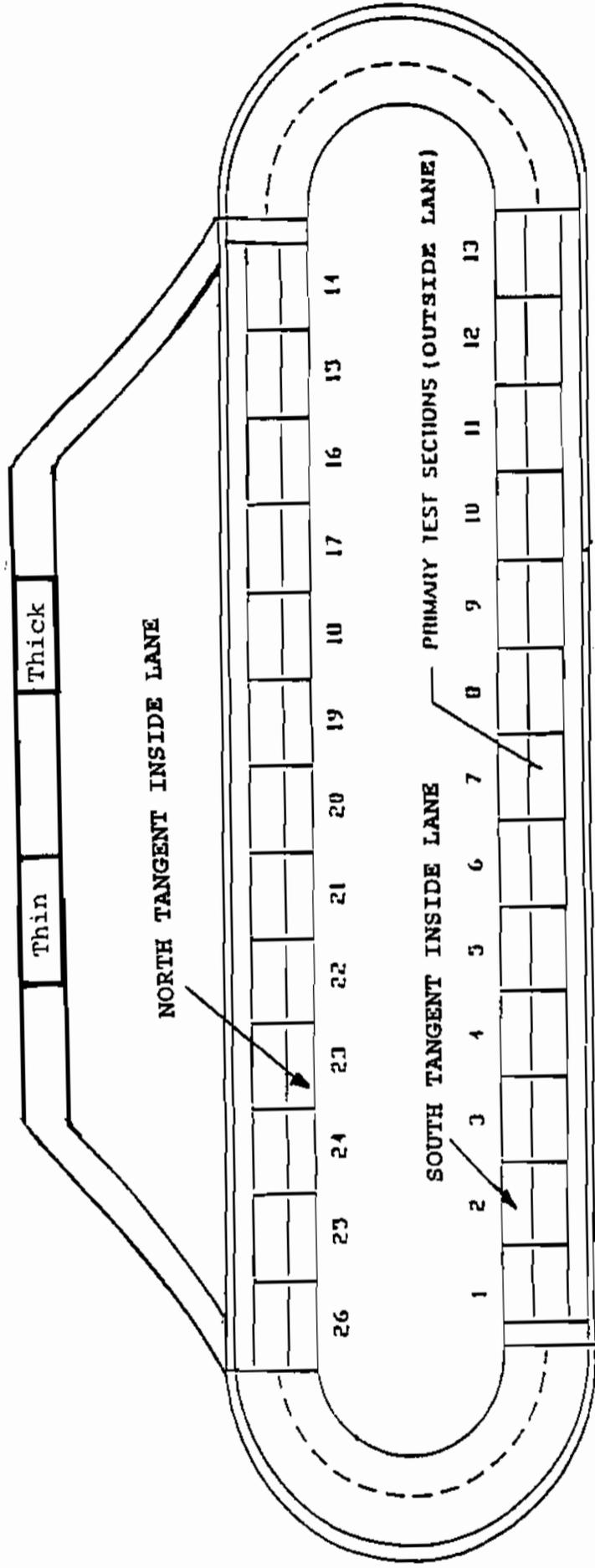


Figure 25. Location of north and south tangents and inner lane sections proposed for the test program.

During the first part of the field testing, the sections located on the south tangent (sections 1-13, Figure 25) will be loaded with vehicles fitted with dual tires on one side and super-single tires on the other. Each single axle will be loaded with 89 KN (20,000 lb) which would provide a total of 360,000 ESALs for each month of loading. The location of the loads will be shifted to achieve equal load levels on both sides of the axles. The four vehicles will run on the inside lane while traveling on the south tangent and then shift onto the outside lane while traveling on the north tangent. The performance of the south tangent sections will be monitored for 2-3 month. It is anticipated that a 2-3 month of continuous loading during the hot summer will produce significant performance data. The relative damage of the super-single tire will be evaluated by comparing the performance of the wheel track on the south tangent loaded with dual tires with the one loaded with the super-single tire.

During the second part of the field testing, the sections located on the north tangent (sections 14-26, Figure 25) will be loaded with vehicles fitted with dual tires on one side and singled-out tires on the other. Each single axle will be loaded with 89 KN (20,000 lb) which would provide a total of 360,000 ESALs for each month of loading. The location of the loads will be shifted to achieve equal load levels on both sides of the axles. The four vehicles will run on the inside lane while traveling on the north tangent and then shift onto the outside lane while traveling on the south tangent. The performance of the north tangent sections will be monitored for 2-3 month. It is anticipated that a 2-3 month of continuous loading during the hot summer will produce

significant performance data. The relative damage of the singled-out tire will be evaluated by comparing the performance of the wheel track on the north tangent loaded with dual tires with the one loaded with the singled-out tire.

- Retrofit instrumentation into one pavement section on the south tangent and one section on the north tangent. The retrofitted instrumentation will include: 1) a multi-depth deflectometer (MDD), 2) strain gauges at the bottom of the AC layer, and 3) thermocouples throughout the depth of the AC layer. Collect pavement response data from the instrumented sections during the performance testing of both tangents. The collected pavement response data will be used to validate the pavement dynamic load model described under the Main Evaluation Plan described earlier.
- Use the collected pavement performance data to evaluate the relative damage of single tires as compared to dual tires for the axle type and load level that were included in the experiment, i.e. single axle with 89 KN (20,000 lb) load under a single speed of 64 km/h (40 mph) and one tire inflation pressure.
- Use the collected pavement performance data to validate rutting and fatigue performance models. The validated performance models will then be used with the validated dynamic load model to expand the evaluation into the conditions described earlier under the sections entitled: "*Field Test Program.*"

- Use the validated pavement performance models and pavement response model to conduct the *Sensitivity Analysis* and to develop *Approaches to Control Single Tires Damage* as described under the main evaluation plan.

Advantages and Disadvantages

The above described alternative evaluation plan has some advantages and some disadvantages. Its advantages can be summarized as follow:

1. It provides actual pavement performance data on several pavement test sections.
2. It provides actual pavement performance data to validate rutting and fatigue performance models to be used in the expanded analyses.
3. It allows one-to-one comparison of single tires with dual tires under highway speed.

Its disadvantages can be summarized as follows:

1. The application of 360,000 ESALs per month on a single lane using four trucks following each other at short distances does represent an accelerated mode of loading which may not represent actual field conditions.
2. The collected performance data will be limited to just single axle with one level of load, inflation pressure, and vehicle speed. Eventhough the validated model will still be used to expand the study to other levels.
3. The field performance experiment will have to be conducted during the summers of 1998 and 1999 which will require changing the end date of the project beyond the current end date of July 1999.
4. Additional funds will be required to complete the proposed field performance plan.

COMPARISON OF THE MAIN AND ALTERNATIVE PLANS

As can be seen from the above recommendation, the main and alternative evaluation plans have different approaches. The following paragraphs compare the concept of each one and summarize the corresponding deliverables.

The concept of the main evaluation plan is based on the fact that pavement responses can be effectively used to evaluate the relative pavement damage caused by single tires as compared with dual tires. This concept is strongly supported by the findings of the ALF experiment and the comparison of the ALF data with several response type studies. The deliverables of the main evaluation plan can be summarized as follow:

1. A database of relative pavement damages caused by single tires verified by pavement responses under a wide range of pavement structure, axle type, axle load, tire type, tire inflation pressure, vehicle speed, and environmental conditions.
2. An analytical procedure validated using pavement responses under a wide range of pavement structure, axle type, axle load, tire type, tire inflation pressure, vehicle speed, and environmental conditions.
3. A software package which can be used to evaluate the relative damage of single tires on flexible pavements for cases that are not covered by the developed database.

The concept of the alternative evaluation plan is based on the fact that pavement performance should be used to evaluate the relative pavement damage caused by single tires as compared with dual tires. The deliverables of the alternative evaluation plan can be

summarized as follow:

1. A database of relative pavement damages caused by single tires on twenty-six sections of the Westrack pavement Testing Facility. The database is limited to single axle with 89 KN (20,000 lb) load under 64 km/h (40 mph) vehicle speed.
2. An analytical procedure validated using pavement responses and performance under a limited combination axle type, tire type, inflation pressure, and environmental conditions.
3. A database of relative pavement damages caused by single tires as compared with dual tires developed using the analytical procedure that was validated in step 2.

BUDGET AND TIME REQUIREMENTS

Table 50 summarizes the task-by-task budget for the Main Evaluation Plan while Table 51 summarizes the task-by-task budget for the Alternative Evaluation Plan.

The Main Evaluation Plan will have the following requirements:

Phase I Expenditures:	\$ 62,500.00
Phase II Expenditures:	\$ 337,500.00
Total Budget:	\$ 400,000.00
Additional Funds Needed:	\$ 0.00
Completion Date:	July 31, 1999

The Alternative Evaluation Plan will have the following requirements:

Phase I Expenditures:	\$ 62,500.00
Phase II Expenditures:	\$ 411,412.00
Total Budget:	\$ 473,912.00
Additional Funds Needed:	\$ 73,913.00
Completion Date:	July 31, 2000

Table 50. Budget for the Main Evaluation Plan.

Category/Name	Role in Study	% Time	Hr. Rate	Task 6		Task 7		Task 8		Total Hours	Total Cost (\$)
				Hrs.	\$	Hrs.	\$	Hrs	\$		
University of Nevada											
A. Salaries											
P.E. Sebaaly	PI	20	48.48	562	27,146	479	23,222	100	4,848	1,141	55,316
J. A. Epps	Research Eng.	10	73.28	81	5,936	292	21,398	50	3,664	423	30,998
R. Siddharthan	Research Eng.	8	51.60	34	1,754	288	14,861	30	1,548	352	18,163
Grad. Student	Research Asst.	20	11.25	122	1,373	688	7,740	50	563	860	9,676
Secretary		5	12	0	0	0	0	165	1,980	165	1,980
Total of Salaries				799	36,309	1,747	67,221	395	12,603	2,941	116,133
B. Fringe Benefit					1,065		1,877		1,002		3,944
C. Operating					14,921		488		529		15,938
D. Travel					1,600						1,600
Subtotal for UNR					53,895		69,586		14,134		137,615
UNR OVERHEAD											
A. 44.3% 1st \$25,000 of NATC Subcontract					11,075						11,075
B. 44.3% UNR Subtotal					23,875		30,826		6,261		60,962
Total UNR Overhead					34,950		30,826		6,261		72,037
Total for UNR					88,845		100,412		20,395		209,652

Category/Name	Role in Study	% Time	Hr. Rate (\$)	Task 6		Task 7		Task 8		Total Hours	Total Cost (\$)
				Hrs	\$	Hrs	\$	Hrs	\$		
Nevada Auto. Test Center											
A. Salaries											
C. Ashmore	Research Eng.	8	32.49	260	8,448	100	3,249	80	2,599	440	14,296
J. Keany	Comput. Spec.	1	38.86	100	3,886					100	3,886
D. White	Vehicle Tech.	4	14.83	240	3,559					240	3,559
E. Brown	Vehicle Oper.	10	8.92	560	4,995					560	4,995
G. Works	Inst. Tech.	2	10.74	80	860	30	322	40	430	150	1,612
Secretary		3	8.11	290	2,356					290	2,356
Direct Labor					24,104		3,571		3,029		30,704
Labor Escalation (1.5%)					362		54		45		461
Total Labor Cost (TLC)					24,462		3,625		3,074		31,161
B. Fringe Benefit (46% TLC)					11,253		1,668		1,414		14,335
C. Overhead 20% (TLC+B)					7,143		1,059		898		9,100
D. Facilities Cap. Cost of Money 5.5% (TLC+B)					1,964		291		247		2,502
E. Operating					33,460						33,460
F. Test Section Construct.					20,000						20,000
G. Fee 7% (TLC+B+C+E+F)					6,742		445		377		7,564
H. General and Admin Cost 9% (TLC+B+C+E+F)					8,669		572		485		9,726
Total for NATC					113,693		7,660		6,495		127,848
GRAND TOTAL (UNR + NATC)					\$ 202,538		\$108,072		\$ 26,890		\$ 337,500

Table 51. Budget for the Alternative Evaluation Plan.

Category/Name	Role in Study	% Time	Hr. Rat(\$)	Task 6		Task 7		Task 8		Total Hours	Total Cost (\$)
				Hrs.	\$	Hrs.	\$	Hrs	\$		
University of Nevada											
A. Salaries											
P.E. Sebaaly	PI	20	48.48	350	16,968	400	19,392	100	4,848	850	41,208
J. A. Epps	Research Eng.	10	73.28	40	2,931	120	8,794	50	3,664	210	15,389
R. Siddharthan	Research Eng.	8	51.60	50	2,580	150	7,740	30	1,548	230	11,868
Grad. Student	Research Asst.	20	11.25	700	7,875	400	4,500	50	563	1150	12,938
Secretary		5	12	0	0	0	0	165	1,980	165	1,980
Total of Salaries				724	30,354	1,070	40,426	395	12,603	2,605	83,383
B. Fringe Benefit					769		1,132		1,002		2,903
C. Operating					1,000		500		529		2,029
D. Travel					2,000						2,000
Subtotal for UNR					34,123		42,058		14,134		90,315
UNR OVERHEAD											
A. 44.3% 1st \$25,000 of NATC Subcontract					11,075						11,075
B. 44.3% UNR Subtotal					15,117		18,632		6,261		40,010
Total UNR Overhead					26,192		18,632		6,261		51,085
Total for UNR					60,315		60,690		20,395		141,400

Category/Name	Role in Study	% Time	Hr. Rate (\$)	Task 6		Task 7		Task 8		Total Hours	Total Cost (\$)
				Hrs	\$	Hrs	\$	Hrs	\$		
Nevada Auto. Test Center											
A. Salaries											
C. Ashmore	Research Eng.	8	32.49	600	19,494	30	975	100	3,249	730	23,718
J. Keany	Comput. Spec.	1	38.86	100	3,886					100	3,886
D. White	Vehicle Tech.	4	14.83	1000	14,830					1000	14,830
E. Brown	Vehicle Oper.	10	8.92	1000	8,920					1000	8,920
G. Works	Inst. Tech.	2	10.74	40	430					40	430
Secretary		3	8.11	100	811					100	811
Direct Labor					48,371	975	3,249				
Labor Escalation (1.5%)					726	15	49				
Total Labor Cost (TLC)					49,097	990	3,298				
B. Fringe Benefit (46% TLC)					22,585	455	1,517				
C. Overhead 20% (TLC+B)					14,336	289	963				
D. Facilities Cap. Cost of Money 5.5%(TLC+B)					3,943	79	265				
E. Operating					135,000						
F. Test Section Construct.					0						
G. Fee 7%(TLC+B+C+E+F)					15,747	121	405				
H. General and Admin Cost 9%(TLC+B+C+E+F)					20,246	156	520				
Total for NATC					260,954	2,090	6,968				
GRAND TOTAL (UNR+NATC)					\$ 321,269		\$ 62,780		\$ 27,363		\$ 411,412

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V REUNIÓN ORDINARIA DE LA COMISIÓN TÉCNICA DEL SUBGRUPO DE TRABAJO N°5 “TRANSPORTE” DEL MERCOSUR



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Habilitación de vehículos simples de tipo ómnibus, camión, tractor o remolque de 4 ejes en dos grupos de ejes

- La separación entre los ejes constituyentes de un mismo grupo deberá ser mayor a 1,20 metros y menor a 2,40 metros Y EL sistema de suspensión DEBERÁ asegurar una distribución ADECUADA del peso entre los ejes constituyentes.
- La distancia mínima entre ejes extremos de los vehículos deberá ser mayor o igual a 6,25 metros.
- Los pesos brutos totales de cada grupo de ejes deberá respetar lo indicado en la resolución gmc n° 65/08 (CON LA MODIFICACIÓN PROPUESTA)
- El peso bruto total máximo de los vehículos no podrá



MUCHAS GRACIAS



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