Truck Tire Characteristics and Asphalt Concrete Pavement Rutting

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Increased truck tire inflation pressures have been perceived as a major contributor to premature wheelpath rutting of asphalt concrete (AC) pavements. Consequently, a critical evaluation was conducted of available information pertaining to heavy-vehicle tire inflation pressures and related characteristics as they influence AC pavement performance, particularly premature wheelpath rutting. However, the collection, review, and evaluation of literature and information extended into the larger subject area of vehicle-tire-pavement interaction A large number of documents plus personal interviews and discussions were reviewed to provide the basis for the critical evaluation. The essential findings are that (a) recent increases in truck tire inflation pressures are not the primary cause of premature AC pavement rutting, (b) high tire-pavement contact pressures can influence wheelpath rutting of AC surface courses, (c) improvements in AC mix design offer the best potential for minimizing wheelpath rutting, and (d) the wide variations in vehicle-tire configurations significantly influence AC pavement performance.

Increases in truck tire pressures over the past 20 years have been perceived by many in the highway industry as contributing to reduced pavement performance of America's highways, particularly premature wheelpath rutting of asphalt concrete (AC) surfaces. In 1985 AASHTO approved a resolution that, among other things, objected to the introduction of higher-pressure truck tires, and subsequently established the Task Force on High Pressure Truck Tires (*1*). On February 12 and 13, 1987, a workshop on high-pressure truck tires was conducted in Austin, Texas (*2*). At the workshop it was indicated that the tire pressure problem interacts with such other factors as vehicle design, wheel loads, pavement design, and quality of pavement construction. The consensus was that tire pressure is merely one component of the issue of larger truck sizes and weights. There is a more general need for an improved understanding of the basic vehicle-tire-pavement interaction. Many of the information needs concerning this interaction are being addressed by current and planned research in NCHRP, FHWA, and Strategic Highway Research Program (SHRP) activities. Consequently, an immediate need exists for a critical assessment of available research and experience to determine what information can be implemented and the existence of any remaining information gaps.

At the request of the AASHTO Joint Task Force on Pavements, an NCHRP project, Critical Assessment of Tire Pressure Research, was conducted with objectives being (a) to identify and critically evaluate previous and ongoing research pertaining to truck tire pressures and pavement performance, (b) to determine potential impacts of developments in the truck and tire industries on the subject, and (c) to identify information gaps and research needs.

PROBLEM SCOPE

All vehicle loads must be transmitted from the vehicle body through the suspension systems and tires to the pavement surface, where they are then distributed through the pavement structure to the subgrade soils. Determination of the unit loads expected to be applied to the pavement surface would be simple if the loads were static and the tires had no structural characteristics. However, such is not the case, and tire contact pressures are not uniform. The magnitude and significance of this contact pressure nonuniformity have not been absolutely documented and are discussed in detail in the following paragraphs.

A major concern of the highway community in recent years has been the occurrence of premature wheelpath rutting in AC pavements. Because of substantial evidence that operating tire pressures of heavy trucks have been increasing, the higher tire pressures have been perceived as contributing to pavement rutting. This perception has generated considerable research on documentation of actual operating tire pressures, influence of tire type on pressures, relationships between tire inflation pressures and tire-pavement contact pressures, and distribution of contact pressures within the contact area. Because pavement rutting can be controlled both by reducing tire-pavement contact pressures and by increasing resistance to the contact pressures through improved AC mix design, research and other developments have occurred in the mix design area.

In 1984 the Subcommittee on Materials of the Western Association of Highway and Transportation Officials (WASHTO) held a conference on asphalt pavement rutting because some agencies considered rutting one of their most pressing issues. After the conference, a report (*3*) was issued dealing primarily with the material and construction aspects of the problem. The report contained recommendations on mix design, construction procedures, selection of aggregates and asphalt materials, and the need for performance type specifications.

Many recommendations in the WASHTO report were incorporated into an FHWA Technical Advisory (*4*). This publication recognizes that implementation of available knowledge and experience in such areas as materials selection, mix design, plant operation, and construction procedures can pro-

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duce high-quality AC pavements that will minimize premature wheelpath rutting.

In 1987 the AASHTO Highway Subcommittee on Construction conducted a survey on the pavement rutting problem. Of 62 responses, 52 (84 percent) were of the opinion that rutting of AC pavements is a major (or significant) type of distress on their highway system, and 54 (93 percent) expressed the opinion that heavy-truck tire pressures was a major cause of rutting. Subsequently, the AASHTO Joint Task Force on Rutting was formed to follow up on the survey and its results. A report was submitted to the Standing Committee on Highways at the 1988 AASHTO meeting (*5*).

Although increased axle loads, traffic volumes, and tire pressures have contributed to the pavement rutting problem, the AASHTO joint task force believed that other factors within the control of highway agencies have contributed to the problem and that asphalt pavement rutting can be minimized when such pavements are properly designed, built, and maintained. Even in areas where rutting is not perceived as a serious problem, improved mix design and construction controls could reduce development of distress and increase pavement life (*5–9*).

TIRE TYPES AND PRESSURES

Until recent years, there appears to have been little interest and concern about the tire factor in the tire-pavement interaction system. Even with the increased research activity, this factor is the least understood and most controversial aspect of the problem. Some analytical studies (*10*) indicate that contact pressures can be as much as four times tire inflation pressures at localized spots in the contact area, but the actual existence and significance of such localized pressures on pavement performance have not been verified. The gross loads applied to tires, and tire selection and design in relation to those loads, influence contact pressure distribution. In an effort to control wheel loads in relation to tire type and size, 28 states currently regulate load per inch of tire width. Eighteen states limit the load to 600 lb/in. of width. The most significant concern to be resolved may be the determination of realistic tire contact pressures for pavement design purposes.

At the time of the AASHO road test, the primary tire type was bias ply with a cold inflation pressure of 75 psi. In the intervening 30 years the prevalent tire type has changed to radial-ply design, and increased axle loads have resulted in the selection of tires with recommended cold pressures of 85 to 105 psi. Actual field measurements of truck tire inflation pressures indicate an average of about 100 psi, but information on tire sizes and temperatures at the time of measurement is generally not available (*11–16*). Although the averages are about as expected, inflation pressures above the average—with highs up to 150 psi—were often recorded. The excessive tire pressures may also have been associated with gross wheel overloads. The heat generated during operation of the vehicle over the road results in a hot-tire inflation pressure of 5 to 15 psi above the cold-tire inflation pressure.

Most of the earlier studies of tire-pavement interaction were of the analytical type and involved various assumptions. AC pavement prediction models based on limiting tensile strain at the bottom of the AC layer were generally used. Rutting was often evaluated on the basis of compressive stresses at the base or subgrade surface. In some cases, tire-pavement contact pressure distribution within the contact area was estimated to have localized peaks of as much as four times the inflation pressure (*10*).

Recent research (*17*) has provided more realistic information on actual tire-pavement contact pressures under a variety of conditions. Carefully instrumented experimental studies by Goodyear Tire and Rubber Company (*18*) indicate that increasing inflation pressure at constant load shifts the point of maximum contact pressure to the center region of the contact area, whereas increasing tire load at constant inflation pressure shifts the point of maximum contact pressure toward the perimeter (see Figure 1). The Goodyear experimental work also showed that the maximum contact pressure levels for three tire types were about 1.5 to 2 times the inflation pressure (see Table 1).

Although several research reports have described analytical methods for evaluating the influence of tire type and tire

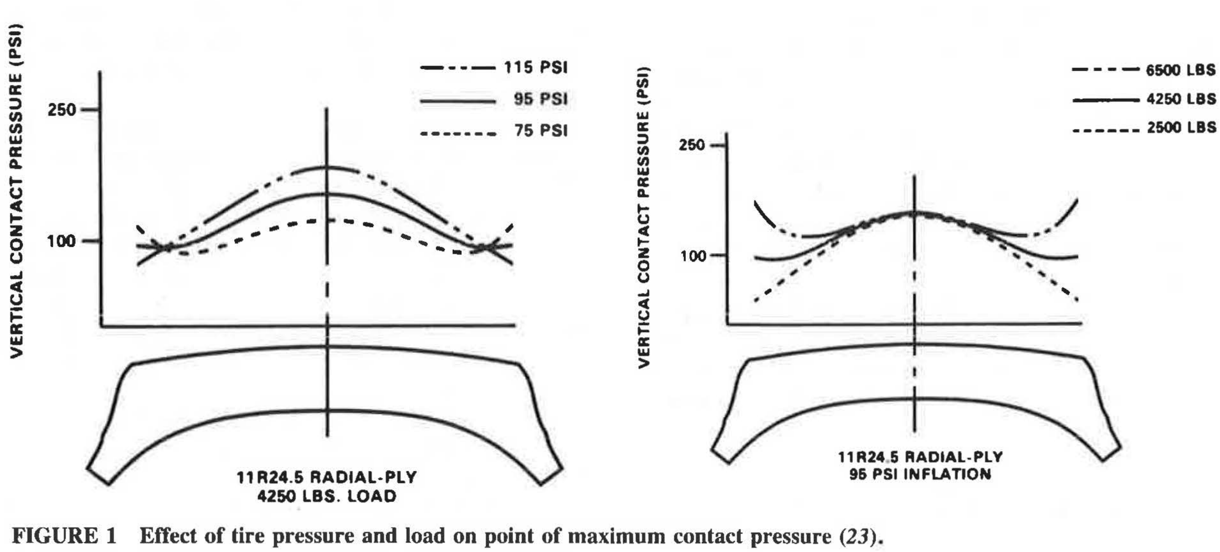

FIGURE 1 Effect of tire pressure and load on point of maximum contact pressure (*23*).

TABLE 1 RATIO OF MAXIMUM CONTACT PRESSURE TO INFLATION (*23*)

	INFLATION (psi)	MAXIMUM CONTACT PRESSURE (M.C.P.) (psi)	RATIO (M.C.P.) TO INFLATION
11-24.5	65	117	1.8
4250 lbs. LOAD	75	114	1.5
	95	118	1.2
11r24.5	75	122	1.6
4250 lbs. LOAD	95	152	1.6
	115	182	1.6
385/65R22.5	100	200	2.0
8500 lbs. LOAD	120	226	1.9
	140	252	1.8

inflation pressures on pavement performance, a study recently completed by FHWA (*19*) provides the most complete and documented analysis of relationships among wheel loads, tire types, and tire pressures on two AC pavements. The study was conducted at the full-scale pavement testing facility at the Turner-Fairbanks Highway Research Center in McLean, Virginia, using the Accelerated Loading Facility (ALF) testing machine. Loads were applied by one-half of a dual-tire, single-axle assembly and ranged from 9,400 to 22,500 lb. Bias- and radial-ply tires at cold inflation pressures of 76, 108, and 140 psi were used, making over 500,000 passes during the pavement performance evaluation. The effects of wheel load, tire type, and tire inflation pressure were evaluated in terms of measured responses (deflections and strains), pavement rutting and cracking, and changes in pavement materials after the traffic loading. Tire-pavement contact pressure distribution was not measured.

The project report (*19*) for this comprehensive research study includes much meaningful information. The following are of special significance:

- For the dual-tire wheel assembly loads, tire pressures, pavement sections, and climatic conditions studied, the effect of load was greater than that of tire pressure. The measured pavement responses doubled for an increase in load from 9,400 to 19,000 lb, whereas increasing the tire inflation pressure from 76 to 140 psi resulted in less than a 10 percent increase in measured response (see Figure 2).
- The combination of high tire pressure, high temperature, and thin pavement was extremely damaging.

From a technical standpoint, tire inflation pressure alone does not appear to be a major contributing factor in premature rutting. Inflation pressure only roughly influences contact pressures at the pavement surface. As wheel loads are increased, inflation pressures and contact pressures will of necessity increase. Although AC pavements can be designed and built to perform satisfactorily under current load and contact pressure conditions, realistic contact pressure limits must be established for the future.

The overriding concern from a pavement standpoint is the potentially damaging influence from the use of wide-base (super

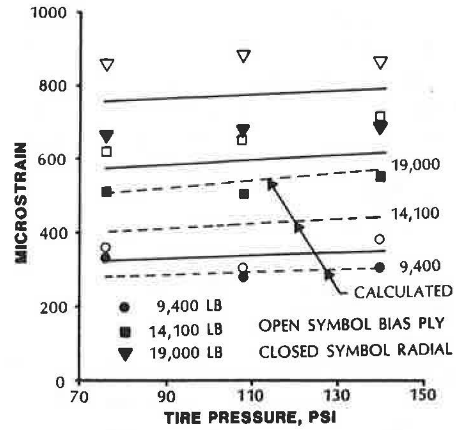

FIGURE 2 Effects of load and tire pressure on strain at bottom of asphalt layer for Lane 2.

single) tires as a replacement for dual-tire configurations on the heavy-truck fleet in the United States. Currently, only a limited amount of actual experience and documented research exist on the subject.

Findings of a number of theoretical and experimental studies, (*20–23*) agree that wide-base single tires cause greater pavement damage than conventional dual tires at comparable axle loads by an average factor of about 1.5. The various computed equivalencies depend on pavement structure, assumed distress relationships, tire size and type, tire inflation pressure, and procedures for determining tire-pavement contact pressures. For example, Sharp et al. (*20*) conducted an experimental study in Australia to evaluate the relative damaging effects of single, tandem, and triple axles with conventional dual and wide-base single tires. The tires were 11.00R22.5 and 18.00R22.5, inflated to 100 psi cold. Tire contact areas were measured, but uniform contact pressures were assumed. Deflection testing took place at two sites, one with conventional AC and the other with a seal coat over granular base. Regression equations were developed between deflection ratios and corresponding loads. Different axle loads were considered equivalent if they induced identical deflection ratios. The findings were as follows:

• Wide-base single tires produced greater pavement deflections than conventional dual tires for comparable loads.
• For a single axle, a load of 13,000 lb on wide-base single tires was considered equivalent to a load of 18,000 lb on conventional dual tires. (The damage factor ratio was 1.38.)
• For tandem-axle groups, a load of 24,300 lb on wide-base single tires was considered equivalent to a load of 29,900 lb on conventional dual tires. (The damage factor ratio was 1.23.)
• For triaxle groups, a load of 37,600 lb on wide-base single tires was considered equivalent to a load of 40,700 lb on conventional dual tires. (The damage factor ratio was only 1.08.)

Significant experimental work on the influence of tire type on AC pavement performance has also been conducted in Finland at the Technical Research Center, Road and Traffic Laboratory (*21*). The measurements were made by pressure cells and strain gauges installed in two AC pavement test sections in the Virttaa test track. Recent research included the comparison of two dual-tire assemblies and three wide-base single tire assemblies, all with three different axle loads and three tire pressures. Uneven tire loads within the dual assemblies were simulated with inflation pressure differences. The following tire assemblies were used:

1. 12R22.5 duals,
2. 265/70R19.5 duals,
3. 445/65R22.5 wide-base single,
4. 385/65R22.5 wide-base single, and
5. 350/75R22.5 wide-base single.

The diameter of the second assembly is 20 percent less than that of the first assembly, and the tires are slightly narrower, to permit a lower trailer platform. Strain and deflection measurements were converted to equivalent axle passes by fatigue failure criteria, with a 10-t single axle load on dual 12R22.5 tire assemblies as the reference. Some of the conclusions are as follows:

• Damaging power for all tire assemblies is influenced to the greatest extent by axle loads.
• When distribution of load is equalized between tires, the least damaging assembly is the conventional dual 12R22.5 followed by the smaller dual and the wide-base single tire assemblies. The narrower wide-base single tires were as much as four times more damaging than the reference assembly.
• Contact pressure is greatest in the center of all radial tires tested. Maximum contact pressures were not available.

The uneven load distribution between dual tires was simulated in a series of measurements with one tire inflated to 72.5 psi and the other to 145 psi. This pressure just about doubled the damaging power of the dual assembly.

A recent study (*22*) of the effect of the tire pressure and tire type on flexible pavement response conducted at the Pennsylvania Transportation Institute included the measurement of tire-pavement contact pressures and the use of the actual pressure distributions in mechanistic models to predict the responses of flexible pavements under various loading conditions. Tire types tested were 11–22.5 bias, 11R22.5 radial, and 385/65R22.5 wide-base single at inflation pressures of 75 to 145 psi. Contact pressure distributions were all nonuniform, with a maximum of 1.75 times inflation pressures and the maximum occurring along the center rib for all three tire types. As axle loads were increased, the portion carried on the outer tread of radials increased and the ratio of maximum to minimum contact pressure decreased. The more significant results of the analytical portion of the study are as follows:

• Magnitude of the axle load is the predominant factor for all variations in pavement response for the tire types, inflation pressures, and pavement thicknesses investigated (see Figure 3).
• The wide-base single tire produced the maximum tensile strains and compressive stresses under all combinations of axle loads and layer thicknesses.

Extensive literature reviews on vehicle-tire-pavement interaction have been conducted by Papagiannakis et al. (*23*) for the Canadian Ministry of Transportation and Communications and by Cebon (*24*) of the University of Cambridge, England. Their observations and findings are generally consistent with those described.

Investigations of AC pavement rutting and the influence of suspension systems on dynamic loading of pavements have been conducted for the Federal Minister of Transport in Germany (*25,26*). Of particular significance is the finding that, for the conditions of the test (a hot summer day), wheelpath rutting was the result of deformation flow (shear) within the AC rather than consolidation. Carpenter and Freeman (*9*) of the University of Illinois question the use of vertical stress to characterize AC mixtures with regard to resistance to wheelpath rutting, particularly for AC overlays on rigid surfaces.

CONCLUSIONS

A substantial research effort aimed at determining more realistic loadings to use in pavement design was conducted by

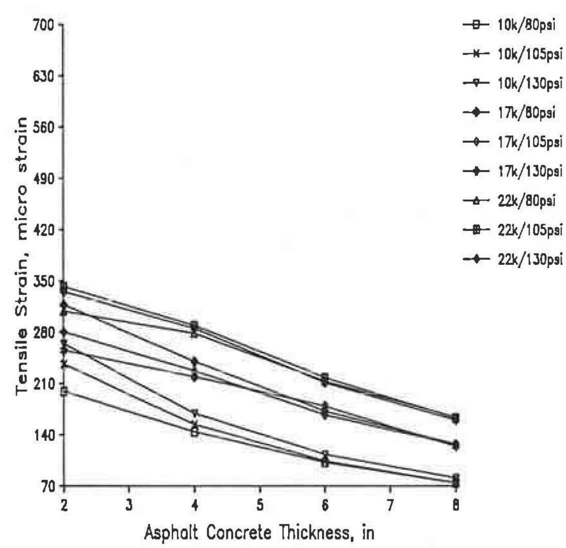

FIGURE 3 Effect of tire pressure and load on tensile strain at bottom of asphalt layer for dual radial tires (*27*).

the Roads and Transportation Association of Canada in 1984–1986 (*27,28*). Field testing involved 13 instrumented flexible pavement sections at various locations in Canada, as well as several combinations of axle loadings and configurations. Vehicles were also instrumented to record dynamic load for different suspension types and road roughness. Measurements of surface deflections and tensile strains at the bottom of the AC were used to determine load equivalencies for various vehicle configurations. Bump-induced dynamic loads were 130 to 200 percent of the static loads for one bump (see Figure 4); with multiple bumps that caused whole body oscillation (bounce), estimated load equivalency factors were 6.5 to 12.5 times the magnitude of predicted equivalency factors for smooth pavements.

Indications are that the technical tools and information will be available shortly to optimize vehicle-pavement interaction and to produce the most cost-effective and efficient movement of goods and services over highways. Recognizing the progress being made toward optimization, current and future research activities should be coordinated in a manner that will ensure the most effective results. An initial step in this direction could be expansion of tire pressure research to include a critical assessment of heavy vehicle–pavement interaction. A major requirement for eventual accomplishment of efficient movement of goods and services is continued communication among the drivers, vehicle truck operators, and highway industry personnel to develop realistic policy for use of the information to produce the desired optimization.

Although increased axle loads and traffic volumes have contributed to asphalt pavement rutting, research and experience provide the basis for minimizing premature rutting in the future, assuming vehicle configurations, tire types, and paving materials do not change drastically. In addition, current research should provide the means for optimizing AC pavement mix design and vehicle configurations that will substantially improve pavement performance in the future. A major requirement for producing this improvement is the determination of realistic tire-pavement contact pressures that can be accommodated by both the highway paving and tire manufacturing industries. Although no indication is currently available concerning realistic and attainable contact pressures, it is recognized that 350-psi tire pressures are successfully accommodated by airfield pavements. The NCHRP and SHRP research in progress will provide the tools for working toward this optimization.

SUMMARY

A brief summary of the study findings, identified information gaps, and research needs follows:

Essential Findings

Tire Inflation Pressures

Increases in tire inflation pressures are not the primary cause of premature AC wheelpath rutting. Tire inflation pressures are only one of the components of the issue of larger truck sizes and weights. Although average truck tire inflation pressures have increased about 20 psi over the past 30 years, research indicates that these increases significantly influence the performance only of thin asphalt pavements. In the opinion of experienced materials and pavement engineers in the western states, where premature rutting is considered most prominent, long-lasting and good-performing AC pavement can be designed and built using currently available materials and technology to withstand wheel loads and tire inflation pressures generally being used at the present time.

Tire-Pavement Contact Pressures

High tire-pavement contact pressures can influence AC pavement wheelpath rutting. Although tire inflation pressures, interacting with wheel loads, do influence tire-pavement contact pressures, the two are not equal. Contact pressures are not uniform within a tire-pavement contact area and are influenced substantially by tire type and design. This condition

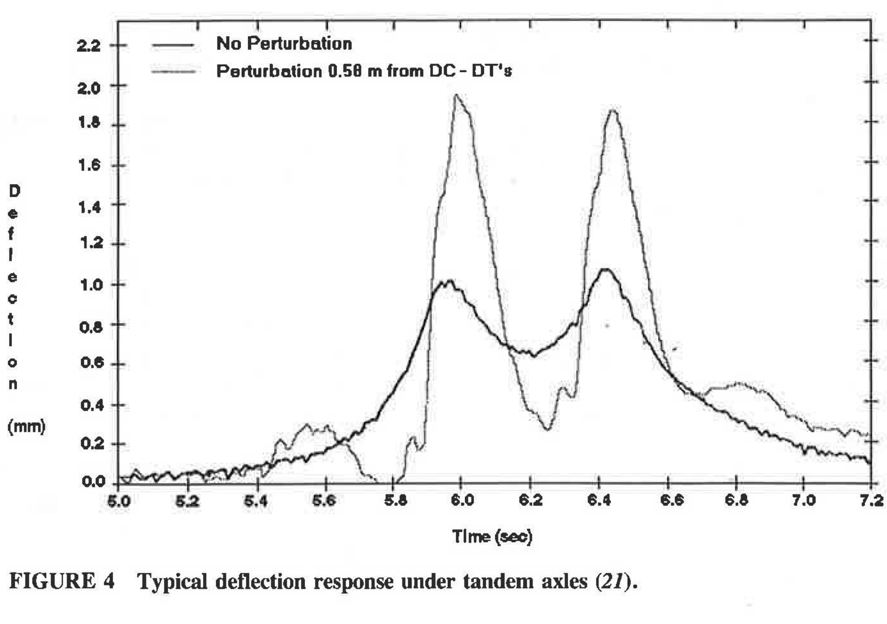

FIGURE 4 Typical deflection response under tandem axles (*21*).

can result in maximum contact pressures being as high as double the inflation pressure. AC pavement analysis and design procedures should consider properly determined maximum tire-pavement contact pressures rather than tire inflation pressures.

Variations in Vehicle-Tire Configurations

The number of variations in vehicle-tire configurations has increased and will likely continue to do so. All of the following factors affect pavement performance to varying degrees:

- Number of axles;
- Load per axle;
- Axle spacing and configuration;
- Load per inch of width of tire;
- Tire type, size, and configuration;
- Tire contact pressure (maximum and distribution);
- Tire diameter; and
- Suspension system.

With regard to load per inch of width, 18 states currently limit the load per wheel to 600 lb/in. of tire width. This approach is applicable regardless of the number or type of tires per axle. The use of wide-base single tires may provide benefits or, as some research indicates, cause increased pavement deterioration. When used to replace narrower tires on the front steering axles of heavy trucks such as concrete mixers, these tires are likely to result in reduced contact pressures. When used to replace a conventional dual-tire assembly without reducing the axle load, research indicates that they increase pavement damage. The optimization of the vehicle-tire-pavement system could result in the identification of an appropriate use for this type of tire.

Information Gaps

Realistic Tire-Pavement Contact Pressures

Although significant progress has been made in recent years in the areas of AC mix design and construction control, which has reduced the potential for premature rutting, changes in heavy-vehicle components and configurations could result in further increases in contact pressures. On the other hand, anticipated improvements in asphalt cement and asphalt-aggregate mixtures technology from SHRP could result in the ability to produce AC pavements capable of performing satisfactorily under increased tire-pavement contact pressures. It is essential to establish realistic maximum limits for tire-pavement contact pressures for which AC pavements can be designed and built using readily available materials and generally accepted construction technology, not only to minimize pavement deterioration now but also to provide the critical link to vehicle-tire-pavement optimization in the future.

Optimization of Vehicle-Pavement Design

Information and tools are being developed by recently completed, in-progress, and programmed research that could lead to accomplishment of the ultimate objective of optimizing the vehicle-tire-pavement system to provide the most efficient movement of goods and services.

Research Needs

Determine Realistic Tire-Pavement Contact Pressures

Advances in AC mix design, specifically NCHRP and SHRP asphalt research activities, will provide promising tools for determining realistic maximum limits for tire-pavement contact pressures based on laboratory testing of available materials. The need is for application of these tools by follow-on research to determine realistic contact pressures. Identification of such limits should be used during optimization of vehicle-tire-pavement design. The tire industry in particular should be encouraged to consider these realistic limits during tire design. A means to regulate compliance with established criteria must also be found.

No current or programmed research by NCHRP, SHRP, or FHWA appears to respond directly to this needed research. AASHTO should support an NCHRP study with the objective of determining realistic tire-pavement contact pressures.

Critical Assessment of Vehicle-Tire-Pavement Research

This is an opportune time to advance the optimization of vehicle-tire-pavement design based on the extensive research being conducted worldwide on pavement design and performance, the influence of vehicle dynamics on pavements, and various vehicle components and configurations. Because of the interactions among the various factors, a critical review and an assessment of all research activities are needed to encourage the necessary interaction and to identify any gaps in the information being developed.

Continuous oversight and coordination of the various research activities should be provided in some form either by AASHTO, TRB, or FHWA staff, or by a research project.

Public Agency Vehicle Configuration Policy

As research reveals information leading toward optimization of vehicle-tire-pavement design to maximize highway transport productivity and minimize pavement and vehicle wear, there will be an increasing need for highway agency policy decisions. Some of these decisions may be required in the near future, before completion of all research. For example, wide-base or super single tires are already being used in other countries as a replacement for dual-tire assemblies and have been observed in this country. These tires are being used rather extensively on the front steering axles of concrete mixers and other heavy trucks that frequently operate off paved roads. The trend toward pounds per inch of tire width as a regulatory tool could alleviate the immediate problem but is not likely to resolve the issue in the long term. There is a need for policy actions to effectively control the use of these tires. The vehicle-tire-pavement optimization activities will determine their ultimate acceptability.

AASHTO should be constantly aware of policy considerations resulting from the extensive amount of vehicle-tire-pavement research and worldwide trends and should appoint a committee or task force to monitor developments and to act on policy concerns as they arise.

In summary, the extensive amount of research and experience on tire-pavement interaction adequately addresses most of the concerns about pavement rutting and tire pressures. The substantial switch from bias-ply to radial truck tire design has generally been beneficial to pavement performance.

The most prominent need is the determination of realistic tire-pavement contact pressures to avoid future pavement deterioration as loads and vehicle configurations change. Although beyond the original scope of the study, the tire-pavement problem is one component of the issue of larger truck configurations, sizes, and weights. Consequently, the ultimate need is for optimization of pavement and vehicle design to provide improved trucking productivity while minimizing adverse impacts on pavements. Because of the extensive current and planned research in this area, the primary action required is the coordination of these activities, particularly between the pavement and vehicle industries.

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