DESIGNING BITUMINOUS PAVEMENTS FOR WHEEL LOAD STRESSES

-- A BRIEF REVIEW

by

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This review is written for the practicing civil engineer who has not been primarily concerned with pavements. No documentation of the sources of the information contained is presented. It is believed that most of the statements made are accepted by those versed in pavement design, but some must surely be the author's own opinion. The factors covered in the discussion are those considered to be of primary importance in designing pavements for the Texas environment at this time. Some factors of secondary importance are discussed; however, no attempt has been made to be all-inclusive. It is of critical importance that the reader note that this paper is concerned only with wheel load stresses. Those stresses induced by the environment, that is, those that come from heating or cooling, wetting or drying, freezing or thawing, or chemical changes in materials, are not considered at all in this paper. However, these environmental factors are frequently of primary importance.

Critical Stresses or Strains

It is generally believed that three types of stress-strain situations are the primary sources from which distress originates. If these critical

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situations can be controlled by maintaining stress levels lower than strengths (or strain levels lower than allowable strain levels for the given materials), the designer has accomplished his goal as far as designing for wheel loads is concerned. These three stresses generally occur in distinctly different types of material used in bituminous pavement structures. The materials can be grouped in these categories: the foundation material which will be referred to as the subgrade in the remainder of this paper, unbound base materials, and bound materials which include surface courses, asphaltic base courses and other asphalt-treated materials. Note that the asphalt-treated materials can behave under certain conditions very much like the unbound materials. Therefore, we must think of bituminous materials as grading from unbound to very rigidly bound depending on temperature, moisture, and rate of loading of the materials.

Distress due to repeated loading in paving materials (fatigue) can best be controlled by maintaining stress levels considerably below strength levels. In other words, if the strength of the material is 100 psi, it can take manyfold more repetitions of a 10 psi stress over a 50 psi stress. Therefore, fatigue will not be considered separately except to say that the more load repetitions expected the lower the stress application relative to the strength or the more "overdesigned" the road must be. (It is possible to increase the fatigue resistance of materials by certain mix design techniques; however, the largest payoff in increasing the fatigue life of a road generally will be by reducing stress levels.)

Figure 1 illustrates the critical stresses referred to earlier: vertical compressive stress on the subgrade, designated C_s; shear stress in an unbound base, designated S_b; and the tensile stress in the bottom of bound surface courses, designated T_s. The remainder of this paper discusses each of these stresses separately as well as the strengths of the associated materials.

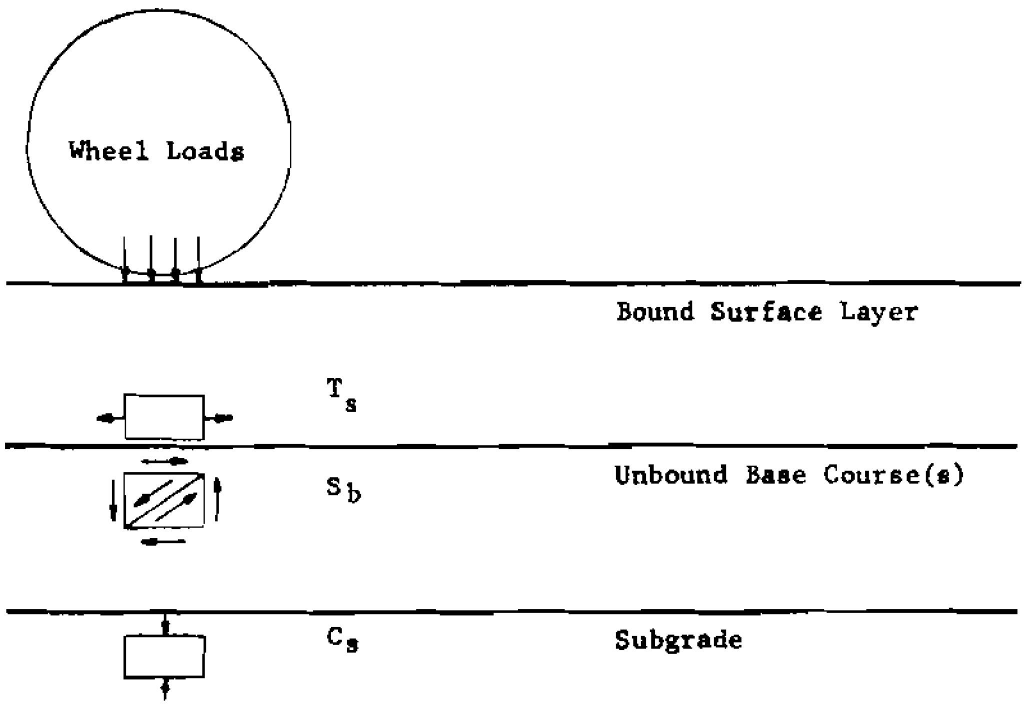


Figure 1. Critical Wheel Load Induced Stresses in Pavements

Compressive Stress on the Subgrade, C_s

To control the effect of wheel loads on the natural soil materials, the designer has available the options shown in Table 1. He can either provide lowered stresses on the subgrade or attempt to strengthen the subgrade. Usually, he does some of both.

It is considered almost a necessity that the water table be kept at least two feet below the paved surface and that surface infiltration to the subgrade be kept to a minimum. It is usually impossible to keep capillary moisture out of the subgrade.

Few natural subgrade materials are strong enough to resist truck wheel loads on an all-season basis. Some rock cuts could be an exception, but generally a pavement structure is required if an all-weather road is needed.

Shear Stresses in Base Courses, S_b

Table 2 summarizes methods that can be used to either decrease the shear stress in unbound base courses or to increase their strengths to withstand higher stresses. Most of the items are self-explanatory. However, Item 5 under the strength side of the picture is a newly quantified consideration. Briefly, it appears that there is an optimum clay content for unbound base courses and this optimum depends upon the rainfall, runoff, evaporation, clay mineral-type, freeze-thaw cycles, subgrade suction, salt content, and probably other factors. With too much clay, the base will become wet with a big loss in shear strength, too little clay and the base may become cohesionless.

Tensile Stresses in Bound Layers, T_s

Reference to Table 3 will reveal that tensile stresses in bound layers change dramatically as one goes from thin-membrane surfaces to thicker slab-like structures.

Table 1. Vertical Compressive Stress on Subgrade, C_s

To Decrease Stress	To Increase Subgrade Strength
1. Decrease wheel loads (by load zoning)	1. Lower water table by using deep ditches and higher fills
2. Increase pavement structure thickness	2. Increase density of subgrade
3. Increase pavement structure stiffness	3. Prevent infiltration of surface water by using:
4. Use wider pavements (to lower edge loading)	a. Impervious pavements
	b. Good surface drainage
	c. Internal drainage systems
	d. Good maintenance of surface seals

Table 2. Shear Stresses in Base Courses, S_b

To Decrease Stress	To Increase Shear Strength
1. Decrease wheel load (by load zoning and requiring more tires per truck)	1. Use aggregates with rough surface texture and good angularity
2. Increase thickness of cover on base course(s)	2. Use dense gradations
3. Increase stiffness of cover on base course(s)	3. Compact to high density
4. Provide lateral support with paved shoulders or gutters	4. Use low plasticity fines
	5. Balance clay content, clay mineralogy, and the expected moisture-thermal environment for the pavement
	6. Prevent infiltration of surface water

Table 3. Tensile Stress in Bound Layers, T_s

A. Tensile Stresses in Thin Surface Courses

To Decrease Stress	To Increase Strength
1. Decrease tire pressures* 2. Make surface layer as thin as possible 3. Make surface layer as flexible as possible: a. Use soft asphalt b. Use gap graded aggregates 4. Make next layer as stiff as possible by: a. Keeping it dry by placing a good seal b. Finishing it carefully by "tight" blading and not scabbing c. Getting a good prime	1. Use a high asphalt content 2. Use aggregates with good surface texture 3. Obtain good compaction. Pay special attention to the following: a. Do not place thin surfaces when underlying structure is cool for it will remove heat rapidly b. Roll quickly

B. Tensile Stresses in Thick Bound Layers

To Decrease Stress	To Increase Strengths
1. Decrease wheel loads by load zoning 2. Make layer as thick as possible 3. Make layer stiff 4. Make underlying layers stiff	1. Use high asphalt contents 2. Obtain good compaction 3. Use hard asphalt 4. Use dense gradation

* See text.

Thin surfaces will likely be in compression directly under a wheel load and in relatively small tension between dual tires. However, as one examines increasingly thicker surfaces, the compression under the tire changes rapidly to high tension. With further increases in thickness this tensile stress will decrease. Figure 2 illustrates these conditions for both a flexible and a stiff bituminous material.

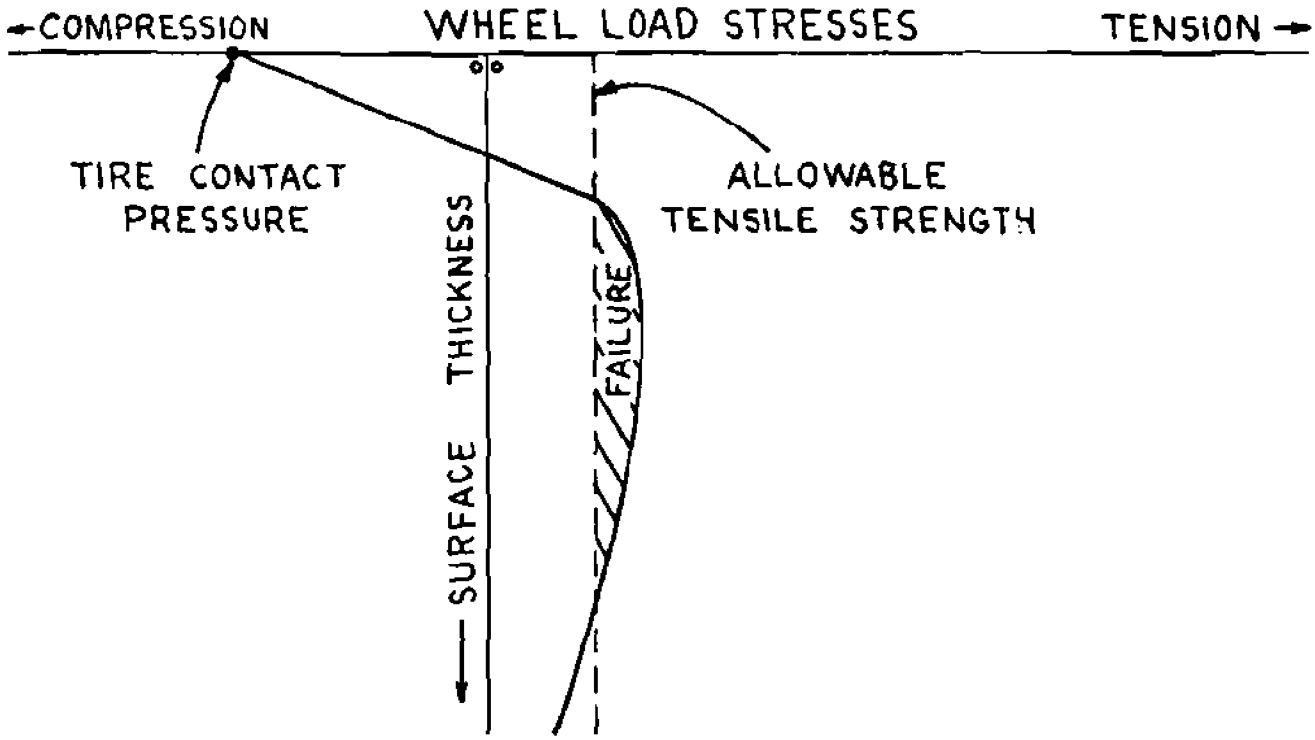
Experience has shown that membranes that (1) are kept less than two inches in thickness, (2) are intentionally made flexible, and (3) are placed upon a base course that has enough strength to withstand shear stresses can give satisfactory service in the Texas environment.

For thicker bound layers it is necessary to make them thick enough for the expected conditions. For highway traffic, minimum thicknesses should be from five inches for the lightest trucked roads to eight inches for the heaviest trucked roadway.

The thicknesses mentioned in the two preceding paragraphs, less than two inches for thin-membrane type surfaces to five- to eight-inch minimums for the thicker slab-like structures, are predicated upon the underlying layer being an unbound material. If the underlying layer is bound and if provisions are made to obtain an adequate bond between the two, the pavement should be considered a composite slab. It should then be designed as a slab.

Note that the thin membranes "feel" tire pressures rather than gross load. For such a member, one automobile tire will do approximately one-third (30 psi tire pressure) as much damage as one truck tire (90 psi tire pressure). For other members in a pavement structure the auto may only do 1/100 to 1/10,000 the damage of a truck.

A. Using Flexible Surfacing Materials



B. Using Stiff Base & Surfacing Materials

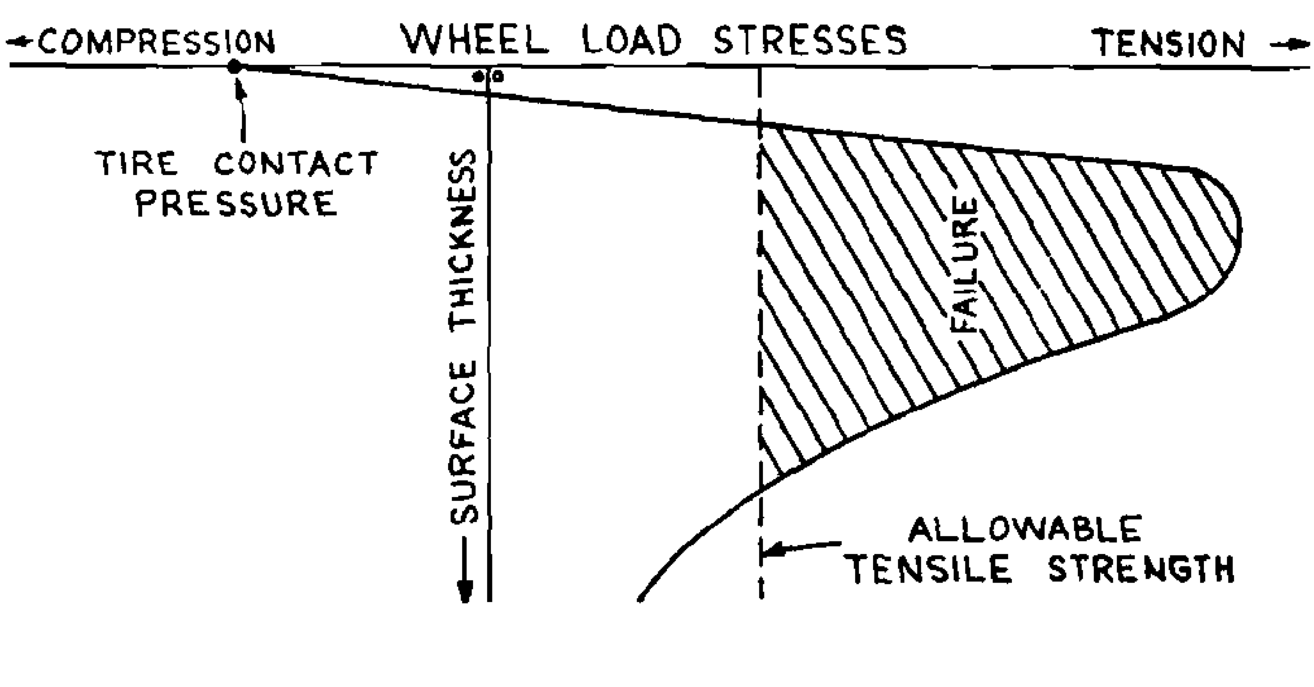


Figure 2. Stresses Beneath Tires in the Bottom of Bound Layers with Varying Thicknesses

In summary, it appears that thin-membrane surfaces should be flexible and as thin as possible; thick slab-like structures should be stiff and as thick as necessary. Further, intermediate thicknesses (between two and five to eight inches) can be expected to crack early if built of bituminous mixes conventionally used in Texas today.