Experimental work and service results have shown that sands which previously were refused as being too coarse or too fine may be successfully used Leading authorities in asphalt paving mixtures contend that the problem is one of combining bitumen with the aggregates at hand in anintelligent manner

Research has indicated that thorough compaction of the pavement mixture is of at least as great importance as the grading of the aggregate

Aside from the integrity of the pavement, the combining of the fine aggregate and the asphalt is most important in the securing of a smooth riding surface A mixture which cakes and which is difficult to rake or screed presents a serious stumbling block to a smooth riding pavement

Coarse aggregate bituminous concretes, where little or no grading of the aggregate was attempted, have been constructed successfully and have stood up under severe traffic in some cases for twenty years or longer

In the maintenance of bituminous concrete pavements success has attended the use of materials and methods similar to those that produced the original pavement

Both bituminous macadam and bituminous concrete lend themselves to various methods of repair Bituminous concrete bonds easily with bituminous macadam, and bituminous macadam is being successfully repaired with bituminous concrete Similarly, penetration patches have been made in bituminous concrete surfaces successfully

When expediency demands it and the costs are of secondary importance, successful bituminous macadam and bituminous concrete repairs have been made with various proprietary pavement mixtures

WHEEL LOAD AND IMPACT IN PAVEMENT DESIGN

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In discussing the relation of wheel load and impact to the structural design of a rigid pavement, there are several phases and inter-relations that should be considered These are: the magnitude of the forces, their duration of application, their points of application, their degree of concentration as to area and linear width, and the stresses produced under the influence of these factors Complete data and information concerning each of these factors is not available. During the past few years this committee has collected and considered some information and facts which will be discussed at this time

Knowledge concerning the influence of the time and duration of applied loads and forces in producing deformation and stress is quite limited and rather uncertain The discussion here is divided under the two general headings of "Loads Without Impact" and "Impact Loads"

LOADS WITHOUT IMPACT

Under this classification are included the static wheel loads, and loads of slowly moving vehicles whose speed does not exceed two miles per hour This is an arbitrary classification, yet justified by the inspection of experimental data plotted to show the relation of impact versus speed The data show that vehicles traveling at less than two miles per hour do not ordinarily produce vertical wheel loads appreciably greater than the static weight of the wheel

The maximum static wheel load, or load without impact, which a pavement will be required to sustain is known from the regulations applying in the particular territory The permissible wheel load is usually considered as being the maximum gross wheel load If the

TABLE I

Approximate Wheel Loadings

Class of road	Maximum one wheel load pounds
(a) Park-way, or other light roads for pneumatic tired passenger vehicles and one-ton business trucks	2,500
(b) Ordinary city street and rural highway for general traffic, where character and loading may be restricted	11,000

value of this maximum wheel load is not specified, it may be obtained by taking 35 to 45 per cent of the gross weight of the truck and its capacity load

Additional load allowances are sometimes made to provide for loading violations, emergencies, or special permits Such allowances are mainly arbitrary, they are of the value of 50 to 100 per cent and may be entirely provided for in the factor of safety The wheel loadings given in Table I indicate the approximate values that may be expected on two classes of roads

A vehicle may pass over all parts or may stop at any point on a road surface, and the pavement must therefore be designed to support the maximum static load at any point The point of application of wheel loadings depends upon the wheel spacing of the vehicles and the nearness of adjacent traffic The minimum spacing will be between the two rear axles of a six-wheel truck, which is generally not less than three feet, and this also is a reasonable allowance for the minimum distance between adjacent wheels of passing vehicles With this minimum spacing of three feet there is very little stress increase under one wheel due to the load influence of the nearest other wheel There is, however a reversal of stress, changing from compressive to tensile on the top of the slab, between the wheel loadings This top tensile stress due to such conditions is not of such a magnitude (except at corner loadings) that it should be considered in the strength design It may have some slight influence on the endurance limit

Under actual conditions wheel loads are not concentrated at a point of small area but are distributed over areas and widths depending upon the tire equipment These tire-contact areas on the pavement vary from 20 to 80 square inches, with widths of from 3 to 14 inches Only the total load is of importance in structural design The unit load, which usually does not exceed 200 pounds, is of importance only when the compressive strength of the material is considered

The development of stress in rigid pavement slabs under the influence of loads without impact is complex and the exact value is somewhat indeterminate The determination of stress values by analytical methods is further complicated by the fact that a pavement slab is supported on a subgrade which has defied complete analysis as to its elasticity and resilience Experimental stress measurements based on the deformations and the modulus of elasticity of the material have indicated

(1) That stress varies directly with the magnitude of the wheel load

(2) That in a slab of uniform thickness the maximum critical stress for a given wheel load will be, either

  (a) A tensile stress in the bottom of the slab directly under the wheel load, or,

  (b) In the case of a load at the corner it will be a tensile stress in the top of the slab The place of maximum stress depending upon the subgrade support

(3) The effect of adjacent wheel loads, due either to vehicle design or to passing traffic, does not appear to be of major importance and may be disregarded for purpose of design

Theoretical analysis has corroborated these indications of stress measurements Our present knowledge obtained from experimental evidence, however, indicates that there should be some additional consideration made for the possible condition of fatigue To provide for this contingency the maximum stress should not exceed fifty per cent of the modulus of rupture of the material

IMPACT LOADS

Under this classification of loadings are those forces which are developed by the vertical acceleration or deceleration of the wheel Impact forces from vehicle wheels have been found to have a time duration not greater than one-tenth second Such forces are produced by a wheel rolling rapidly over obstructions and irregularities They do not include loads from rapidly moving vehicles where the wheel has no appreciable vertical movement

The magnitude of the impact forces which will be imposed upon the pavement depends principally upon four conditions which are: road roughness, tire equipment, wheel load and vehicle speed The trend in surface roughness conditions is toward smoother pavements both in the original job and in maintenance It is a known fact that impact forces decrease with smoother surfaces The trend in tire equipment is toward better cushioning qualities, pneumatics being used more and more as original tire equipment, and solid tires being kept in better condition, with the result that impact forces have decreased Where excessive gross vehicle loads are permitted the tendency is to use three or more axles, thus reducing the wheel load The trend in wheel load is towards a maximum not exceeding 11,200 pounds Impact forces increase with increased wheel loads The trend in vehicle speed is upward So far as is known, however, the critical speed is between 12 and 15 miles per hour, particularly for heavily loaded vehicles Our present information leads us to believe that any adverse effect due to higher speeds is offset by the favorable trends of other factors

On a moderately smooth road carrying normal vehicular traffic, our present information indicates that the maximum impact forces which will be produced probably do not exceed two or three times that of the static wheel loads, and that those figures may be considerably reduced if the vehicles are completely equipped with pneumatic tires With pneumatic tire equipment, impact increases only slightly with increase of sped up to 25 miles per hour The net trend of changes in the influencing factors discussed in the preceding paragraphs is such that the impact forces will probably not exceed the above limits in the near future

When the road surface temporarily becomes unusually rough, as by ice coatings during winter or when vehicles use anti-skid chains, the impact forces increase greatly The best way to protect the highway when such abnormal conditions exist, is by a reduction in wheel load or vehicle speed, or both, until conditions again become normal

Distribution surveys have shown that the wheel loads are likely to occur at any point on the pavement notwithstanding the tendency to follow certain lanes, so the pavement must be designed to carry the full impact load at any point

Although the magnitude of impact forces which are ordinarily developed under given traffic conditions are fairly well known, the stress conditions produced by such forces are not fully understood There has been no investigation on impact stress that has given us information which we are justified in using directly in strength design Until definite information is available concerning the effect of impact forces in producing stresses, we are not justified in assuming that a known impact force is equivalent to a static force of the same magnitude

Large static loads (truck wheel loads) may produce large impact forces if other conditions are equal, but for vehicular traffic other conditions usually are less in their effect as the static load increases For the condition of heavier vehicular loads there will be a slower speed resulting in a lower vertical acceleration, and the springs hold the wheels more in contact with the road surface This results in an impact force that is a less percentage of the total than for lighter wheel loads Therefore, the total load (static plus impact) may possibly not be any greater for heavy trucks than for the light trucks

PRACTICAL APPLICATIONS AND SUGGESTIONS

The preceding paragraphs have set forth the factors which should be considered concerning the loads for which a pavement should be designed In view of the fact that complete data are not available concerning all these factors, the engineer must still be guided to a considerable extent by current good practice

There is no question but that a pavement should be designed to carry at least the maximum static wheel load at any point Good practice indicates that this load should be increased to take care of impact conditions

Where heavy frequent wheel loads are expected to be prevalent during the life of the pavement, it is believed that the working stresses should be reduced to allow for the effects of fatigue

The best means thus far advanced for determining the proper thickness of pavement slabs for any given conditions of load, stress, and subgrade support is according to Westergaards' method by theoretical analysis [1]

Since there is at the present time no definite direct method of using impact stress values in design, except to consider them as an additive stress value to the static stresses, recourse must be made to the method of reducing all impact stresses and forces to static equivalents, and then apply the usual analysis and design methods for static conditions.

The effort in highway design should be directed most energetically towards improved methods of construction that will insure lasting smooth riding surfaces which will eliminate the greater part of the impact forces.

This committee strongly recommends that further impact investiga-

[1] See Proceedings of Fifth Annual Meeting of the Highway Research Board, 1925, p 90

tions should be started and vigorously prosecuted to secure information and data concerning

1 Relative stress effect under equal static and impact forces
2 Effect upon stress development of various velocities of applications of the impact force
3 The fatigue effect and endurance limit under impact conditions

DISTRIBUTION OF WHEEL LOADS THROUGH VARIOUS RUBBER TIRES

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The purpose of the experiments was the determination of the distribution of the wheel load in the contact area of a pavement through solid, cushion and pneumatic rubber tires

The apparatus used in these experiments for determining the static load imparted by the tire at the various points in contact with the pavement, is a series of spring scales acting as the measuring medium It is designed to register the load in transverse segments two and one-half inches in width taken across the tread width of the tire Actual contact areas[1] of the tire with the several sections are determined from the properly oriented imprint of the tire by means of a planimeter Results are expressed in pounds per square inch per section

The greatest stress in the contact area of all the tire types is at the point where the plane of the center line of the axle is normal to the pavement and decreases in intensity in both directions from this point

APPARATUS (SEE FIGURES 1, 2, AND 3)

The apparatus consists of ten helical springs (*6*) four inches in height, and two and one-quarter inches outside diameter, arranged in pairs lying eighteen inches apart in a rigid frame, built of two sections of steel channels (*7*) connected by cross pieces (*8*) These springs are seated in cap plates top and bottom (*9*) Resting on the upper cap plate and moving freely in slots one-half of an inch wide, and lying two and one-half inches apart in the frame are steel beams (*10*) three inches wide with iron angles (*11*) screwed to the upper edges, beginning two inches from one end of the beam, and ending two inches from the other so that the upper surface of the machine, when leveled, is a plane fourteen

[1] By "actual contact areas" is meant the area of that part of the tire or lugs actually in contact with the road surface as indicated by the imprints taken under the various loadings and does not represent any included or subtended area