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Influence of Vehicular Positions and load Limits of Concrete Pavements

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Abstract- Structural response of concrete pavements is influenced by the position of the axle loads and if criticalload positions are not considered in concrete pavement analysis, the design may be inadequate and lead to early failure of the pavement. Whilst there has been a great deal of research conducted on concrete pavement performance and deterioration under vehicular loads and environmental forces, there is a lack of adequate information on effects of vehicular load positions on pavement responses. Critical positions of different axle groups in uncurled and curled jointed concrete pavement with different configurations were determined in the current study. Results indicate that a structural performance of concrete pavement is significantly affected by boundary conditions between concrete slab and base. Corner loading was found to be critical in bonded concrete pavement. Corner loading is also critical when a separation occurs between unbonded concrete slab and base. Furthermore, the benefits offered by unbonded boundary condition cease at a certain differential temperature. Hence, a particular care needs to be considered in projects constructed in extremes of heat or cold. In presence of high differential temperature together with axle loading, joint faulting in unreinforced concrete pavements is affected by concrete slab thickness.

I. INTRODUCTION

Although there has been a great deal of research conducted on pavement performance and deterioration under vehicular loads and environmental forces, there is a lack of adequate information on effects of vehicular load positions on pavement responses. If the load positions which give the maximum response parameters are not considered in the analysis, the design may be inadequate and lead to early failure of concrete pavements. Structural response of concrete pavements is affected by vehicular load configurations, magnitude of applied loads and position of axle groups on the pavement as well as environmental effects. This paper treats the influence of vehicular load positions on pavement responses in terms of induced tensile stresses. Effects of configuration and magnitude of vehicular loads on pavement responses have also been investigated in concrete pavements, applied loads are generally transferred to base and subgrade layers by the bending action of concrete slab which results in a tensile stress at the top or the bottom surface layers of the concrete slab. The applied loads can be vehicular and/or environmentally related position of vehicular loads upon the pavements.

So Load limits restrict how much weight can be carried on an axle, a single tire or pair of tires, and on the vehicle or vehicle combination in total. Concerns over the impacts of tire load and gross vehicle weight on a fragile infrastructure were first addressed in the 1913 and 1915 Legislative sessions, respectively. Tire loads began at 400 pounds per inch width of tire and a gross vehicle weight limit was established at 24,000 pounds. In almost every subsequent legislative session, through 1975, load limits have been refined to address changes in infrastructure design and observed effects of vehicle loads.

In 1975, federal laws were implemented to provide protection to the highway infrastructure and uniformity among the states for interstate use. The Washington State Legislature adopted the federal weight limits for all state highways.

II. METHODOLOGY

In this study, distance between transverse joints and distance between longitudinal joints were considered to be 4600mm and 3600mm respectively. Tied shoulders with 1500mm width were considered. The slab thickness was considered to be 250mm with modulus of elasticity and Poisson’s ratio of 28000MPa and 0.2 respectively. A cement stabilized base of 150mm thickness, 5000MPa modulus of elasticity, and 0.2 Poisson’s ratio was considered beneath the slab and upon a subgrade with modulus of subgrade reaction of 0.03MPa/mm (CBR _ 3.5). Transverse joints were doweled by eleven evenly spaced cylindrical bars having 32mm diameter, 450mm length and 1000MPa dowel-slab support modulus. Tie bars with 13mm diameter and 1000mm length spaced at 1000mm centre to centre were considered at longitudinal joints. These secure load transfer efficiency (LTE) of 95% in both transverse and longitudinal joints for bonded boundary condition and LTE of not less than 85% in transverse joint and 70% in longitudinal joints for unbonded boundary condition. Since information on behaviour of debonding layer provided in the literature did not lead to a specific conclusion, fully bonded and unbonded boundary conditions between concrete slab and base are taken into consideration in the current study to determine how provision of this layer as either bonded or unbonded affects concrete pavement responses.

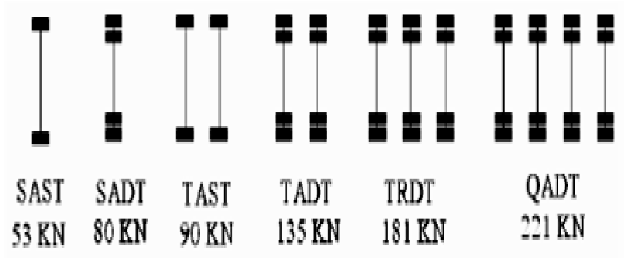


Fig. 1 Axle groups

In regards with effects of modulus of sub grade reaction and thickness of concrete slab on induced tensile stress of a curled pavement different base thicknesses of 200, 250 and 300mm and different modulus of sub grade reactions of 0.03, 0.05 and 0.07MPa/mm were considered in a full pavement configuration.

SAST, SADT, TAST, TADT, TRDT, and QADT with average gross loads of 53 kN, 80 kN, 90 kN, 135 kN, 181 kN, and 221 kN (Fig 1)] were respectively applied as the vehicular loads at the centre, middle of the longitudinal edge and corner of the centre slab as shown in Fig 2. These load locations are respectively called a centre, mid-edge and corner loadings in this paper. A rectangular shaped tyre-pavement was considered in the current study. Other assumptions for load configuration were as follows:

- Tyre inflation pressure: 750 kPa,
- Width-to-length ratio of tyre contact area: 0.7,
- Space between centres of dual tyres: 300 mm,
- Axle width: 1800 mm,
- Distance between axles in a given axle group 1250 mm.

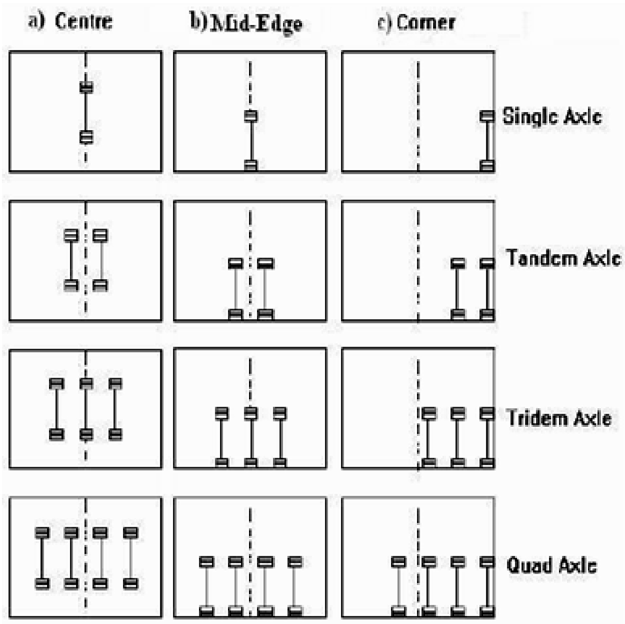


Fig. 2 Corner of the centre slab

It should be noted that for those projects where valid statistical information on axle configuration are not available, research on critical axle group configurations showed that the critical width-to-length ratio of tyre contact area is between 0.6 and 0.8 with average of 0.7, the critical distance between axles in a given axle group is between 1050mm and 1150mm with average of 1100mmfor all axle groups. In addition for TAST and TADT groups this value can also be between 1350mm to1450mm with an average of 1400 mm. However, a value of 0.7 for width to length ratio of tyre contact area and 1250mm distance between axles in a given axle group, as assumed by have been chosen in the present study in order to compare present results with their results.

As high differential temperature (more than 25_ C) would result in severe damage of unreinforced concrete slab of a normal thickness, linear differential temperature of −25_ C (night time temperature) to 25_ C (daytime temperature) were therefore considered between the top and the bottom surface layers of concrete slab. The concrete coefficient of thermal expansion was considered to be 1×10−5 mm/mm/_ C.

Weight limits placed on axles and tires

Tire and axle limits are imposed for a number of reasons; foremost, is to ensure that loads carried by trucks are transported safely. Having defined load limits allows engineers to design pavements that will hold up under anticipated truck traffic with minimal maintenance required for fixing cracks, ruts, and potholes. Load limits are also necessary for protecting bridges from structural weakening or fatigue, preventing unsafe conditions and early replacement of bridge structures. Current information shows that even slight changes in load limits have major impacts on pavement and bridge performance. Both the axle and tire load affect pavements and bridges.

Total axle loads affect large areas of a pavement or a bridge, while tire loads affect smaller, more localized areas. Narrow width tires concentrate the vehicle’s weight on a small area, while wider width tires distribute the weight over a larger area and cause less stress on a single spot. As the total load carried by an axle increases, so does the total load on the pavement or bridge. An axle carrying 20,000 pounds puts the same total weight on a bridge or a pavement whether 6-inch wide or 12-inch wide tires are used. The total load may cause damage or failure, even if the local point stresses under the tires are not large.

The current tire and axle load limits

Loads are typically defined according to the type of axle as well as the number of tires per axle. Legal load limits for the various axle configurations

Tire Load	600 lb/inch of tire width
Single Axle	20,000 lbs
Single Axle with two tires (carrying more than 10,000 lbs)	500 lb/inch of tire width
Tandem Axle	34,000 lbs
Gross Vehicle Weight	105,500 lbs

Bridges exposed to loads that they were not designed to handle

Concrete and structural steel bridges exposed to overweight loads, or increased legal load limits, most often suffer from fatigue. Fatigue results from repetitive stress, much like bending a paper clip back and forth repeatedly, eventually the metal fatigues and breaks. Structural steel fatigue cracks continue until the carrying capacity of the affected structure is reduced to the point that it will no longer support a load. In steel reinforced concrete bridges, fatigue cracks the concrete and allows water or other contaminants to affect the steel reinforcing bars. The bars corrode and cause expansion, which breaks off the concrete cover and creates more exposure for corrosion. This process continues until the carrying capacity is reduced to the point that the bridge can no longer support a load. The heavier and more frequent the loads, the faster these fatigue cracks will grow in size and length.

Bridges consist of several different structural elements, combining together to form the complete bridge. Loads greater than the current legal loads affect these structural elements in different ways. Bridge decks must transfer the wheel load to the main support beams, which in turn transfer the load to the foundation supports. Each of these elements can experience fatigue and fatigue damage from larger than legal loads (Fig 3, 4 and 5).

will accommodate 3 vehicles in addition to the passengers. All subsystems discussed in the following sections are featured on both capsules.

For travel at high speeds, the greatest power requirement is normally to overcome air resistance. Aerodynamic drag increases with the square of speed, and thus the power requirement increases with the cube of speed. For example, to travel twice as fast a vehicle must overcome four times the aerodynamic resistance, and input eight times the power.

Just as aircraft climb to high altitudes to travel through less dense air, Hyperloop encloses the capsules in a reduce pressure tube. The pressure of air in Hyperloop is about 1/6 the pressure of the atmosphere on Mars. This is an operating pressure of 100 Pascals, which reduces the drag force of the air by 1,000 times relative to sea level conditions and would be equivalent to flying above 150,000 feet altitude. A hard vacuum is avoided as vacuums are expensive and difficult to maintain compared with low pressure solutions. Despite the low pressure, aerodynamic challenges must still be addressed. These include managing the formation of shock waves when the speed of the capsule approaches the speed of sound, and the air resistance increases sharply. Close to the cities where more turns must be navigated, capsules travel at a lower speed. This reduces the accelerations felt by the passengers, and also reduces power requirements for the capsule. The capsules travel at 760 mph (1,220 kph, Mach 0.91 at 68 ºF or 20 ºC).

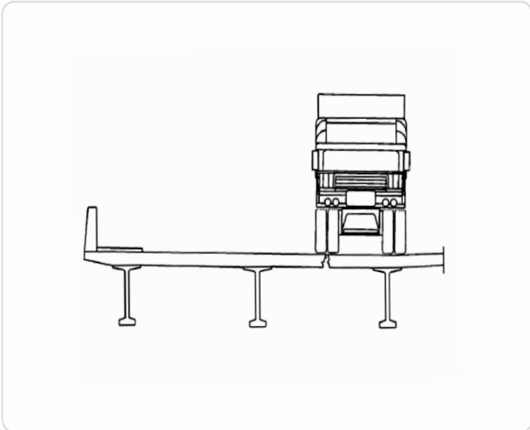
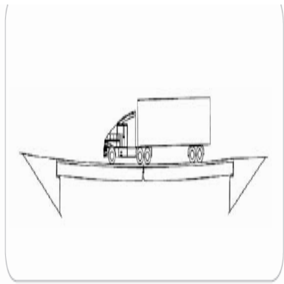


Fig. 3 Concrete Roadway Deck Section and Fatigue Location



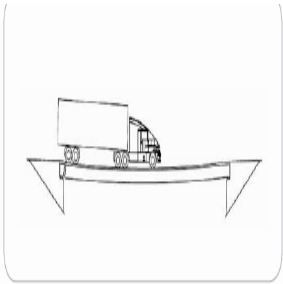


Fig. 4 Beam “Bending” Failure Fig. 5 Beam Shear Failure

Most of the current state highway system, and all new state highways, are designed using these load limits. Some of the older highways were not built to current design standards and require work to upgrade to today’s standards. As designed, these highways can withstand current legal loads without damaging the pavement structure

Maintenance varies by pavement type:

- The surface of pavements wears out a need to be replaced on a regular cycle, about every 15 years, but the pavement below the worn surface remains. Replacing just the surface is much less expensive than replacing the full depth of the pavement structure.

- Concrete pavements are designed to handle the weight of legal loads and last for up to 50 years. These pavements need to be “ground” smooth about every 25 years to remove wear caused by studded tires. This is much less expensive than replacing cracked and broken concrete.

III. CONCLUSION

Critical positions of different axle groups in uncurled and curled jointed concrete pavement with different configurations were studied. Results of the current study also show that pavement performance under combinations of vehicular loads and differential temperatures is significantly affected by boundary condition between concrete slab and base. The reasons behind longitudinal, transverse and corner cracking were addressed. The significant findings in this area were (i) corner loading is critical when there is a bonded boundary condition between concrete slab and base (ii) corner loading is also critical when a separation due to environmental forces occurs between the unbonded concrete slab and base. Furthermore, the benefits offered by consideration of the unbonded boundary condition cease at a certain value of differential temperature. Hence, a particular care needs to be given to those pavement projects constructed in hot or cold weather where high differential temperature gradients may be produced in concrete depth. Moreover, corner, centre and mid-edge loadings can result in different types of fatigue failure of the concrete slab depending on differential temperature.

There is an inverse relationship between induced tensile stress and thickness of concrete slab so that an increase in thickness of concrete slab decreases the magnitude of induced tensile stress. However, a maximum slab thickness or dowel arrangement at corners of the slab shall be considered in unreinforced concrete pavement as thicker slabs are sensitive to high differential temperature together with axle loading. An increase in modulus of subgrade reaction can increase or decrease the magnitude of tensile stress depending on boundary condition between concrete slab and base, corner or mid-edge loading and daytime or night time differential temperature

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