Preparation of the Vehicle Weight Safety Study Academic Report

Agreement: CTC-C-25-008

Task 7. Analysis of the relationship between passenger vehicle weight and degradation of road infrastructure

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This memorandum addresses the scope of Task 7, which is to develop a research synthesis that addresses this topic: analysis of the relationship between passenger vehicle weight (and, if relevant, vehicle weight distribution) and degradation of road infrastructure, including but not limited to pavement impacts.

The effects of vehicles on pavement, the primary road infrastructure asset, have been studied since the 1920s. The original work developed by O.J. Porter (California State Pavement Engineer 1928-40) identified failures in terms of subgrade shear leading to rutting and excessive deflections leading to fatigue cracking from repeated axle loads. He developed asphalt and aggregate base thickness design curves based on field observations for different soils classified by his new test, the California Bearing Ratio (CBR) test for soil shear strength. He went to the Army Corps of Engineers where the CBR test and design curves were updated for bombers and used around the world for highways and airfields[1]. A key outcome was that axle loads (or in terms of the wheels on the ends of the axles) control pavement damage, not gross vehicle weights (GVW).

His successor, Francis Hveem (California State Pavement Engineer 1945-1971) helped pioneer better quantitative characterization of the damaging effects of different axle loads and repetitions of those axle loads starting with the WASHO[2] Road Test in the 1940s where the damaging effects of relative loads on axles were first quantified for thin asphalt pavements, and the more comprehensive AASHO[3] Road Test from 1958 to 1960[4] where a much wider range of pavements (various thicknesses of asphalt, concrete, and bases) and trucks (varying axle loads and configurations) were used to determine axle load damage rates. Trucks with different loads and configurations were driven for several years on their own closed-circuit tracks with different pavement types and thicknesses in each loop and pavement damage and cracking and rutting were measured as the cumulative axle loads increased on each pavement section. The lightest truck of the 10 truck types in the experiment had 2,000 lb axle loads on a two-axle vehicle (4,000 lb GVW), essentially a pickup truck, and the heaviest had five axles and a 108,000 GVW, with the axle loads exceeding the current Caltrans legal limit by 41%.

The outcome was a set of tables relating the damaging effects of axles with different loads on different pavement structures and a simplified rule to calculate a quick approximation of those effects called the "4th power law"[5]:

$$\text{Damaging effect of an axle load} = \left(\frac{Load}{Reference\ Load}\right)^4$$

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[1] https://www.ucprc.ucdavis.edu/ccpic/pdf/Mechanistic-Empirical%20Empirical%20Pavement%20Design%20Using%20CalME%20and%20PavementME.pdf

[2] Western Association of State Highway Officials (WASHO)

[3] American Association of State Highway Officials, now the American Association of State Highway and Transportation Officials (AASHTO)

[4] https://onlinepubs.trb.org/Onlinepubs/sr/sr61/61-g.pdf

[5] The Caltrans pavement design method from the 1964 to 2006 used an exponent of 4.2 instead of 4 based on Hveem's combining AASHO Road Test results with California field observations.

Using this quick approximation the following can be seen:

- The damaging effect of one pass of the heaviest axle on the heaviest Tesla car[6] compared to the damaging effect of one pass of a 20,000 lb maximum truck legal California single axle load = $(3,360/20,000)^4$ = 0.000797; taking the inverse, this means that it takes approximately 1,255 passes of the Tesla axle to cause the same damage as one pass of the truck legal limit single axle.
- The damaging effect of one pass of the manufacturer's maximum rear axle load on a Super Duty ¾ ton Ford pickup (F250) compared to the damaging effect of one pass of a 20,000 lb maximum truck legal California single axle load = $(6,340/20,000)^4$ = 0.0010098; taking the inverse, this means that it takes approximately 99 passes of the pickup axle to cause the same damage as one pass of the truck legal limit single axle.

Due to the insignificant damage caused by cars of any weight, including typical personal use or trade use pickups up to ¾ ton models, they have been completely excluded from consideration of pavement thickness design and pavement structural damage calculation (rutting and fatigue cracking on asphalt pavement, cracking on concrete pavement) since pavement design methods were first developed.

Since 2006, Caltrans has been developing increasingly sophisticated pavement structural analysis and design methods for asphalt and concrete pavements. In the early 2020s, Caltrans completed the most comprehensive calibration of those pavement design methods ever undertaken globally using data collected for the entire 50,000 lane-mile network from 1978 to 2018 (truly big data)[7].

Those asphalt and concrete pavement programs can consider the pickup load shown above and the effect on the pavement life, as well as the range of heavier truck axle loads occurring on state and local roads. As an example, using CalME[8], the Caltrans asphalt pavement design method, the damaging effect of 10 million passes of each of the following three axle loads on an asphalt pavement with 4.8 inches of asphalt and 6 inches of aggregate base on a clay subgrade are:

- 6,340 lb F250 Super Duty rear axle maximum allowable load: the pavement has a 95% chance of lasting 40 years before it needs a minor rehabilitation
- 10,000 lb single axle load: the pavement has a 95% chance of lasting 8 years
- 20,000 lb legal single axle load: the pavement has a 95% chance of lasting 6 months

For these reasons, and because the car and pickup axle examples shown (heaviest Tesla car, heaviest pickup) are extremes, **it is expected that heavier cars and light trucks, including those with electric batteries and fuel cells, will continue to have a very minor effect on pavement damage and pavement maintenance and rehabilitation costs.**

A 2022 report for the legislature[9] looked at the effects of battery electric and fuel cell implementation in medium and heavy trucks and similarly found a small impact on pavement. **Extrapolating those results to heavier cars and light trucks, there should be insignificant effects on pavement.** Looking at the analysis in that report of the effects of heavier trucks on bridges, **it is expected that heavier cars, including battery electric and fuel cell vehicles, and light trucks will have no effect on bridge maintenance and rehabilitation**.

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[6] https://www.carparts.com/blog/what-is-the-curb-weight-of-tesla-models/#
[7] https://escholarship.org/uc/item/03p4h24f; https://escholarship.org/uc/item/460234g0
[8] https://www.ucprc.ucdavis.edu/calme/
[9] https://escholarship.org/uc/item/4z94w3xr