Stability and Highway Damage

a correction of the Transportation Research Board's special report #267 recommendations concerning the Regulation of Weights, Lengths, and Widths of Commercial Motor Vehicles

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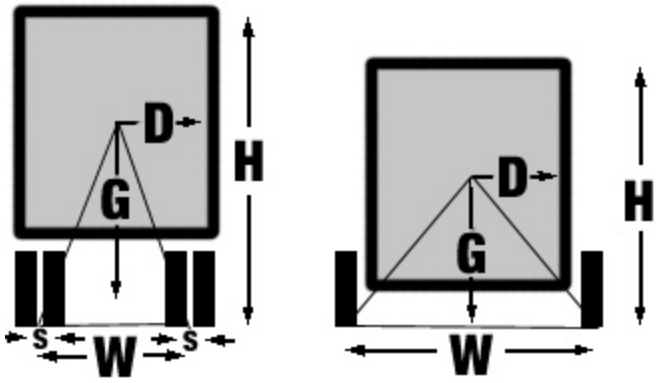
Part 1: Calculating Highway Damage

Using the Transportation Research Board's assumption that the highway damage caused by any truck axle varies by the fourth power of its weight {"That is, a pavement that could withstand 1 million passages of the 18,000-lb standard axle before reaching a specified terminal serviceability rating could withstand 16 million passages of a 9,000-lb axle before reaching the same rating." (special report #267, p58)}, it is possible to calculate the relative amounts of damage caused by unstable top heavy vehicles compared to safer, low profile truck designs by mathematical extrapolation:



Load Transfer Ratio = (D/G)/(W/H)
Highway Damage Multiplier = $(1 + DH/GW)^4$

D = Deceleration in ft/sec²; G = Gravity [g = 32 ft/sec²];
W = Wheelbase; H = Height

Deceleration is a measure of a truck's stopping ability, which varies according to speed, type of highway surface, tire pressure, amount of carbon black in the tire rubber, and tread pattern. A truck that takes six seconds to stop from 60 mph decelerates at 10 mph/sec, which is equal to 14.6 ft/sec². Such a truck will have a calculated stopping distance of 306 feet from 60 mph. Trucks with anti-lock brakes do better than this and are able to achieve a 16 ft/sec² average rate of deceleration. If the truck's tires have a block, zigzag, or cross hatch tread pattern, its resistance to being pulled sideways by centrifugal force when negotiating a high speed curve will approximately equal the stopping ability because the linear and lateral coefficients of friction are approximately the same. Thus, deceleration can be used as a substitute for lateral skid resistance in estimating vehicle stability and highway damage.

Using deceleration as a substitute for lateral skid resistance and the height to wheelbase ratio to substitute for center of gravity offset, it is possible to estimate the Load Transfer Ratio (the proportion of vehicle weight that is transferred to one side of the vehicle when negotiating a high speed curve) by factoring the maximum deceleration the truck is capable of divided by the gravitational constant with the width of the wheelbase divided by the height [i.e. D/G:W/H]. {Note: If the truck has dual wheels, the wheelbase is measured from points on the ground exactly between the dual tires on each side; thus an 8½ foot wide truck will have an approximately 6½ foot wide wheelbase.}

Federal weight and width restrictions presently prohibit trucks wider than 8½ feet. If an 8½ foot wide truck with a 6½ foot wide wheelbase is 13 feet tall and can decelerate at 16 ft/sec², then its Load Transfer Ratio will be approximately equal to one. If the Load Transfer Ratio is greater than one; the truck will roll over rather than slide sideways on a high speed curve. If the Load Transfer Ratio is less than one; the truck will slide sideways on the curve rather than roll over and the weight on the outside tires will be increased by the amount of the Load Transfer Ratio. The destructive scrubbing action of these severely overloaded tires on the highway surface is represented by the Highway Damage Multiplier [$(1 + DH/GW)^4$], which is thought to vary by the fourth power of the weight as estimated by the TRB. If the TRB's assumptions are correct, then the damage caused by a top heavy truck speeding around a curve will be sixteen times greater than if the same truck negotiated the curve at slow speed.

Part 2: Vehicle Height and Highway Damage

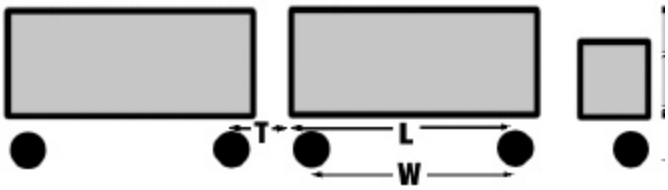
A lower, wider truck such as the Trescott Safety Truck will do less damage to highway curves when traveling at high speed than a high profile vehicle. A 9½ foot tall truck with a 9½ foot wide wheelbase will only transfer 50% of the weight on one side to the other side before the wheels start to slide. Its Highway Damage Multiplier will be only 5 times greater than the damage done at low speed rather than 16 times greater as with high profile vehicles. If reducing highway damage is not a priority, the Safety Truck can accommodate an axle weight one third greater than a high profile truck without doing any additional damage to curves when traveling at high speed. Because even a small amount of load transfer due to sway in a high profile vehicle significantly increases highway damage (i.e. a 10% load transfer results in a 50% increase in highway damage; a 20% load transfer from one side to the other doubles the highway damage), even small amounts of sway, such as when an inexperienced driver is weaving from side to side, can significantly increase highway wear. If inexperienced drivers are to be employed, the benefits of low profile trucks in reducing highway wear will not be limited to high speed curves.

An advantage of doubles and triples combinations is that trailers bound for different destinations can be combined on a single truck. For this reason, the Trescott Safety Truck is designed to carry two 20 foot containers at once. While 28 foot pups offer greater cubic capacity than 20 foot containers, increasing the containers' height to 12 feet would eliminate this advantage. 12 foot tall, 20 foot long containers hauled by a Safety Truck would have 95% of the capacity of 13½ foot tall 28 foot pups. The damage to highway curves would be 8½ times greater with a high profile Safety Truck compared to 16 times greater with pups.

Part 3: Multi Trailer Combinations and Highway Damage

Given the excessive highway damage predicted by top heavy vehicles in the above arguments and the well known risk of life threatening roll overs when such tripping mechanisms as pot holes and rutting are present, it is difficult to understand why the Transportation Research Board would recommend the use of long combination vehicles such as 33 foot double trailer combinations (special report #267, p.205). Such vehicles with multiple points of articulation exhibit rearward amplification—a tendency of additional trailers to magnify even small amounts of sway, such as that caused by a blustery crosswind, even when driven by experienced drivers.

Rearward amplification is caused by the tendency of dual wheeled vehicles to resist turning. Most vehicles have differential gears in their powertrains so that tires mounted side by side on the same axle can turn independently of each other. This is not true of dual wheel vehicles. Although the separation between the tires is only a foot and a half between centers, one of the dual tires must be made to skid if the axle is to turn. Minor steering corrections will not have an immediate effect, causing the vehicle to off track to the outside of the turn until enough force builds up in the flexible treads and sidewalls of the tires to make them skid. When this happens, the turn occurs suddenly, amplifying the lateral forces and increasing the highway damage. The lateral Rearward Amplification force applied to the pintle hook of a trailer pulling a dual wheel converter dolly or "congear" is:



Rearward Amplification Force = DS/2GT multiplied by the axle weight;

D = Deceleration in ft/sec²; S = Separation or Spacing between the dual tires on center;
G = Gravity [g = 32 ft/sec²]; T = Tongue length of the congear.

The Skid Resistance force available at the pintle to resist the rearward amplification force is:

Skid Resistance Force = DW/GL multiplied by the axle weight;

W = Wheelbase length of the front trailer from kingpin to axle;
L = Length of the front trailer from kingpin to pintle hook.

Dolly Jack

A normally loaded set of 28 foot doubles has a lateral Skid Resistance Force ten times greater than the Rearward Amplification Force. This means that a front trailer jackknife will normally not occur unless the front trailer axle is on a surface with one tenth the traction of the surface the dolly axle is riding on, such as if the truck drives over a patch of black ice. When the front trailer is on the ice, there will be insufficient force to steer the congear and the dolly will go in whatever direction it happens to be heading, pushing the front trailer sideways in front of it. When the front trailer regains traction, this condition can lead to a dangerously unstable condition called a "dolly jack" where the front trailer suddenly snaps back into alignment with the tractor, jerking the congear sideways on the ice so that the 5th wheel hinge provides little or no support to prevent the second trailer from rolling over. An experienced professional can prevent dolly jack by accelerating when he feels the first trailer break loose, but the increased use of low wage government subsidized truck driving school graduates to replace high wage skilled professionals has increased the likelihood of rollovers even

on dry pavement.

Dolly jack can occur whenever over-aggressive braking causes the front trailer axle to skid. Weight shifts forward onto the congear during braking and off of the front trailer axle, thus increasing the Rearward Amplification Force while decreasing the Skid Resistance Force. If an anti-lock system reduces braking pressure to keep the trailer axle tires rotating, the trailer may snap back into alignment with the tractor after a skid—causing a dolly jack. It is the propensity of anti-lock equipped vehicles to slide sideways off the road while braking on curves that may explain the dramatic 21% increase in single vehicle trucker fatalities in 1997, the year anti-lock brakes were mandated. Single vehicle trucker fatalities have remained 16% higher since then (NHTSA).

Long Combination Vehicles

While anti-lock brakes do not offer a solution to dolly jack, adding weight to the back of the first trailer reduces the problem: A "Rocky double" (a 48 foot semi-trailer pulling a 28 foot trailer) having a 34,000 lb. tandem axle with L = 45 and W = 42 provides almost twice the lateral skid resistance of a 20,000 pound pup axle with L = 25 and W = 22. While the Transportation Research Board has recommended adding tandem axles to 33 foot long doubles, the benefits of this are not a great as with Rocky doubles because of the less optimal kingpin to pintle length vs. wheelbase ratio. If the wheelbase of a 33 foot trailer were kept at 22 feet from kingpin to suspension rocker to retain the same low speed cornering ability as a 28 foot pup i.e. L = 30 and W = 22, then skid resistance is only improved by 50% instead of the 90% improvement provided by the Rocky double combination over the 28 foot pups. The TRB has also recommended a permit program that would allow multi-axle dollies. This recommendation is ill advised because the rearward amplification force of a 34,000 pound tandem axle congear is twice that of a 20,000 pound single axle dolly. Multi-axle congears should only be used on long turnpike doubles or behind tridem axle sets. Interestingly, the TRB did not recommend super single tires on dollies to reduce rearward amplification (S = ½ tread width). The rearward amplification force of a tandem axle congear is calculated thus:

Rearward Amplification Force = $D(S_a+S_t)/2GT$ multiplied by the axle weight;

S_a = Axle Separation; S_t = Dual Tire Separation on centers.

Part 4: Cargo Weight Limits and Highway Damage

Special report #267 fails to mention another obvious method of improving safety and reducing pavement wear: cargo weight limits. Truckers cannot determine the weight of cargo just by looking at it. By the time they find out they are overweight, they are already guilty of violating weight laws and are routinely coerced to pay fines for summary violations even when no motive or criminal intent can be proven. Cargo weight limits would shift the burden of enforcement from innocent truckers to the unscrupulous shippers who knowingly overload their trucks. If truckers were given large rewards for reporting unscrupulous shippers instead of being fined after being victimized by them, the problem of highway damage caused by overweight loads would quickly disappear. Yet, the TRB's recommendation to allow heavier trucks seems designed to thwart the idea of cargo weight limits because their "Recommended Bridge Formula Limits for Axle Groups" (special report #267, Appendix D, chart ES-3, p.260) would allow virtually every possible vehicle configuration to carry a different weight of cargo.

Cargo weight limits offer obvious benefits in regulating long combination vehicles. A 50,000 pound industry wide cargo weight limit would not affect present truck operators since an 80,000 pound 18 wheeler cannot safely carry more than that anyway, yet there would be benefits to those operators who carry bulky light weight cargo such as empty beer cans or building insulation. A turnpike double with less than 50,000 lb. of cargo would do less damage to the roads than two smaller trucks because the weight of one tractor is eliminated, a multi-axle congear is not needed, and the axles are not loaded heavily enough to cause pavement damage due to sway. A trucker pulling a rocky double with 50,000 pounds of cargo evenly distributed along the length of its trailers could slide its trailer tandems forward to obtain a turning radius and cornering ability equivalent to an ordinary 18 wheeler when traveling at low speeds, then slide the tandems all the way to the rear for better stability than the 33 foot pups recommended by the TRB when traveling at high speed. It is difficult to understand why the TRB would recommend 33 foot pups (special report #267, p.205) when Rocky doubles will be safer, do less damage to the roads, and provide an additional 720 cubic feet of cargo space.

Replacing the 80,000 pound gross vehicle weight limit with a 50,000 pound cargo weight limit would allow truckers to retrofit existing trucks with crash absorbent bumpers, disc brakes, sway bars, additional axles, batteries for regenerative braking, and other safety equipment which is currently discouraged under the existing weight laws. The use of unusually light weight components to comply with rigorous vehicle weight limits not found in Canada, Mexico, or Europe has made American made trucks unreliable and prone to constant breakdowns. To carry 50,000 pounds of cargo on a 30,000 pound truck is the equivalent of an entire family riding around in a 300 pound go-cart! Increasing vehicle weights as recommended by the TRB without restricting cargo weights will do nothing to improve safety or reduce pavement wear. Unscrupulous shippers will just increase the weight of their cargoes and truckers who choose to equip their vehicles with additional safety equipment will continue to be cited for violating weight laws.

20 Metric Ton Cargo Weight Limit

Congressman Ron Paul's Safer Truck Act (HR 1248) creates an exception for non articulated single unit trucks to allow a cargo weight of 20 metric tons or 44,080 pounds in a 40 foot container regardless of bridge law restrictions. Under the TRB's TTI HS-20 recommended bridge formula [Gross Weight =1,000 (Wheelbase Length/2 +62)], a Trescott Safety truck with a 43 foot wheelbase could legally weigh 83,500 pounds—only slightly less than the 86,000 pounds its 34,000 pound tandem steer axles and 51,000 pound tridem rear axles would reasonably permit. Because of the almost insignificant difference between the recommended bridge law limit and the exception to it, this cargo weight limit is more of an enforcement issue than a structural one: It is not practical to set up million dollar weigh stations along the very short local routes upon which intermodal vehicles operate. Without a cargo weight limit, intermodal vehicle weight limits will be unenforceable. Worse than that, weight limits might be selectively enforced in much the same way as Road Railers were put out of business in the early '90's when weight enforcement officers, fearing the loss of their jobs to intermodalism, set up portable scales and stopped every trailer that had rail wheels dangling from it. Drivers who were paid only $25-30 per shag quit their jobs rather than pay several hundred dollars in overweight fines per five mile trip.

Containers on container chassis weigh approximately 6,000 pounds more than an equivalent truck trailer; therefore the cargo weight limit for containers should be 6,000 pounds less than permitted in a truck trailer. 20 metric tons is a round number that international shippers can easily remember and it is 5,920 pounds less than the 50,000 pounds customarily carried on domestic trucks. International shippers will be encouraged to pack dense cargoes into 20 foot containers. The Trescott Safety Truck will be able to carry a 15 metric ton 20 foot container on its rear tridem in place of a 20 metric ton 40 foot container.

Part 5: Conclusions and Recommendations

It is not possible to establish a direct relationship between the tendency of a vehicle to sway and the amount of highway damage it causes because that depends on the skill of the driver. It is reasonable to assume, however, that if an inexperienced driver in a top heavy vehicle is twice as likely to roll over as an experienced driver in a safe vehicle, then the amount of highway damage caused by that driver or vehicle will be at least twice as great. There is little moral suasion for skilled professionals to comply with weight laws if they must compete with government subsidized truck driving school graduates operating unsafe vehicles. Even if a skilled professional overloads his truck with twice the legal weight of cargo, he may do so with a clear conscience if he feels he is doing no additional harm to the pavement than his competitor.

Changing regulations can have unintended consequences. Unless cargo weight limits are imposed, allowing 6 and 7 axle trucks to carry additional cargo could lead to a proliferation of severely overloaded 5 axle trucks as their owners struggle to stay in business at a severe competitive disadvantage. The availability of 55° multiple steering axles on 45 and 50 foot long 5 axle unibody trucks will make them more maneuverable and easier to drive than 18 wheelers. They will be capable of very high speeds—faster than a car can safely go. Such vehicles could also have trailers like articulated busses with steerable tridem rear axles. While today's motorists complain about slow trucks, future truckers may compete with air freight companies and complain about slow cars.

Posted speed limits are increasing. Truck stopping distances need to improve. While a short haul intermodal truck such as the Trescott Safety Truck can have a lower tire pressure to achieve better stopping ability than a long haul truck without fear of overheating the tires, the above math demonstrates that better tread adhesion increases the risk of rollover. Even cars will roll over if the tire pressure is low enough (as in the case of the Ford Explorer SUV). Before improvements in stopping ability can be considered, trucks must be made less top heavy.

HR 1248 will deregulate the overall width of trucks to allow wider wheelbases so that detachable cargo bodies such as intermodal containers with built in rail wheels can be lifted from railroad tracks, ships, and barges to replace top heavy long haul trucks. Skilled professionals will find the safer trucks easier to drive, despite their additional width, because they will not sway. Local governments may choose to widen certain roads in industrial neighborhoods to help inexperienced truck drivers stay in their lanes, but this will not be necessary for skilled professionals. The significant savings in highway maintenance from eliminating top heavy long haul trucks will easily offset any additional cost in maintaining local roads. But, the transition to intermodal will be less complete if cargo weight limits are not imposed on existing trucks. If larger, heavier trucks will reduce the number of trucks on the road, then putting trucks on trains and barges will reduce the number even more.