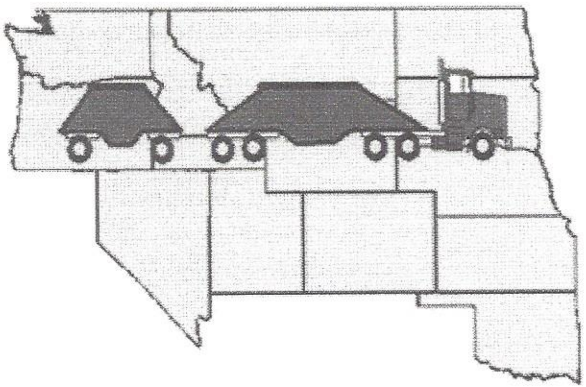
U.S. Department of Transportation Federal Highway Administration

Attachment J page 1

Chapter V

Bridge



Western Uniformity Scenario Analysis

Introduction

Damage to highway structures represents the most critical infrastructure cost of allowing larger and heavier trucks on the nation's highways. All of the studies performed by the Federal Highway Administration (FHWA), the Transportation Research Board (TRB), and several universities in the last ten years that examined potential impacts of truck size and weight (TS&W) increases have found that the estimated damage to bridges would be the greatest single infrastructure cost caused by larger, heavier trucks.

Impacts of Truck Loads

Bridges must be strong enough to safely accommodate all vehicular traffic. This accommodation of truck loads is the critical element in the design of highway bridges, except for the few very large bridges where the weight of the bridge itself is so much greater than the traffic loads that the bridge weight is the critical element. The analysis described below examines and compares the bending moments (and therefore the bending stresses) produced by the set of scenario trucks and the base case trucks with the moments caused by the bridge rating vehicle. Before documenting this analysis, bridge behavior when subjected to truck loads is briefly discussed.

Stresses

In general, bridges must accommodate three forms of stress: bending stress, shear stress and fatigue stress. If a weight were placed at the center of a beam that is supported at each end, the beam would bend, or deflect. Material at the bottom center of the beam would stretch and at the top of the beam it would compress. Truck loads produce a bending moment, which inflicts this stress. A bending moment is a load times a distance; in bridges it is a point or equivalent point load (in cases of uniform or non-point loads) times the distance of that load to the nearest support. There is a direct one-to-one relationship between bending moment and bending stress.

Shear stresses can be thought of as those stresses caused by a force that cuts (i.e., shears) rather than bends the beam. For example, if a very large load were applied very close to the support, there would be no significant bending action (since the distance to the support is very small), however, the beam would resist the "cutting" action, that is, the shear stresses. Fatigue stresses are, most simply, repeated bending stresses. Everyone who has repeatedly bent a paperclip back and forth until it breaks has caused fatigue stresses to the metal of the clip. Although bridge engineers consider and design for all three stresses, in most cases, the bending moment stresses are the critical factor in the design.

Types of Loads

Live Load Stress (weight) Dynamic Load Stress (moving weight)

Trucks affect bridges in several ways. When moving across a bridge, they produce static live loads and dynamic live loads.

These loads result in the bridge experiencing bending, shear and fatigue stresses. The weight of the vehicle causes the live load stresses; its movement across the bridge, in conjunction with its weight, causes the dynamic stresses; and the movement, weight and the number of repetitions cause the fatigue stresses. When designing bridges, engineers typically increase the static load by a fixed percentage (about 10 to 30 percent) to account for the dynamic load.

Additionally, the bridge must withstand dead loads (the weight of the bridge itself, including the weight of future overlays), wind, thermal, earthquake, and other loads. The AASHTO bridge design manuals provide procedures to account for all these stresses.

Critical Stresses for Analysis

This analysis concentrates on bending moment stresses for several reasons. Generally a bridge designed to accommodate the bending moment stresses caused by the live, dead and dynamic loads, will also accommodate the fatigue and shear stresses. Thermal, wind and seismic stresses are not a function of vehicle weights and dimensions. If the bending stress is excessive, the other stresses usually are excessive as well. This is one reason that bridge replacement often is the best solution for an overstressed bridge. Another important reason is that highway agencies often must improve safety features, alignment, lighting, utilities, and other level of service characteristics if they strengthen a bridge. When costs of these other improvements is added to the cost of strengthening, total bridge replacement often is found to be more cost effective. Strengthening is possible for only some bridge types. Steel girder, some truss and even some prestressed concrete beam bridges can be economically strengthened if they meet all other stress and level of service criteria, but reinforced concrete slab and several other bridge types cannot be easily strengthened.

Bridge analysis for nationwide policy studies must rely on readily available nationwide data. The FHWA's National Bridge Inventory (NBI) is the only such dataset that meets this objective. Unfortunately, the NBI does not contain any detailed data describing the bridge geometry, location of details and the like which effectively rules out the analysis of fatigue, shear or other stresses that require this level of detailed data on the individual bridge design elements. However, the NBI does contain sufficient data describing the bridge length, support type, design type, material, etc., that permits the accurate estimation and computation of the live load and total bending moments. This is an additional reason why previous studies of national TS&W policy issues have either ignored fatigue and other less critical stresses or have handled them in a very simplified manner. But, as noted above, little is gained by considering fatigue or other stresses, since the bending stress is a reasonable proxy for all stresses.

Design Vehicles, Ratings and the Federal Bridge Formula B

An examination of design vehicles, ratings, and the Federal Bridge Formula B (BFB) is necessary in any study of the impacts of TS&W changes, because these three concepts are interrelated with the concept of bridge overstress, which is the measure used to identify bridges that might require improvement if size and weight limits were changed.

Design Vehicles

Bridge engineers developed the concept of design vehicles prior to World War II. They are hypothetical vehicles intended to represent the entire truck fleet in the vehicle stream. Use of the design vehicle allows the engineer to design bridges to safely withstand live load stresses caused by a single envelop vehicle rather than having to estimate stresses for each of the many different types of trucks on the road. Most States use one type of design vehicle, the HS vehicle. The HS vehicle is a three-axle vehicle with the load on the steering axle of X tons, a load on the second axle of 4X tons 14 feet behind the steering axle, and a load on the third axle also of 4X tons spaced 14 to 30 feet from the other non-steering axle. The engineer tests several axle spacings for the distance between the second and third axles to determine which axle spacing produces the maximum stresses. In most cases, the HS vehicle with the short 28-foot wheelbase is most critical. The number immediately following the HS is the total weight of the vehicle in tons divided by 1.8. Consequently, the HS vehicle weighing 72,000 pounds would be the HS20 vehicle, since 36 tons (72,000 pounds) divided by 1.8 is 20. This vehicle would have a 4-ton load on the steering axle and loads of 16 tons on each of the other two other axles.

Bridge Ratings

States report two bridge ratings to the FHWA for inclusion in the NBI, the inventory rating and the operating rating. The inventory rating is effectively 55 percent of the yield[15] stress of the bridge and the operating rating is 75 percent of the yield stress. The design stress level for new bridges is effectively the same as the inventory rating, 55 percent of the yield stress. The FHWA requires that states report these ratings in terms of the hypothetical HS vehicle.

To determine the inventory rating of a bridge the analyst will compute the heaviest HS vehicle that can traverse the bridge such that the weakest structural member is effectively at 55 percent of its yield stress. In a well-designed bridge, once loaded, all the designed members will be at or near 55 percent of their yield stress. Generally, that produces a safety factor of 1.8 (1÷0.55). Most States allow full and legal operation of trucks that produce bending moments on a particular bridge less