Designing the Highway
for the Vehicle

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Basically, all highway designers, traffic engineers, planners and expediters are concerned with one problem: designing a highway to accommodate an optimum number of vehicles with a minimum amount of discomfort for the least cost.

The major difficulty facing the highway designer of today is the lack of a formal design procedure. Unlike the more organized engineering approach, wherein a design is developed from first principles and then tempered by experience, the highway engineer relies almost entirely upon prior knowledge. Thus, we have the "grade-separation" expert, the "drainage man," the "intersection designer," the "traffic engineer," and so forth, each of whom is a specialist able to reproduce his given speciality based on accumulated experience. This situation is not new. The history of engineering is replete with similar examples, as witness the coefficients of the hydraulics people prior to the formulation of fluid. mechanics, the "code" expert who pre-dates soil mechanics, and others. In each area, rule-of-thumb methods prevailed until the advent of a more scientific approach.

It is evident that if highway design is to be organized into a rational procedure, our knowledge must be consolidated around a framework of design concepts. To demonstrate the feasibility of this approach, an analogy will be drawn between highway design and the better known fundamentals of structural design.

NATURE OF LOAD

The loading concept for highway design is traffic, generally expressed on a volume of vehicles per unit time basis (vehicles per hour). All loads are dynamic, with magnitudes and frequencies strictly time dependent.

For open highway conditions there are two characteristic loads, passenger vehicles and trucks. For fairly level conditions, one truck

is considered equivalent to two passenger vehicles, and for rolling terrain the ratio is 1:4. This is much the same as designing a structure for dynamic loads by using static formulae, adjusted by empirical factors.

At intersections, where the turning characteristics of vehicles control, four design vehicles are considered, passenger vehicles, (P design); single unit trucks, (SU design); and two semitrailer combinations, (C 43 and C 50). Occasionally, where extraordinary vehicles are encountered, the characteristics of these vehicles are studied and appropriate adjustments are effected.

ALLOWABLE STRESS

The design speed sets the level of design. It can be thought of as being analogous to the allowable stress. For example, suppose we were to design a beam to carry a load that produces a unit tensile stress of 25,000 psi. Obviously, the use of unreinforced concrete is out of the question. Similarly, a multilane highway would not evidence a rope bridge. Design speeds are generally expressed in ten-mile-per-hour increments from 30 to 70 MPH.

In engineering design, the allowable stress represents a modification of a limiting stress by a factor of safety. Similarly, a design speed of 60 MPH does not imply that vehicles cannot traverse the roads at higher rates. Indeed, it must be assumed that some vehicles will exceed this speed. Thus, the design must possess sufficient flexibility to permit occasional excesses without resulting in failures (accidents and stagnation). In the case of highways, however, the reduction from the ultimate stress to the allowable (from stagnation to design) is achieved through a modification of the section modulus (from possible capacity to design capacity).

WORKING STRESS

The average running speed of a highway is its working stress. That is, it allows us to proportion the highway with a finer degree of control than is furnished by the design speed. Thus where we are concerned with the design at points of stress concentration, such as intersections and channelized sections, or with individual elements of the road, such as super elevations, curves and so forth, the average running speed provides a more positive means of measuring the security of our design.

For design, the average running speed is considered as a percentage of the design speed, varying linearly from 70 per cent at

70 MPH to 90 per cent at 30 MPH, often, simply assumed as ¾ of the design speed.

SECTION MODULUS

The concept of a section modulus has its counterpart in highways in the number and width of traffic lanes; the *capacity* concept. This concept lends itself to the so-called handbook approach, wherein a 12 WF 50 section is specified for a beam with a given load and span, assuming suitable lateral support. The capacity counterpart of a highway would be a 12 ft. wide lane for a two-lane highway with 750 vph, in both directions, with 10% trucks on a level terrain, assuming no restrictive lateral clearance within 6 ft. of pavement edge. This capacity is called the design capacity as it is directly applicable for use in design. It should be noted that just as the AISC design tables are based upon reasonable working stresses (20,000 psi) so are the design capacity values based upon typical speeds of operation 45-50 MPH in rural areas, 35-40 MPH in urban areas.

As noted above, the design capacity represents a reduction of the ultimate by a factor of safety. That is, for any section of highway, according to AASHO, there exists a "maximum number of vehicles that can pass a given point of a lane of a roadway during one hour under the prevailing roadway and traffic conditions, regardless of their effect in delaying drivers and restricting their freedom to maneuver." The highway section commensurate with this volume is said to bear the possible capacity. Generally the factor of safety, that is, the ratio of the possible capacity to the design capacity, is 2-2.5.

NATURE OF MEDIUM

Highways are truly elastic. Although a facility may be strained during the so-called rush hour or peak periods, recovery is complete once the load is removed. Also highways are perfect examples of plastic design. That is, highways are often required to carry traffic loads either in sections (ramps), or in total far greater than its design capacity. This generally results in temporary speed reductions, much like larger deformations; however, unlike its structural counterpart, upon the lightening of the overload immediate and perfect recovery is realized.

A facet of design which appears to offer considerable promise to highway "designers" is the "theory of similitude," relating the flow characteristics of highway vehicles with the inanimate theories of the flow of heat, of electric current and of fluids. The principle deterrent of this approach is the character of the highway vehicle.

In kinematics, we interest ourselves in the motion of particles. In kinetics we study the forces which cause these movements and the reaction to this motion. The particle itself, other than its inertia, is passive and must follow a prescribed path at a velocity dictated by the external forces. Relative to its path, a vehicle can also be considered as a particle. However, a vehicle is a free agent capable of creating from within forces that can alter its path. It is this inner being that complicates our prediction of vehicular action.

How severe is the assumption of a vehicle as a particle? Certainly, it provides us with adequate estimates of stopping distances and superelevation rates. Is this assumption less sophisticated than the rational approaches of the sister engineering disciplines?

Consider the following: For the most general elastic material there are 36 elastic constants of which 21 are independent. Assuming isotropy and homogeneity—there are only two (Poisson's ratio, and Young's modulus). Thus, in almost all problems homogeneity and isotropy are assumed *a priori* with the degree of approximation bearing the apology of a factor of safety. In fluid mechanics, assumptions of Newtonian fluids, of incompressible fluids, and of infinite drag are not uncommon. Engineering science is replete with semi-infinite masses, point loads, infinite velocities etc.

Assuming particle-like attributes to highway vehicles, we have at our disposal powerful analytical tools for predicting the behavior of the vehicle. For example, applying the well-known one-dimensional heat flow problem, with the thermal conductivity as a measure of the resistance to vehicular flow, the specific heat as the energy required to accelerate, and the density of the material as the traffic density, we can easily calculate the velocity distribution of vehicles. Or, perhaps, what is more important, by observing velocity distributions at highway sections, we can evaluate quantitatively the various elements of the highway for different vehicles with a variety of traffic densities. Once we have attained a measure of these components, a rational framework of design will have been established.

To date, with rare exceptions, the contributors to this philosophy have been in the area of "Operation Research." The results of their work clearly demonstrates the validity of this approach.