DESIGNING PAVEMENTS FOR REALISTIC TRAFFIC

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ABSTRACT

Pavement design in the United States has taken several forms in each of the states and local highway agencies over the last 50 years. In most cases the designer has made some estimate of the existing and projected traffic that will use the facility over its intended life. Often these estimates are made from very small amounts of actual site data, and projections are made with little concern for the growth in individual classes of vehicles.

The Iowa Department of Transportation has been involved in two weigh in motion projects that are designed to provide the designer with accurate estimates of the weights and axle configurations that travel over the existing roadways and contribute to its performance or lack thereof. The dynamic weights of the vehicles are correlated to the static weights to provide the designer with two methods of design, the first being that of the conventional pavement design using the static loads and the associated stresses. The second provides the designer with a way to look at all the loads (legal and illegal) and consider the dynamic stresses that are induced by the traffic stream in addition to considering the material characteristics in a truly mechanistic design.

Examples of the information gathered at an I-35 and I-80 site are used to illustrate the effect improved methods of data collection to obtain weight and axle configurations using the Weigh in Motion equipment as compared to the static weights used in conventional designs. Estimates of the difference in required pavement thickness and the pavement performance for each type of data will be presented to indicate the impact of the vehicle information on the design of pavements.

Recommendations regarding the types of traffic data that can aid the pavement designer in providing a better performing pavement are identified. Weigh in motion devices are identified as the best way to meet the need to provide detailed, site specific, and timely data for the best pavement design traffic.

INTRODUCTION

Pavement design in the United States has come a long way over the past 50 years. What began as a cut and try type method with each pavement being designed to meet current traffic and soil conditions, has evolved into a sophisticated process to predict many of the variables prior to construction. Early pavements relied on the experience of the designer to observe the past performance of different pavement designs and continue to improve on that past performance. Todays methods now rely on statistics and a knowledge of the foundation and pavement materials performance characteristics to provide a pavement that meets certain traffic service criteria. This mechanistic approach is coupled with historical performance (empirical knowledge) of similar pavements in operation at the time of the design. The 1986 AASHTO Pavement Design procedure allows the designer to characterize the behavior of the foundation layers in terms of strength and pavement layer resistance to certain types of distress in an effort to limit or predict the time, type and amount of failure.

One of the major inputs into the pavement design that is often slighted is that of the traffic estimate whether it be the current or future prediction over the expected life of the pavement. It is important that the designer and the traffic planner properly communicate the magnitude, type, and volume of traffic that is currently and will use the pavement being designed. This means that consistent and accurate data, complete with the assumptions included must gathered and transmitted between the parties. It means that the designer must gain a greater understanding of the traffic characteristics using a given route to properly assess the reasons for distress that may be apparent in the existing route and to develop a design that will resist the anticipated traffic demands in the future.

For the purposes of this paper, an instrumented section of I-80 in western Iowa will be used as an example of how the traffic problem might result in changes in design or performance.

EXAMPLE SITE DESCRIPTION

The Iowa Department of Transportation and Iowa State University are currently involved in a Pavement Instrumentation project (Demonstration Project No.621) for the Federal Highway Administration in western Iowa along I-80. The site, located in the westbound lanes, approximately one mile East of the junction of I-80 and I-680, includes a forty foot length of instrumented portland cement concrete and modern piezo electric cable configurations. The piezos are used to both classify the vehicles in either lane upstream from the strain gage instrumented slabs and act as a weigh in motion site downstream from the instruments.

The site is supplemented with a continuous recording loop detector approximately one and one half miles east of the piezo cable site. Data from this site for each lane and direction is telemetered to the Central office daily for development of statewide data files on classification and vehicle volumes.

Permanent static weight scales are located some seven miles East of the piezo cable site and are used on a random basis by the Iowa DOT for a truck law enforcement site. Improvements are underway at this time to improve the scales to handle a 90 foot axle spacing in one weighing. This site is used also to calibrate the piezo cable output.

The instrumented site is situated near a small stream bridge which tends to direct the traffic over the sensors rather that provide alternate ways to bypass the data collection units. Weight in Motion devices have been effectively used on bridges or on standard pavement sections to detect traffic characteristics. This site was first planned for the bridge weight in motion device use, but changed to include the piezo classification unit east of the bridge as a trigger for the instrumented pavement and the weigh in motion site west of the same instrumented pavement.

Piezo cables are located in such a manner as to provide vehicle, axle and gross weights, axle spacing, vehicle speed, speed, and lateral location in the lane (on scale detector). The weigh in motion arrangement allows for the measurement of the tire print width and area to aid in the contact pressure calculation. Strain gages in the pavement section between the classification piezos and the weigh in motion cable arrangement will allow the research team to measure pavement deflection, concrete and steel strain. Tubes under the pavement in the same area will allow the designer to observe relationships between the moisture and density of the base and the pavement performance.

TRAFFIC CONSIDERATIONS

Much can be learned about the current pavement distress problems in a given pavement by assessing the vehicle classification and weight data for the particular site. This is the reason that the Strategic Highway Research Program sought to have classification and weight data gathered with each Long Term Monitoring Section.

Information was present for the test site on I-80 for both classification and weight data. It was the intent of the writer to use data from the weigh in motion sensors to illustrate the problems and solutions to the traffic problem. This proved to not be possible due to calibration problems at the site lack of access to such data at the present time. Permanent static scale, and permanent classification recording devices east of the site will provided the information for illustration of the problems and solutions.

The first piece of information that the designer usually has access to is some type of traffic log. In Iowa this is an annual report that identifies the average annual traffic volumes one each segment of the State Road system, along with presenting information on the various vehicle classifications and the vehicle miles of travel estimated on the section in terms of trucks and busses and all vehicles. The designer should be informed about any seasonal variations that might influence the performance of the pavement during times of seasonal subgrade reductions in support. Most new pavement design programs do take these reductions into account, but the designer should check this option in the program to understand how the impacts are considered. Some eleven classes of vehicles from cars to double bottom trucks are included in the listing. The data for the test section is as shown below:

Pottawattamie County I-80 from the Co Road L66 to Co. Road M16
Length - 4.41 miles
Average Daily Traffic - 11,700 vpd
All Vehicle Miles of Travel - 51,597 daily
Truck and Buss Vehicle Miles of Travel - 19,642 daily
Classifications (vehicles per day)
    Cars - 5,876
    Pickups/vans - 1,370
    2 axle single unit trucks - 296
    3 axle single unit trucks - 112
    Busses - 45
    Recreation vehicles - 219
    Truck and trailer - 9
    3 axle truck-tractor semi trailer - 25
    4 axle truck-tractor semi trailer - 29
    5 or more axle truck-tractor semi trailer - 3,499
    Double bottom truck-tractor semi trailer - 220

From this document the designer can view the current total volume (cars and trucks) to identify construction scheduling and traffic control plans. A review of the number of large trucks in the traffic stream may point to the stability required in any temporary pavements to maintain traffic during construction.

In the past many designers would have assumed the volume of trucks as a percentage of the total traffic (38% in the example). This works fine as a way of identifying the volume constraints in capacity analysis for the pavement, but misses several important aspects of how the vehicles will damage the pavement over its life. The designer must begin to look at the characteristics of the single and multi-unit vehicles in assessing the reasons for the current condition of the pavement. Some of the questions to be asked about the data are: How many of the vehicles are using each lane? How many are loaded vs empty and in which direction are the loaded vehicles travelling? What times of the day are the loaded vehicles using the pavement? Of those loaded vehicles, what is their weights (axle and gross) and what if any are the magnitude of the overloads? What is the configuration of the axles on the vehicles and what is the damage done by each axle on the existing pavement? How has the registration and weight laws effected the configuration of the vehicles using the road in question? By now you're saying "pavement design was simple prior the cars getting smaller and the trucks getting larger" and it was to some degree. In an effort to regain control of the pavement design process, we have developed new ways to gather data to answer the questions.

In the case of the test section, a continuous recording station consisting of electronic loop detectors in the pavement is located 1.5 miles West of County Road M-16 on I-80. The unit provides a count of the total vehicles in each lane by a given increment of time on a twenty four hour basis. The unit is polled daily by a micro computer at a central location to down load all the previous days' information. Some seven days of such information were analyzed for the site (Wednesday, March 1-Tuesday, March 7, 1989). The data shows that there is nearly an even split directionally in the traffic (51% Eastbound and 49% Westbound) on an average daily basis. It is important to inspect this aspect of the traffic to determine the difference in pavement wear that may result from excessive vehicle miles of travel in one direction. The same data indicates that 83% of the traffic is using the outside lane in each direction. This may account for any unusually rapid increase in the distress occurring in the outside vs inside lane in each direction.

The same data provides three classes of vehicles by axle spacing. The spacing criteria is flexible, and is currently set to identify: passenger cars and pickups, single unit trucks, and tractor-trailer semi in per lane and sum hourly over a 24 hour period. This information confirms the directional split (51/49%) and shows that approximately 60% of the trucks are travelling over the section during the period between 1 PM and 6 PM on primarily weekdays. This is important in several ways. It can be used to determine the safest times to do rehabilitation work. Since the test site is a newly reconstructed portland cement concrete pavement, it indicates that a majority of the heavy loads will likely pass over the pavement during the warmest part of the day when the slabs are tightly locked together. This may prove to enhance the performance of the pavement. There will be examples of pavements that are subjected to the heaves loads during the part of the day when they are in their weakest position where the joints are curled up and loss of support is accelerated.

The same information indicates that nearly 46% of the traffic using the outside lane is trucks while the inside lane contains primarily cars (23%) trucks. This is another factor accounting for the unequal amounts of stress being placed on the pavement and the potential for unequal amounts of distress to appear in the different lanes. It may become a factor in the design of the thickness of each lane or the scheduling of rehabilitation plans.

No traffic analysis is complete without information on the weight of each vehicle that will use the pavement. In the case of Iowa, truck weight studies are conducted biannually to determine the profile of truck weights passing over the highway system. In the test site case area, such a study was completed in 1987 and the permanent truck scale location on I-80, 4 miles East of U.S. 59 (approximately 9 miles East of the test section). The study is completed without the use of traffic enforcement in an effort to gain a more accurate sample. This has been the approved method prior to the advent of weigh in motion devices. Some 18 such stations are located around the state for use in selected years to develop a picture of the various truck weights, identify the commodities being transported and gather information relative to the vehicles and drivers. The weight information is also used to develop damage factors (18 Kip Equivalent Single Axle Loads) for single and tandem axle configurations in each of the various weight classes and vehicle axle classifications specified by the Federal Highway Administration (FHWA) reporting requirements.

The FHWA study data is provided to the user agencies in the form of summary tables. The W-4 table provides such damage factors for one set of rigid and flexible pavement criteria for each of thirteen weight classes for single axles (under 3,000 - over 30,000 lbs.) and sixteen tandem axle classes (under 6,000 - over 50,000). This document is important to the designer in determining which vehicles are providing the largest portion of the damage to the pavement. A quick review of such a table of data from a site near the test pavement or on one of similar traffic classification and use provides the designer with a look at the predominant weights noted for single and tandem axles during the weight study for each classification of vehicle.

The same study field data can indicate the number of empty and loaded vehicles by direction on the test segment. The test site data indicates nearly equal amounts of loaded vehicles in each direction. If this road had served a quarry, grain loading facility of similar location, the data would indicate large differences in loaded vehicle numbers by direction. Data such as this helped answer the question of premature failure of one lane in a county road pavement in Iowa.

Trucks exceeding the legal limits can also be identified in such a study to some degree. Even though no tickets are written in conjunction with a weight study, many overloads are observed taking alternate routes or waiting until the study is complete prior to travel through the test area.

Some 41,092 trucks were counted, including 13,712 trucks weighed on the Interstate as part of the 1987 study. This included 429 trucks at the permanent scale site on I-80 (site 93P) as shown in the FHWA table (W-6). It is interesting to note that 98% of the trucks weighed at this station where five axle tractor trailer units. Of those trucks weighed, 12% exhibited gross weights in excess of legal limits. In most of the cases the excess amount of weight was minimal but indicated an desire on the haulers part of maximize the use of the vehicle and its licensed weight. Another 8% of the vehicles exhibited axle weights in excess of the legal limits by more than 10% (20,000 lbs single, and 34,000 lbs tandem). A detailed review of the vehicle weight data indicates that most of these illegal loads were found on the five axle vehicles and on the highest overloads being found on the tractor tandem axles and the rear axle on the trailer. The excess weights on these axles was in the range of 23% over the legal load.

The overload information is sometimes not communicated to the pavement designer and this can be dangerous. The Portland Cement Association design method associates pavement stress to loads beginning with the largest loads first and working toward the point where the allowable stress repetitions are exhausted by the loads. Failure to use all loads expected on the pavement could overestimate the life of a given thickness or underestimate the number of vehicles that a given pavement will serve. The AASHTO design procedures uses all the vehicle types and weights to develop the damage factors for each axle in determining the thickness required for a given set of expected traffic conditions. The pavement thickness can be underestimated unless all existing truck weights are considered in conjunction with the increase in truck weights over the past years. An 18 Kip growth factor commensurate with each class of vehicle and functional class of roadway is a must for proper estimation of the traffic and the required pavement thickness. That value should be determined from weight studies and contain at least ten years of data to be reliable for prediction use.

EXAMPLE PAVEMENT DESIGNS

In a effort to consider the importance of proper traffic analysis, a sample design for the test site was developed using the AASHTO design procedure. The information provided for the design variables is representative of Iowa conditions rather than being the exact values for this site. Design inputs that were held constant in the example included: effective subgrade modulus of 150 pci, concrete elastic modulus of 5 million psi, concrete modulus of rupture at 650 psi, load transfer factor of 3.2 for dowelled pavement with no tied shoulders, drainage coefficient of 1.0, allowable changed in present serviceability index of 2.0 (4.5-2.5), reliability of 95%, and a standard deviation of 0.3.

The traffic used in the example is the same that was identified in the classification information earlier in this paper. Traffic loading (18 Kip) growth factor of 2% were applied to the cars, pickup, and panels, 4% was applied to all the single unit trucks and buses, and 6% was applied to the multi-unit trucks for the example. A 30 year design period was assumed. Four pavement design thicknesses were determined using the AASHTO design nomograph. In each case the pavement was to be a jointed pavement with dowels and asphalt shoulders as is the test site. Each design differed in the following manner:

1. Traffic load data was obtained using the most predominant single and double axle weights in the W-4 tables for each vehicle type and excluding any overloads. An examination of the results indicates that over 80% of the damage is done by the five axle semi trailer trucks.
2. Traffic damage factors for the five axle truck in example one were changed to provide for the observed load on the steering axle and the legal load limit for tandems on the remaining axles. This was to compensate for the overloads observed in the truck weight data.
3. Traffic damage factors were again changed to account for the fact that the five axle truck only may have single axles under the trailer rather than a tandem axle configuration.
4. This case assumes that a WIM is in place at the site and is providing values approximately 15% higher than the static weights observed in the truck weight study. In this case, all the weight values were increased by 15% over those predominant values from the truck weight study.

The examples included damage factors from the Iowa W-4 tables and assumed directional splits of 50/50 and traffic in the design lane of 83% of the directional total based on the classification counts.

Resulting design lane loadings and estimated thicknesses to be required as follows:

1. Design lane estimated loadings - 18 million repetitions
   Thickness required - 11.5 inches
2. Design lane estimated loadings - 21.5 million repetitions
   Thickness required - 12.25 inches
3. Design lane estimated loadings - 28.6 million repetitions
   Thickness required - 12.75 inches
4. Design lane estimated loadings - 28.1 million repetitions
   Thickness required - 12.75 inches

Note that exclusion of the overloads (design 2) would underestimate the fatigue life of the pavement and reduce its expected life by some 5 years. If the vehicle owners all went to use of the single or belly axle configuration on their trailers (design 3), the traffic damage could be underestimated by some 37% and the life of the pavement shortened to 19 years vs 30. Design four provides a way to guard against the uncertainties of the changes in truck equipment and to identify the true profile of truck classifications and weights using the pavement at the time of the design. The AASHTO procedure also provides a way to allow for the estimated growth of the axle loadings over the design period. Failure to use such data could shorten the life of the pavement to 19 years also.

CONCLUSIONS

The results of the test pavement designs indicate that the designer must begin to understand more about how their pavement will be used over its design life. More accurate and timely information on the specific design site is need on the following items:

1. Truck axle configurations and weight limits to be allowed
2. Actual truck axle spacings and weights being applied to segment pavement
3. Directional and lane distributions of vehicles be classification and weight distribution to include the amount of empty vs loaded vehicles by direction and lane
4. Damage factors associated with each configuration
5. The effect of surface texture on lane usage and dynamic loads
6. Condition of the pavement when subjected to the maximum loads during the day or night.
7. Seasonal changes in the loadings and the time of day that they are being applied.

It is not economically justifiable to collect such data on every mile of an agency highway system, but the current weigh in motion equipment can be moved from project site to site during the planning mode to obtain representative samples for design purposes. The equipment on the market can be calibrated, using temperature and vehicle axle spacing factors, to a known vehicle for the pavement in question to provide values very near the static weights (5-10% difference). The test designs indicate the importance of accurately assessing the impact of the five axle truck. The designer may find that in a particular location, another truck is the predominant vehicle in the damage equation and may create completely different geometric problems in the design. We can no longer rely only on a traffic volume and percentage of trucks to design a pavement. The designer must become knowledgeable of the traffic characteristics and how they effect the overall design.

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The data analysis and the conclusions identified as a result of the study are solely those of the author and do not necessarily represent those of the University or the Iowa Department of Transportation.

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