Project Summary

Texas Department of Transportation

0-4875: Minimum Longitudinal Grade at Zero Cross Slope in Superelevation Transition

Background

Superelevation transitions are used to help balance centrifugal forces on vehicles moving through curved highway sections. At superelevation transitions, the outside lane cross slope is rotated from negative cross slope at normal crown conditions to positive cross slope at fully superelevated conditions. This change in cross slope alignment creates longer drainage path lengths for stormwater runoff and increased ponding depth of water on roadway surfaces.

This research addressed highway drainage issues at superelevation transitions through physical and mathematical modeling and focused on three major questions: 1) whether literature characterization of sheet flow mechanics provides appropriate models for application to highway drainage, 2) whether kinematic or diffusion wave models are applicable for simulation of highway runoff near superelevation transitions, and 3) how the pattern of pavement drainage at superelevation transitions is influenced by longitudinal grade. The underlying objective was to determine whether there is a minimum longitudinal grade below which stormwater ponding depth becomes excessive.

What the Researchers Did

A rainfall simulator and roadway model were constructed to investigate sheet flow behavior on rough impervious surfaces during storm events. The test surface was coated with granular material and resin to represent the hydraulic behavior of concrete and asphalt type pavements. Three different conditions of surface roughness were tested with longitudinal slopes of 1%, 2% and 3%. Three sample ports for measurement of flow depth and flow discharge were located near the downstream end of the testing platform. A total of 1432 data were generated to evaluate sheet flow behavior under rainfall and non-rainfall conditions.

Both kinematic and diffusion wave numerical simulation models were developed. For regular (normal crown) surfaces, these models give equivalent results. However, with irregular roadway sections such as found near superelevation transitions, the kinematic wave model formulation cannot be used because transverse head gradients can become significant. In contrast, the diffusion wave model formulation is capable of addressing all flow conditions that would be expected. Diffusion wave model formulation is much simpler than full dynamic wave models, and solution methods are much easier to develop and apply. The diffusion wave model formulation was successfully used during this research.

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What They Found

With the experimental program, the primary interest for this research is the effects of surface roughness and rainfall intensity on the hydraulic behavior of stormwater runoff from pavement surfaces. The physical modeling program has shown that conventional models from fluid mechanics (logarithmic boundary layer theory) can be used to describe sheet flow behavior on rough surfaces with a primary variable that is directly related to surface roughness. Significantly, the much simpler Manning equation provides a model that is equally capable of representing the experimental data. Estimated magnitudes of roughness height determined using the logarithmic boundary layer model and Manning's equation are very similar and correspond directly to the material characteristics that were used to create the three different experiment surfaces. The effective flow depth should be measured from near the top of the roughness element height and corresponds to the depth that is significant in determining hydroplaning potential. Manning coefficient values are consistent with literature values, and when effective flow depth is used in the flow calculation, the Manning coefficient value does not depend on flow rate. While there is large uncertainty in predictions for small flow rates, the general lack of flow rate dependence on the Manning coefficient is different than found in other recent highway-related research studies and greatly simplifies model development and application. Finally, for sheet flow over rough surfaces, the effect of rainfall intensity does not have a consistent effect on flow behavior. The chaotic effects of raindrops impacting sheet flow do not significantly affect flow behavior beyond that caused by the surface roughness. Rainfall intensity need not be directly included when selecting hydraulic model parameters for estimating stormwater runoff.

The primary features that influence pavement drainage and ponding of stormwater runoff near superelevation transitions are the combined effects of the longitudinal slope and the change from negative to positive lateral grade for the outside lanes of a curve near the transition. The magnitude of the maximum flow depth increases compared to normal crown conditions and the location of maximum depth changes with the longitudinal slope. For transitions entering a superelevated section with positive longitudinal grade (down slope), the location of maximum depth is near the outside edge of pavement for slopes up to 0.4% (which corresponds approximately to the relative gradient, *G*, for a design speed of 100 km/hr). For longitudinal slope values between about 0.4 and 3%, the location of maximum ponding depth is located near the roadway centerline, but on the outside lanes. For longitudinal slope values greater than about 3%, the location of maximum flow depth is located on the inside edge of pavement at a distance downstream from the zero cross slope (ZCS) station (on the superelevated side). For transitions entering a superelevated section with negative longitudinal grade (up slope), the location of maximum flow depth is always located near the outside edge of the pavement at a distance downstream of the ZCS station (on the normal crown side) that increases with longitudinal grade. For both configurations, the magnitude of the maximum flow depth changes very little with longitudinal grade.

What This Means

Manning's equation can be used for design and assessment of stormwater runoff from roadway surfaces without concern for whether the effective Manning coefficient value depends on flow rate or rainfall. There is no minimum longitudinal grade below which ponding depth on roadway surfaces becomes excessive. The maximum ponding depth does not depend on longitudinal grade, but the location of the region with maximum ponding depth is sensitive to longitudinal grade. Results from this research may be especially helpful in identifying locations where enhanced drainage treatments, such as local application of porous friction course (PFC), may be useful.

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