STREAMBANK STABILIZATION MEASURES FOR HIGHWAY STREAM CROSSINGS

EXECUTIVE SUMMARY

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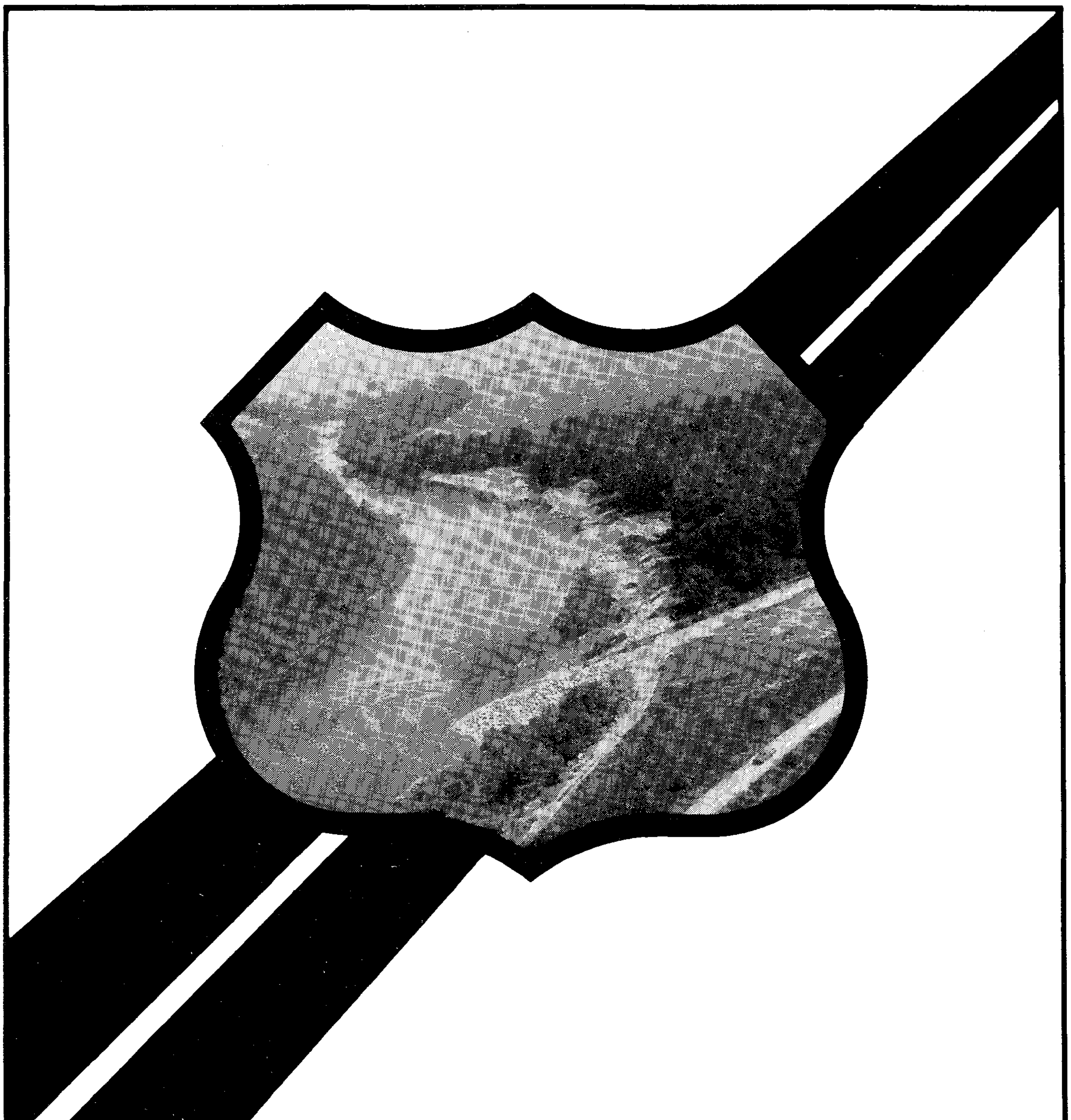

FOREWORD

This report summarizes a study investigating the applicability and usefulness of streambank stabilization countermeasures. Also included is the presentation of guidelines for the selection of individual countermeasure types, and for the design of spur-type streambank stabilization structures.

Research and development in streambank stabilization is included in the Federally Coordinated Program of Highway Research, Development, and Technology Project 5H "Highway Drainage and Flood Protection." Dr. Roy E. Trent is the Project Manager and the Contracting Officer's Technical Representative for this study.

Sufficient copies of this report are being distributed to provide a minimum of two copies to each FHWA regional office, one copy to each division office, and two copies to each State highway agency. Direct distribution is being made to the division offices.

Richard E. Hay, Director
Office of Engineering
and Highway Operations
Research and Development
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16. Abstract

A summary of two reports resulting from a review of the applicability and usefulness of countermeasures used to stabilize eroding streambanks in the vicinity of roadways and at bridge crossings is given. The first report discusses erosion processes in channel bends and methods of controlling this erosion, identifies useful flow control and streambank stabilization structures, and provides guidelines for the selection of an appropriate flow control or streambank stabilization countermeasure for a particular field design condition. Some design information for specific countermeasure types is also included.

The second report looks in detail at the applicability and design of spur-type-flow-control and streambank stabilization structures. The report alerts engineers to the utility of spurs, including economic and other advantages, and provides a treatment of the effectiveness and limitations of spur-type structuring. Design guidelines for these spur-type structures are developed based on field and laboratory experience.

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Streambank erosion; River training; Streambank stabilization; Flow control; Bank protection; revetments; retardance; structures; spurs; groins; jetties	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

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STREAMBANK STABILIZATION MEASURES FOR HIGHWAY STREAM CROSSINGS

Executive Summary

A study has been conducted to review the applicability and usefulness of measures used to stabilize eroding stream banks in the vicinity of roadways and at bridge crossings. Initially, the objective of the study was to provide design guidelines for the design and application of spur-type streambank stabilization structures. The analysis of the applicability and usefulness of spur-type streambank stabilization structures required considerable analysis of the usefulness and applicability of other streambank stabilization structures for comparison purposes. A significant amount of information relating to the application and usesfullness of these other types of streambank stabilization structures was uncovered during this analysis. The information uncovered was deemed useful to highway engineers, and for this reason the study of spur-type stabilization structures was expanded to include coverage of the applicability and usesfulness of most major streambank stabilization structures. Subsequently, the study resulted in two reports; one coverilng the general applicability of a variety of streambank stabilization structures titled "Streambank Stabilization Measures for Highway Engineers," and the other providing guidelines for the application and design of spur-type streambank stabilization structures titled "Design of Spur-Type Streambank Stabilization Structures." Each of these reports is summarized below.

STREAMBANK STABILIZATION MEASURES FOR HIGHWAY ENGINEERS

This report provides guidelines for the selection and design of flow control and streambank stabilization structures. It is intended to alert engineers to the advantages, disadvantages, effectiveness, and limitations of the more common types of flow-control and streambank-stabilization structures. This report is based on a thorough literature review, extensive review and evaluation of field installations, and numerous personal contacts with design engineers involved in designing streambank stabilization structures.

The first consideration is a discussion of flow and erosion processes in channelbends. To control bank erosion adequately at a specific site, it is important to understand the geomorphic processes and erosion mechanisims at work. Therefore, discussions of geomorphic erosion processes, as well as the dynamics of streambank erosion are included. It was found that the most prevalent causes of streambank erosion result from human activities within a watershed which change the natural regime of the channel system. Some of these activities include:

- agricultural development,
- urbanization,
- construction activities,
- streambed mining of gravel and sand,
- inter-basin flow transfers, and
- reservoir development and operation.

The dynamics of streambank erosion include consideration of soil displacement mechanisms, and streamflow dynamics. Important soil particle displacement mechanisms include:

- streamflow-induced shear stresses,
- surface weathering,
- abrasion,
- wave erosion, and
- chemical action.

Of these, streamflow-induced shear stresses and subsurface flow and seepage were found to have the greatest impact on channelbank stability. Streamflow dynamics influencing channelbank stability are primarily related to velocity and streamflow distributions within a particular bend and the effect channelbend curvature has on the magnitude and variation of these distributions. Evaluation of the soil displacement mechanisms and streamflow dynamics at a particular site is important to the selection of an appropriate countermeasure for that site.

Additionally, factors influencing the magnitude and rate of streambank erosion are identified. These characteristics include:

- channel-flow conditions,
- channelbank composition,
- channelbank vegetation, and
- channelbed stability.

Consideration of these factors will aid in the determination of the level of protection necessary for a particular site.

Methods of controlling streambank erosion are also identified. These include:

- provide an armor layer on the bank,
- provide flow retardance along the bank,
- shift the primarly flow current away from the control device, or
- relocate the roadway or bridge.

Countermeasures for flow control and streambank stabilization are defined as structures that protect channelbanks by providing an erosion resistant barrier between the flowing water and the bankline or by controlling the direction and/or velocity of the flowing water. Types of streambank stabilization structures are classified by their mechanism of bank protection. The following four types of countermeasures are covered:

- spurs,
- bank revetments,
- retardance structures,
- logitudinal dikes, and
- bulkheads.

Specific countermeasures within each of these categories are illustrated, and descriptions of their basic construction are given.

The selection of an appropriate countermeasure type for a specific bank erosion/channel instability problem is dependent on many factors or selection criteria, including:

- structure function or purpose,
- erosion mechanism,
- river characteristics,
- system impacts,
- vandalism,
- maintenance,
- construction-related factors,
- legal considerations, and
- costs.

Of these, the primary criteria are structure function, erosion mechanism countered, and river environment. Structure functions include:

- protection of an existing bankline,
- reestablishment of some previous of new flow alignment, and
- flow control and/or constriction.

Erosion mechanisms countered include:

- streamflow -toe attack,
- streamflow - bank surface attack
- surface weathering,
- abrasion,
- subsurface flow,
- wave erosion, and
- chemical action.

River characteristics include consideration of:

- channel size (width)

- channelbank characteristics,
- channelbed environment,
- channelbed radius,
- channel hydraulics, and
- ice and debris loadings.

These factors define the set of specific countermeasures that are best suited to specific site conditions. From this point, consideration of potential environmental impacts, maintenance, construction-related activities, and legal aspects can be usesd to refine the selection. The final selection criteria, and perhaps the most important, is structure cost, the structure that provides the desired level of protection at the lowest cost will be the "best" for a particular application.

The applicability of individual streambank stabilization structures are then considered in light of the evaluation criteria outlined above. This information provides a basis for comparing the attributes of the most common flow- and erosion-control countermeasures so that an appropriate structure can be used at a given site. A complete listing of conclusions and recommendations from these sections would be too voluminous for inclusion here.

DESIGN OF SPUR-TYPE STREAMBANK STABILIZATION STRUCTURES

This report provides guidelines for tha application and design of spur-orjetty-typeflow control structures. Spurs are defined as linear structures, permeable or impermeable, projecting into a channel from the bank for the purpose of altering flow direction, providing channelbank protection, inducing deposition, and/or reducing flow velocities along the channel bank. The report alerts engineers to the utility of spurs, including economic and other advantages, and provides a treatment of the effectiveness and limitations of spur-type structures as flow control and streambank stabilization structures. The findings and recomendations contained in this report are based on a thorough review of pertinent literature, analysis of over a hundred field sites, and on a recent laboratory study conducted by the Federal Highway Administration (FHWA).

The selection of an appropriate countermeasure for a particular application depends on the purpose of the flow-control/bank-stabilization scheme, the erosion mechanism active at the site, the river environment, system impacts, construction-related considerations, and costs..

The functions for which spurs are applicable include:

- protection of an existing channel bankline,
- re-establishing some previous flow path or alignment, and
- control and/or constriction of channel flows.

The primary advantage provided by spurs in this regard is their ability to provide flow control and constriction, as well as the re-establishment of a previous or new flowpath.

The erosion mechanism countered best by spurs is bank particle displacement caused by abrasion and streamflow-induced shear stresses. Spurs are particularly well-suited for protecting lower portions of the bank from toe scour and the resulting undermining of channelbanks, which has been identified as a primary use of streambank failure.

Spurs have been used in a wide variety of river environments. This criteria applies more to the selection of a specific spur type as opposed to the use of spurs in general. However, the following general criteria for the applicability of spurs are presented:

Spurs have been used in a wide variety of river environments. This criteria applies more to the selection of a specific spur type as opposesd to the uses of spurs in general. However, the following general criteria for the applicability of spurs are presented:

- Spur-type structures are not well suited for use on channels with widths less than 150 ft.
- Spur-type structures are not well suited for use at sites where the bend radius is less than 350 ft.
- Most spur-type structures are best suited for protecting channelbanks to heights less than 20 ft.
- Spurs are well suited for use along steep-cut and irregularly shaped channelbanks where significant site preparation would be required by other countermeasure types.
- In relation to the use of spurs in various river sediment environments, individual spur types have been used successfully under virtually all sediment environments. However, their design is more critically dependent on the channel's sediment environment than are other countermeasures.
- Spurs can pose a hazard to recreational uses of the river in some cases.

In regard to costs, spur-type structures will often provide a significant economic advantage over other countermeasures. Costs reported ranged from $13 per foot of channelbank protected to $445 per foot of channelbank protected, with an average of $56 per foot of channelbank protected.

Spurs have been classified by functional type as retardance spurs, retardance/diverter spurs, and diverter spurs. Spurs within each of these categories can be further categorized as follows:

RETARDANCE SPURS
- fence type (wood or wire)
- jack/tetrahedron

RETARDANCE/DIVERTER SPURS
- light fence (wood or wire)
- heavy diverter

DIVERTER SPURS
- hardpoints
- tranverse dike spurs

Retardance spurs are permeable structures designed to reduce the flow velocity in the vicinity of the channelbank, or over the region of influence of the spur scheme. Retardance/diverter spurs are permeable structures that are designed to function by retarding flow currents along the channelbank and providing flow deflection. Diverter spurs are impermeable structures that are designed to function by diverting the primary flow currents away from the channelbank.

Factors important to the selection of a specific spur type include:

- spur function or purpose,
- erosion mechanism countered,
- sediment environment,
- flow environment,
- bend radius/flow environment, and
- ice and debris conditions.

Table 1 summarizes the applicability of various spur types with respect to the factors listed above. A scale of 1 to 5 is used in the table to indicate a specific spur type's applicability for the given condition. A value of 1 indicated a disadvantage in using that spur type for the given condition, and a value of 5 indicated a definite advantage in using that spur type. A value of 3 indicated that your spur type functions adequately in the given condition, but exhibits no significant advantage or disadvantage with respect to the given condition.

Considerations in addition to those listed in Table 1 include:

- costs,
- channel size,
- channelbed fluctuations,
- vegetation,
- channel geometry impacts,
- aesthetics,
- vandalism and maintenance, and
- construction-related impacts.

Of these, structure costs have the most significant impact on the ultimate selection of an appropriate spur type.

Criteria for the design of spur type flow-control structures are presented. Recommendations are provided for spur permeability, extent of bank protection required, spur length, spur spacing, spur orientation, geometric layout of spur schemes, structure height, crest profile, bed and bank contact, and spur head form. A complete listing of design recommendations would be too voluminous for inclusion here. The following is a partial listing of design recommendations for spur-type structures.

Table 1 - Spur Type Selection Table

SPUR TYPE	FUNCTION			EROSION MECHANISM				SEDIMENT ENVIRONMENT			FLOW ENVIRONMENT: VELOCITY			FLOW ENVIRONMENT: STAGE			BEND RADIUS			ICE/DEBRIS ENVIRONMENT		
	Protect Ext. Bank	Re-est. Prev. Align.	Flow Construction	Transport	Shear Stress - Toe	Shear Stress - Upper Bank	Abrasion	Regime/Low Threshold	Medium Threshold	High Threshold/Rigid	Low	Medium	High	Low	Medium	High	Large	Medium	Small	Minimal	Light Debris	Large Debris/Ice
RETARDANCE																						
Fence Type	3	2	2	3	3*	1	1	4	3	2	3	3	2	3	2	1	3	2	1	3	3	2
Jack/Tetrahedron	3	3	1	3	3	1	1	4	3	1	3	2	1	3	2	1	3	2	1	2	4	1
RETARDANCE/DEFLECTOR																						
Light Fence	3	3	3	3	3	2	2	3	3	2	3	3	2	3	3	2	3	3	2	3	4	2
Heavy Diverter	3	4	4	3	3	4	3	2	3	3	3	3	2	3	4	4	3	3	2	3	4	3
DEFLECTOR																						
Hardpoint	3	4	4	3	3	3	4	2	3	4	3	3	4	3	3	2	3	4	4	3	3	5
Transverse Dike	3	4	4	3	3	3	4	2	3	4	3	3	4	3	3	2	3	4	3	3	3	5

*Henson spur jetties are rated a 4 for this condition

1. Definite disadvantage to the use of this type structure.
2. Some disadvantage to the use of this type structure.
3. Adequate for condition.
4. Some advantage to the use of this type structure.
5. Significant advantage to the use of this type structure.

Permeability

- Where it is necessary to provide a significant reduction in flow velocity, a high level of flow control, or where the structure is being used on a sharp bend, the spur's permeability should not exceed 35 percent.

- Where it is necessary to provide a moderate reduction in flow velocity, a moderate level of flow control, or where the structure is being used on a mild to moderate channelbend, the spurs with permeabilities up to 50 percent can be used.

- In environments where only a mild reduction in velocity is required, where bank stabilization without a significant amount of flow control is necessary, or on mildly curving to straight channel reaches, spurs having effective permeabilities up to 80 percent can be used. However, these high degrees of permeability are not recommended unless experience has shown them to be effective in a particular environment.

- The greater the spur permeability, the less severe the scour pattern downstream of the spur tip. As spur permeability increases, the magnitude of scour downstream of the spur decreases slightly in size, but more significantly in depth.

- If minimizing the magnitude of flow deflection and flow concentration at the spur tip is important to a particular spur design, a spur with a permeability greater than 35 percent should be used.

Extent of Channelbank Protection

- A common mistake in streambank protection is to provide protection too far upstream and not far enough downstream.

- The extent of bank protection should be evaluated using a variety of techniques including:

  - empirical methods,
  - field reconnaissance,
  - evaluation of flow traces for various flow stage conditions, and
  - review of flow and erosion forces for various

flow stage conditions.

Information from these approaches should then be combined with personal judgement and a knowledge of the flow processes occurring at the local site to establish the appropriate limits of protection.

Spur Length

- The projected length of impermeable spurs should be held to less than 15 percent of the channel with at bank-full stage.

- The projected length of permeable spurs should be held to less than 25 percent of the channel width. However, this criterion depends on the magnitude of the spurs permeability. Spurs having permeabilities less than 35 percent should be limited to projected lengths not to exceed 15 percent of the channel's flow width. Spurs having permeabilities of 80 percent can have projected lengths up to 25 percent of the channel's bank-full flow width. Between these two limits, a linear relationship between the spur permeability and spur length should be used.

Spur Spacing

- The spacing of spurs in a bank-protection scheme is a function of the spur's length, angle, and permeability, as well as the channelbend's degree of curvature.

- The direction and orientation of the channel's flow thalweg plays a major role in determining an acceptable spacing between individual spurs in a bank-stabilization scheme.

- A spacing criteria based on the projection of a tangent to the flow thalweg, projected off the spur tip, is presented.

Spur Angle/Orientation

- The primary criteria for establishing an appropriate spur orientatiion for spurs in a spur scheme is to provide an orientation that efficiently and economically guides the flow through the channelbend, while protecting the channelbank and minimizing the adverse impacts to the channel system.

- Retardance spurs should be designed perpendicular to the primary flow direction.

- Retardance/diverter and diverter spurs should be designed to provide a gradual flow training around the bend. This is accomplished by maximizing the flow efficiency within the bend while minimizing any negative impacts to the channel geometry.

- It is recommended that spurs within a retardance/diverter or diverter spur scheme be set with the upstream-most spur at approximately 150 degrees to the main flow current at the spur tip, and with subsequent spurs having incrementally smaller angles approaching a minimum angle of 90 degrees at the downstream end of the scheme.

Spur System Geometry

- A step-by-step approach to establishing an optimum geometry of a retardance/diverter or diverter spur scheme presented.

Spur Height

- The spur height should be sufficient to protect the regions of the channelbank impacted by the erosion processes active at the particular site.

- If the design flow stage is lower than the channelbank height, spurs should be designed to a height no more than three feet lower than the design flow stage.

- If the design flow stage is higher than the channelbank height, spurs should be designed to bank height.

Spur Crest Profile

- Permeable spurs should be designed with level crests unless bank height or other special conditions dictate the use of a sloping crest design.

- Impermeable spurs should be designed with a slight fall towards the spur head, thus allowing different amounts of flow constriction with stage (particularly important in narrow-width channels), and the accommodation of changes in meander tree with stage.

Channelbed and Channelbank Contact

- Careful consideration must be given to designing a spur that will maintain contact with the channelbed and channelbank so that it will not be undermined or outflanked. Methods and examples presented herein can be used to ensure adequate bend and bank contact.

Spur Head Form

- A simple straight spur head form is recommended.
- The spur head or tip should be as smooth and rounded as possible. Smooth, well-rounded spur tips help minimize local scour, flow concentration, and flow deflection.

FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH, DEVELOPMENT, AND TECHNOLOGY

The Offices of Research, Development, and Technology (RD&T) of the Federal Highway Administration (FHWA) are responsible for a broad research, development, and technology transfer program. This program is accomplished using numerous methods of funding and management. The efforts include work done in-house by RD&T staff, contracts using administrative funds, and a Federal-aid program conducted by or through State highway or transportation agencies, which include the Highway Planning and Research (HP&R) program, the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board, and the one-half of one percent training program conducted by the National Highway Institute.

The FCP is a carefully selected group of projects, separated into broad categories, formulated to use research, development, and technology transfer resources to obtain solutions to urgent national highway problems.

The diagonal double stripe on the cover of this report represents a highway. It is color-coded to identify the FCP category to which the report's subject pertains. A red stripe indicates category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, and green for category 9.

FCP Category Descriptions

1. **Highway Design and Operation for Safety**
   Safety RD&T addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act. It includes investigation of appropriate design standards, roadside hardware, traffic control devices, and collection or analysis of physical and scientific data for the formulation of improved safety regulations to better protect all motorists, bicycles, and pedestrians.

2. **Traffic Control and Management**
   Traffic RD&T is concerned with increasing the operational efficiency of existing highways by advancing technology and balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, coordinated signal timing, motorist information, and rerouting of traffic.

3. **Highway Operations**
   This category addresses preserving the Nation's highways, natural resources, and community attributes. It includes activities in physical maintenance, traffic services for maintenance zoning, management of human resources and equipment, and identification of highway elements that affect the quality of the human environment. The goals of projects within this category are to maximize operational efficiency and safety to the traveling public while conserving resources and reducing adverse highway and traffic impacts through protections and enhancement of environmental features.

4. **Pavement Design, Construction, and Management**
   Pavement RD&T is concerned with pavement design and rehabilititation methods and procedures, construction technology, recycled highway materials, improved pavement binders, and improved pavement management. The goals will emphasize improvements to highway performance over the network's life cycle, thus extending maintenance-free operation and maximizing benefits. Specific areas of effort will include material characterizations, pavement damage predictions, methods to minimize local pavement defects, quality control specifications, long-term pavement monitoring, and life cycle cost analyses.

5. **Structural Design and Hydraulics**
   Structural RD&T is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highway structures at reasonable costs. This category deals with bridge superstructures, earth structures, foundations, culverts, river mechanics, and hydraulics. In addition, it includes material aspects of structures (metal and concrete) along with their protection from corrosive or degrading environments.

9. **RD&T Management and Coordination**
   Activities in this category include fundamental work for new concepts and system characterization before the investigation reaches a point where it is incorporated within other categories of the FCP. Concepts on the feasibility of new technology for highway safety are included in this category. RD&T reports not within other FCP projects will be published as Category 9 projects.

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