HIGHWAY RESEARCH CIRCULAR

Number 61 | Subject Areas: Photogrammetry, Highway Design, Highway Drainage, Roadside Development, Pavement Design, Pavement Performance and Bridge Design | January 1967

DEPARTMENT ACTIVITY

Department of Design
Highway Research Board

REPORT ON RESEARCH NEEDS

Research Problem Statements

Contents

HIGHWAY RESEARCH BOARD
NATIONAL RESEARCH COUNCIL NATIONAL ACADEMY OF SCIENCES - NATIONAL ACADEMY OF ENGINEERING
2101 CONSTITUTION AVENUE, N.W. WASHINGTON, D.C. 20418

INTRODUCTION

The research problem statements contained in this edition of the Highway Research Circular have been prepared by the Department of Design as a department-wide undertaking. Each committee within the Department was requested to prepare problem statements for research considered most needed in their several areas. Titles and statements of objectives have been assembled by subject area and are being published to make known the need for research and to encourage its undertaking. The large number of members involved in this effort precludes giving individual credit to the many contributors.

Copies of the complete statements may be obtained at the cost of reproduction by request to the Executive Director, Highway Research Board, 2101 Constitution Avenue N. W., Washington, D. C. 20418

RESEARCH PROBLEM STATEMENTS

PHOTOGRAMMETRY

Research Problem Statement Number 1

Aerial Reconnaissance Survey of Area and Determination of Route Alternatives for Location of a Proposed Highway

Many of our highways are becoming obsolete because of changing conditions. Adequate improvement along existing routes is frequently impractical and unsound economically. New locations must be sought which will avoid the mistakes of the past, assure a maximum of service and avoid early obsolensence. Research is required to determine the most effective, reliable and economic aerial surveying methods and procedures for making the reconnaissance survey of a broad area and determining feasible route alternatives.

Research Problem Statement Number 2

Reconnaissance Survey of Route Alternatives for a Highway, to Compare Them and Select a Route for Preliminary Survey

In the current accelerated expansion of our highway system, adequate surveys and investigation of route alternatives for proposed new highways have not always been accomplished. Reasons for this are the inadequacies of conventional surveying practices on the ground, shortage of qualified engineers and increased cost of surveying by the usual methods. Consequently, more economical, more complete and quicker than on-the-ground methods for obtaining qualitative information and quantitative data are needed for comparison of route alternatives in the second state of reconnaissance surveys for locating highways.

Research Problem Statement Number 3

Preliminary Survey of the Approved Route by Aerial Methods for Design of the Highway Location and Preparation of Detailed Construction Plans and Estimates

Preliminary survey of the selected and approved route of each highway, for design of the highway location and preparation of detailed construction plans and estimates, is becoming increasingly complex and requires more thorough and extensive investigations for which data in greater detail and accuracy must be obtained than has been customary in the past. Development and use of more reliable, faster and economical methods than the usual ground survey methods have become desirable. The new methods must provide sufficient data of adequate scope, detail and accuracy on topograph and land use over a wide band in the preliminary survey stage of highway location.

Research Problem Statement Number 4

Location Survey of a Highway

Current practices in location survey staking on the ground of a designed highway are lagging behind progressive developments and practices in accomplishing reconnasissance surveys and the preliminary survey by aerial photogrammetric methods. In order to keep abreast of the increased output of construction plans prepared during design by use of aerial-survey-obtained information and photogrammetrically-compiled data, research is required to analyze and evaluate current methods and to devise more economical and expeditious methods of location surveying.

Research Problem Statement Number 5

Evaluation of Aerial Color Photographs for Reconnaissance and Preliminary Surveys

Since there has been an increase in the quality of color film and prints and a corresponding decrease in processing costs, a comprehensive evaluation of aerial color photographs and a qualitative and quantitative comparison with black and white photographs now in general use are needed to determine if the use of aerial color photography in the successive stages of highway location and design is economically justified.

Research Problem Statement Number 6

Analytical Aerial Triangulation for Location and Design

Analytical aerial triangulation procedures have been developed for small and medium scale topographic mapping, but they have not been tested for precision large scale highway engineering purposes. Existing analytical aerial triangulation procedures have, in essence, merely passed the experimental stage. Moreover, reducing the costs of establishing supplemental control for engineering and cadastral surveying and mapping purposes by adapting analytical aerial triangulation to such work is an economic necessity.

Research Problem Statement Number 7

Evaluation of Watershed Characteristics by Photographic and Photogrammetric Methods

In the prediction of runoff from a watershed for drainage design it is necessary to evaluate characteristics, several of which are subject to photographic or photogrammetric determination. Research is required into the best methods of evaluating these characteristics as they are identified by hydrologists.

Research Problem Statement Number 8

Traffic Surveys by Aerial Methods

The principal problem is inherent in the fact that for highway engineers to solve traffic problems, reliable and representative data regarding traffic movement; the influence of curbs, number and width of lanes, "bottlenecks", barriers, signals, sight distance, traffic density and weather conditions on

traffic; origin and destination; and many other influences on highway traffic must be obtained, evaluated an analyzed. How well aerial photography will serve as an augmenting aid to other methods of acquiring traffic survey data is vital to attaining progress and in acquiring data which can be re-examined and evaluates when conditions and requirements have changed.

Research Problem Statement Number 9

Cadastral Surveys by Photogrammetric Methods

Large scale graphical representations of property, combined with written documents, serve as a record of title for privately-owned land. It is now possible to supplement and improve the graphical representation of points with a printed record of plane coordinates of adequate accuracy obtained by photogrammetric meathods of measurements. Experience in Europe indicates photogrammetric methods are adequate and economically justifiable. Adaptation, development, and acceptance of photogrammetric methods of measurement in the United States for cadastral purposes and the advantages thereof will not be achieved until feasibility and accuracy are proven by research.

Research Problem Statement Number 10

Application of Aerial Photogrammetry and Electronic Computing to Cadastral Surveys

There is an apparent need for determining suitable and legally acceptable means for giving land owners a definite and acceptable description of landed property to be used either in conveyance or in a condemnation case.

Therefore, technical means must be developed by research for obtaining data rapidly and economically for preparing definite, accurate, and detailed descriptions of real landed properties to be conveyed or acquired for highway improvement purposes.

Character of the topography, type and intensity of the vegetative ground cover, and land uses significantly influence effective instrumentation, and limit the accuracy and reliablity of photogrammetric and analytical methods. In order to ascertain the best combination according to conditions, several combinations of ground control, photogrammetric instrumentation, and electronic computer techniques should be tested.

HIGHWAY DESIGN

Research Problem Statement Number 11

Two-Lane Turning Roadways

As traffic volumes in urban areas continue to increase, the need for more and better knowledge regarding the design and operation of two-lane turning roadways becomes increasingly critical. Not only is there concern that relatively little factual data is available to insure that the two-lane ramps now being designed and built will function as desired, but there are other factors which make it imperative that more be learned about two-lane

operation. A relatively small differential between the projected and the actual traffic attempting to use a high volume one-lane ramp may often justify an early modification to a two-lane ramp. Many facilities are being designed and built to accommodate additional through lanes for traffic levels beyond the design year, but little attention has been given to the desirability of designing the turning roadways so they may be easily converted from one lane to two lanes. Except for a few guides to the design of major forks and a very few studies of two-lane left turns at grade, only vague generalities are known about the details of a two-lane direct connection, the problems inherent in a two-lane semi-direct connection or the undesirability of a two-lane loop.

Research Problem Statement Number 12

Speed Change Lanes

Drivers leaving a through highway at an intersection or interchange ramp must normally reduce their speed before turning. Conversely, drivers entering a highway from a turning roadway or interchange ramp must accelerate to a speed compatible with operation on the through highway. In order to minimize the hazard of such operations and the adverse effects on through traffic flow, it is desirable that speed changing in the most part, or in its entirety, be confined to an auxiliary lane or area which is removed from the path of through travel. Auxiliary lanes which are adequate for the necessary range of speed change and, equally important, which encourage proper usage by drivers can greatly increase the safety, efficiency and capacity of at-grade intersections, interchange ramp terminals and the through highway itself. Detailed studies of operation on various existing facilities are needed to assemble the facts on which desirable designs can be determined. Major factors include: the feature requiring use of an auxiliary lane (at-grade intersection or interchange); vehicle performance characteristics; the nature of speed change (acceleration or deceleration) as practiced by drivers; design speed of the through facility; range of speed change; merging and diverging operational vertical and horizontal alignment of the through facility and of ramps in the case of at-grade intersections; and costs.

Research Problem Statement Number 13

Climbing Lanes

It is common experience for a passenger car to be delayed by a loaded truck slowly climbing a steep grade on a two-lane highway. On a multilane highway, trucks may create a delay when passing one another on a steep grade. The amount of delay depends on length and steepness of grade, available passing sight distance, volume of traffic, running speed of the highway and volume of trucks. Where the volume of trucks is an appreciable percentage of the total volume, the capacity of the highway will be decreased unless a climbing lane is provided. Detailed studies of existing facilities which have climbing lanes are needed to assemble facts from which warrants and design criteria can be developed. Major factors to be considered in this study should include: truck performance characteristics on ascending and descending grades, use of climbing lanes with different proportions of trucks in the total volume of traffic in relation to length and steepness of grade and total traffic volume, cost of providing climbing lanes, use of an additional lane on

steep down-grade where adequate passing sight distance is not available, how much delay should the average driver tolerate before he needs the additional lane for passing, and lane designation when provided in conjunction with an acceleration lane for an interchange on a multilane highway.

Research Problem Statement Number 14

Dropping Freeway Lanes

As a general practice, the number of through lanes on freeways is increased or decreased as a result of a significant change in estimated through traffic at the interchange in the number of freeway lanes normally occurring at ramps which serve or are expected to serve heavy interchange traffic. General observations of freeway operations have indicated that the abrupt dropping of a lane at an exit ramp often times leads to driver confusion and a high accident rate. Detail studies on a wide variety of such conditions are needed to assemble the facts from which desirable design patterns can be determined. Major factors include: the type of interchange,number of through lanes and volumes, proportion and paths of large trucks through the critical area and the costs for added lanes, added structure span lengths, etc.

Research Problem Statement Number 15

Reversible Freeway Roadways

Freeways provide a separate roadway for each directional traffic flow. Provision of an adequate number of lanes to accomodate the peak hour traffic in large urban areas often requires an excessive number of contiguous freeway lanes or the use of two separate roadways for each of the two directional traffic flows. The high volumes of traffic, with a high percentage of peak hour traffic traveling in one direction during the morning peak period and in the opposite direction during the afternoon peak period, coupled with the high costs of freeway construction, have resulted in a growing consideration of the use of a reversible roadway to adequately accommodate peak hour volumes and minimize construction and right-of-way costs. Detailed studies are needed to assemble information about the experience gained in design and operation of the few reversible freeway roadways now in operation.

Research Problem Statement Number 16

Right Turn Lane Versus Minimum Radius Turn

Consideration of better than minimum turning radius is usually required in the design of at-grade intersections where relatively high volume of traffic turns right. As the turning radius is increased beyond a certain length a channelization island becomes necessary and the right turn movement is given a separate turning roadway. Traffic control measures are normally less restrictive for the separate right turn lane than for the through and left turn movements. General observations indicate that improved traffic service is provided by a right turn lane but a method of determining acceptable warrants for the justification of the additional space and construction cost is needed. A comparison of accident rates is needed to relate the merits of a right turn lane to those of a minumum radius turn. Study is also required to determine the geometric design features required for separate right turn lanes considering the various degrees of traffic control.

Research Problem Statement Number 17

Interchange Ramp Terminals at Freeways

There is presently a great variety of layout designs of freeway entrance and exit terminals. Engineering opinions and judgment vary greatly between the principal alternates. Consequently there is a need for detailed study to determine acceptable criteria for the various terminal design elements to assure use of the best features of each wherever appropriate and to achieve uniformity of practice where feasible. Specific areas of study needed include the use of the long taper, compared with parallel type acceleration and deceleration lanes; desirable lengths of acceleration and deceleration lanes considering relative speeds, grades and merging volumes; width of terminal nose; offset of terminal from adjacent freeway lane and the ramp lane; ramp curvature in the terminal area; pavement type and contrast in the gore; and use and details of curbing if applicable.

Research Problem Statement Number 18

Distance Between Ramps

There are six general cases of design problems in determining satisfactory minimum distances between successive ramp terminals:

(1) Two separate exits from a freeway;

(2) Two separate entrances to a freeway;

(3) A freeway exit to a C-D road followed by an exit from that road;

(4) An entrance to a C-D road followed by the entrance of the C-D road to a freeway;

(5) An exit terminal followed by an entrance terminal;

(6) An entrance terminal followed by an exit terminal.

The minimum desirable exit spacing for (1) and (3) is a function of the decision and maneuver time required to execute the proper maneuver at the exit. It should be greater for two successive exits from a freeway (1) than for a secondary exit from a collector-distributor road (3). The spacing should be such that the signing on the second exit would not be a message to the motorist approaching the first exit. Successive entrance terminals, (2) or (4), should be sufficently separated to minimize double merge conditions.

Where an exit terminal is followed by an entrance terminal (5), adequate distance should be provided so that the turbulence to the through movement which may be caused by diverging traffic is not too close to the turbulence which may be created by merging traffic. The spacing between successive inlets either to a collector-distributor road or to a freeway lane (2) should be adequate to accommodate the merging maneuver.

Where an exit erminal of one interchange closely follows an entrance terminal of a adjacent interchange (6), a weaving maneuver may take place.

The establishment of a minimum desirable distance between terminals which would permit a satisfactory level of service is a factor influencing the minimum spacing of interchanges in an urban area.

Research Problem Statement Number 19

Criteria for Design of Curved Ramps

The non-terminal portions of certain ramps, such as the inner loops and outer connectors of a cloverleaf interchange, generally take a curvilinear pattern. Criteria are presently available for the determination of geometric design of these ramps. However, experience has shown that certain existing ramps, even though laid out in accordance with the criteria, have an abnormally high frequency of accidents, possibly because of a combination of curves, tangents and vertical curves requiring unnatural driving patterns. Detailed studies of existing ramps are required to reassess the existing criteria for ramp geometrics and to arrive at a method of relating design to normal driver behavior. Major factors in the problem appear to be the speed reduction from through lane to ramp condition, relationship of operating speed to radius of curvature, combination of horizontal and vertical geometry, lengths of tangents between curves, ratio of compounding curve, superelevation rates, sight distance, and use of spirals.

Research Problem Statement Number 20

Controlled Access Beyond Ramp Terminal

The tremendous increase in the number of interchanges contructed in recent years throughout the nation has opened up thousands of new commercial, industrial and residential sites adjacent to these interchanges. In order to preserve the traffic service of the original interchange design, it is necessary to prevent roadside encroachment immediately adjacent to the crossroad ramp termini.

The crossroad in most instances has as its main function the serving of local areas and local needs, thus it is logical and desirable to allow development to take place in the vicinity of the interchanges. The problem is to find the desirable distance from various ramp termini to the end of the access control.

Research Problem Statement Number 21

Interchange Ramp Terminals on Minor Crossroad

Ramp terminals at crossroads are being designed with various configurations. They may be continuous movement exit and entrance ramps. They may be signal controlled intersections; or they may be stop or yield sign controlled. Each of these intersection types has a definite purpose and use. The problem centers about (a) the selection of the type of intersection, and (b) the actual design of the intersection (flare radii, island configuration, sight distance, etc.). Wrong way movements have been noted at ramps in several section of the country. This in itself poses a major problem in the field of interchange design. A design which results in driver confusion of this type should not be tolerated.

Research Problem Statement Number 22

Warrants for Basic Types of Highway Interchanges

Currently, interchanges are justified primarily on the basis of specific geometric design criteria, total construction costs, traffic service requirements, and potential road user benefits. In many locations, particularly in urban areas, consideration must be given to numerous other factors. These include: (1) physical and cultural controls, (2) esthetics, (3) existing and future arterial street systems, (4) uniformity of interchange patterns, (5) feasibility of stage construction, (6) signing and other safety considerations and (7) anticipated land use adjacent to the freeway. There is need for determining both the absolute and relative importance of each factor.

Research Problem Statement Number 23

Stopping Sight Distance Criteria: Perception Time, Braking Distance for Various Speeds, Both Wet and Dry Conditions

Minimum stopping sight distance is the sum of the distance traversed by a vehicle from the instant the driver sights an object for which a stop is necessary,to the instant the brake application begins and the distance required to stop the vehicle after the brake application begins. The values used to determine these distances for current design criteria are based on limited investigations, particularly for high speed operation, and few investigations have been reported in recent years. Information is needed for various types of pavement, for different sizes and types of tires, and for wet and dry pavements. Also, data are needed as to actual driving practices (speeds) on wet and dry pavements as related to design speed to determine the stopping distance criteria that should be used as a basis for design.

Research Problem Statement Number 24

Frequency of Passing Sight Distance - Two-Lane Highways

Many existing two-lane highways are becoming overloaded under current traffic volumes. The frequency of passing opportunities on a two-lane highway is one of the major factors that affects the operation and the capacity. Detailed studies are needed to determine how much the operation and the capacity of existing highways can be improved by increasing the number of passing opportunities -- or how many passing opportunities should be provided for different levels of anticipated traffic volumes on a proposed highway.

Research Problem Statement Number 25

Curves and Superelevations

Current relations of curvature and superelevation used in design are based on concepts and studies of approximately 30 years ago. There is concern that evolution of vehicle and tire design may have produced some variation in the factors governing this relation. This item is of growing interest because if the increase of design speed to 80 mph on rural freeways, and because of increasing belief that the proper superelevation on descending and

ascending interchange ramps may differ. Of concern also is the attainment of optimum design of facilities with lower design speeds and the reconstruction of existing facilities. There are differing opinions as to the effect of road surface material on optimum superelevation rate. Various practices are used in selection of transition spiral length and the distribution of superelevation change along the transition spiral. Detailed studies of operations are needed on recently constructed portions of the Interstate system in various areas of the country and on older freeways, such as the Pennsylvania Turnpike, and on interchange ramps of varying design, to correlate operating experience with design variation in superelevation rate. Some operation by qualified agencies on new sections before opening and above design speed should be conducted to evaluate operating characteristics under "stress" conditions.

Research Problem Statement Number 26

Design Speed Determination Based on Speed Profile Investigations

Design speed is an accepted and necessary control in design of highways. The aim in selecting the design speed is to have it logical from standpoint of terrain, land-use environment, type of highway and most of all, driver desire. The manner in which the driver operates on a highway, with respect to his speed characteristics, is an important measure of how the facility should be designed. Numerous studies show periodically the trends in average, 85-percentile, and so on, speeds on level tangent highways. Other studies have shown how drivers operate on curves. All of these data have been tremendously valuable in setting design speeds for highways. However, no criteria are available on how, where, and at what frequency the design speed may or should be changed. The aim, of course, is to keep the design speed constant for long lengths of highway. This concept should be adhered to, but changes in design speed or compensation in design for substantially increased or decreased operating speed along the course of a highway must be recognized and allowance made for it in design.

Research Problem Statement Number 27

Design of Narrow Medians, Including Barriers

The geometric design elements of narrow medians, those less than about 20 feet in width, vary considerably throughout the several States. There are a variety of types of curbs and physical barriers as well as various general cross sections such as shallow, well depressed, mounded, etc. There variations in part reflect the highway type and roadside conditions but also local requirements such as drainage, snow removal and the like. Considering all factors, it is deemed necessary to evaluate the general performance and suitability of various median designs to determine acceptable criteria for achieving safety, economy and uniformity where feasible. Detailed study of existing medians is required to determine the effects of those designs on traffic operations and safety and to determine criteria for the use of barrier installations. Study should include medians of the various types and widths both in freeways, divided highways and arterial streets.

Research Problem Statement Number 28

Curb and Rail Offsets

From the standpoint of traffic safety and driver attitude the full crown width including shoulders as used on graded sections of a highway should be carried across all structures, regardless of length. However, it is the usual practice, as recognized in design standards, to provide narrower shoulders or offsets on long structures than on short ones because of the higher unit costs on the former. The benefits that might accrue from full shoulders on long structures have never been properly appraised, and the distinction between a "long" structure and a "short" structure has always been on an arbitrary basis. A balancing of benefits against costs, and a factual basis for classifying structures on which full shoulders are warranted are matters needing resolution.

Research Problem Statement Number 29

Surfaced Shoulders

Practices vary widely between states and within states in the geometric and structural characteristics of shoulders. There is need for information as to conditions under which surfacing of shoulders is warranted, the width to be surfaced and the required structural qualities of the surfacing provided.

Research Problem Statement Number 30

Pavement Cross Slope to Median

On multilane highways the lane nearest the outside shoulder is subjected to heavier loading than the other lane or lanes. This is because most commercial vehicles use this lane and also because a majority of passenger car traffic uses the outside lane except during periods of peak traffic. From the structural point of view the outside lane should therefore have greater strength that the other lanes.

Under the conventional methods of sloping one or more lanes for drainage toward the outside shoulder it is customary to similarly slope subgrade and base course planes toward the outside. Any moisture under the pavement thus concentrates under the lane that bears the heaviest load,weakening its support. A preferred alternate, if suitable in geometric, drainage and pavement structural design, would shape pavement and base courses so that all drainage, both surface and in base courses,would be away from the truck concentration lane.

Research Problem Statement Number 31

Collector-Distributor Roads

Collector-distributors roads may be employed within 4-quandrant cloverleaf interchanges or between closely spaced interchanges where weaving conflicts will affect the through freeway movement. They may also be used where it is desired to collect and distribute traffic from several points of access, but where it is desired to limit the point of ingress to an egress from the through freeway lanes. Collector-distributor roads will usually increase the highway cost and there are no established warrants that are widely accepted as a basis to justify the additional cost to provide the higher level of service possible

with collector-distributor roads. There have also been situations where volumes on the exit and entrance ramps between the freeway and collector-distributor road exceeded the capacity of the ramps. Studies are needed to determine desirable design patterns for maximum efficiency in the employment of collector-distributor roads.

Research Problem Statement Number 32

Arterial Street Widths

The nationwide program of constructing expressway facilities for moving high volume high speed traffic in and through urban areas has emphasized the need to provide more effective surface arterial street systems to feed and receive that traffic. In small communities that do not have expressways the arterial street system is relatively even more important than expressways because it must perform the dual function of carrying the great majority of traffic effectively and it must serve as one of the major tools in developing a desirable land use pattern. Determination of the number of moving lanes for a particular arterial street is only the first step in establishing the proper curb-to-curb street width. The total width will depend on the lane widths, the median width, if one is provided, and whether left turn lanes or parking lanes are to be used. These considerations are variable from one street to another and they are often argumentative. The fact that im many cases two streets with the same number of moving lanes may differ in width by more than fifty percent presents the designers and governmental officials with a difficult problem in satisfying themselves and the general public that a particular cross section is necessary and justifiable.

Research Problem Statement Number 33

Revitalization of Metropolitan Fringe Network by Conversion to One-Way Operation

It is well recognized that the metropolitan area fringe network of highways is being subjected to heavy increases in traffic volume; this increase accelerates with the expansion to the suburbs. In many areas, of which southeastern Michigan is one, the network has changed but little in the last 50 years, and in much of these areas the road surfaces have changed only for the worse in the last 25 or 30 years. A network of county roads developed in 1935 does not have the capacity required in 1965; the rate of reconstruction or new construction is exceeded vastly by the increase in demand, and congestion, delay, and accidents result. The demand for additional capacity will continue to increase rapidly until population stability is reached.

It appears that the capacity of these networks could be more than doubled by conversion to one-way operation, and that the effectiveness of traffic flow, in terms of increased capacity and reduction in delay, could be increased possibly by a factor of four. There is no other way apparent which would approach this improvement quickly.

The specific research needed is to select pilot areas of some magnitude, two counties for example, convert the network to one-way operation, and evaluate the results. Two or more pilot areas should be selected, one with an orthogonal network as in the Detroit, Chicago, and Cleveland areas, and one where the network is not orthogonal and terrain features are more prominent as in New York, New Jersey and New England.

Research Problem Statement Number 34

Hazards Presented by the Ends of Guardrails

Guardrail ends present a severe hazard. When struck by a motor vehicle, they cause high decelerations or sometimes even penetrate the vehicle like a spear. Research is required to provide a guardrail end that will present a minimum hazard to any vehicle that might strike it.

Research Problem Statement Number 35

Effectiveness of Barriers Protecting Bridge Piers

Research should be undertaken to determine the most effective design for guardrails or barriers to protect traffic against the hazard presented by bridge piers installed in medians. Consideration should also be give to suggesting bridge pier geometry which will minimize the hazard they present.

Research Problem Statement Number 36

Terminating Guardrails Where They Meet Bridge Parapets or Railings

Present practice all too frequently provides no continuity between the guardrail and the parapet or even a built-in hazard in the form of a block of concrete at the beginning of the bridge parapet. Research should be conducted to develop adequate and economical methods for attraching a guardrail to bridge parapets or rails. This should consist of the development of a matching section that would provide gradually increasing strength as the guardrail approaches the parapet as well as a smooth rubbing surface over the transition point.

HIGHWAY DRAINAGE

Research Problem Statement Number 37

Runoff from Small Rural Watersheds

Hydraulic design of culverts and other small drainage structures depends on being able to estimate the frequency with which the higher rates of flow are likely to occur. With such data it becomes possible to make economic comparisons to determine the optimum size and type of structure to minimize the sum of annual capital and flood damage costs.

Research is required to develop reliable methods of estimating hydrographs of runoff and related frequency for rural watersheds up to 15 or 20 square miles in area anywhere in the United States. Analysis of the hydrographs rather than peaks alone is proposed since it is expected that parameter describing the hydrograph will give a better correlation with climate and watershed parameter than will peak flows.

Research Problem Statement Number 38

Storm Drain Design

The collection and disposal of stormwater falling on, or draining to, urban highways is a major problem in design. Restricted right-of-way usually

necessitates conveying water on the shoulder or on the pavement to inlets which discharge into an underground pipe system. Movement of traffic will be impeded if water spreads out on traffic lanes and will be stopped if water ponds at low points in the grade line. The problem becomes particularly acute on depressed roadways especially where pumping stations are required. The cost of delays to traffic mount rapidly on heavily travelled multilane expressways.

The so-called rational method of designing storm drains is not adequate for such systems. The basic concepts for a new method of routing rainfall to inlets and routing hydrographs through the underdrain have been evolved and research on the latter problem is underway. Very little has been done in verifying hypotheses on overland and gutter flow; this is the area where research is needed. Research is also needed on the engineering economics of storm drain design.

Research Problem Statement Number 39

Erosion at Culvert Outlets

Storm water discharges from culverts at velocities greater than the normal velocity in the channel, thus causing local erosion. Several types of stilling basins have been developed, but these are designed primarily for relatively high velocities and are costly. There is a need for development of relatively simple devices which can be used in the intermediate range where some protection is needed but elaborate structures are not warranted.

Research Problem Statement Number 40

Riprap Design

Highway embankments along streams as well as stream-banks and channel changes nearby are subject to attack by flowing water, especially during flood stages. Layers of loose rock (riprap) are commonly used to protect slopes, but criteria for sizing and placement of rock is not established on a scientific basis.

Research is required to define the forces acting on banks and to develop criteria for design of riprap to resist these forces.

Research Problem Statement Number 41

Scour Around Bridge Piers

A basic study on the mechanics of scour around structures placed in an alluvial stream bed is being conducted. In addition, earlier model studies have provided qualitative data on the configuration of scour around bridge piers, but positive means of estimating depth of scour under field conditions are still lacking. Field measurements are needed to correlate with experimental data in terms of fundamental equations which can be used to predict the probable depth of scour in the design of bridge foundations.

ROADSIDE DEVELOPMENT

Research Problem Statement Number 42

Utilization of Roadside Rest Areas

In order to provide a basis for site selection and design of roadside rest areas including those on the Interstate system, much additional information on the utilization of existing rest areas is required. This includes percentage of highway traffic and number of people using the rest area, purpose and length of stop, existing facilities used and additional facilities desired.

Research Problem Statement Number 43

Roadside Rest Area Construction and Maintenance Costs

There is very little data concerning the cost of constructing and maintaining modern sanitary facilities in interstate and primary rest areas. These facilities are essential for the safety, health and convenience of the travelling public. Sanitary facility design and maintenance should be evaluated, standards suggested and cost data assembled.

Research Problem Statement Number 44

Parking and Recreational Use of Rights-of-Way

It is increasingly evident that the highway facilities, especially in urban areas, have considerable lands that are necessary in the safe operation of transportation arteries. However, many of the areas could possibly be used for parking, parks and recreation, open space and conservation of scenic and historic sites. It is desirable to assemble information that illustrates what can be and what should be accomplished with these excess lands in the best interests of the highway user and the communities through which they pass.

Research Problem Statement Number 45

Selection and Establishment of Woody Plants

It is increasingly apparent that the slopes and other roadside areas within highway rights-of-way should be covered with desirable woody plant materials. It is considered essential to reduce maintenance by the elimination of areas required to be mowed. From the establishment of woody plant material on highway rights-of-way by direct seeding many economies can be anticipated, as well as the enhancement of our highway roadside areas.

PAVEMENT DESIGN

Research Problem Statement Number 46

Effect of Recent Rigid Pavement Designs

In recent years several very significant changes have been adopted in rigid pavement design and construction. These have included substitution

of contraction joints for expansion joints, use of sturdier load-transfer devices in some instance and elimination of load-transfer devices in others, the sawing of joints and the use of various types, widths and thickness of subbase material. Research into the effectiveness of these changes is needed.

PAVEMENT PERFORMANCE

Research Problem Statement Number 47

Development of Interim Roughness Measurements as Criteria for Highway Pavements

Important evidence now exists showing correlations between user opinion and measurements of road roughness. Research is needed to develop interim numerical standards of the Roughness Index of pavements, as measured by the BPR-type road roughness indicator, that can be used as criteria for the control of new construction and maintenance of pavement surfaces. An outline of a long-range program will be needed to provide verification or refinement of the recommended interim values.

Research Problem Statement Number 48

Develop a Method of Measuring and Criteria for Bridge Deck Roughness

The large number of bridges being built and the increasing volume of vehicles on the highway has focused attention on the bridge deck roughness problem. Methods currently used to measure pavement roughness may not be satisfactory for use on bridge decks. Additionally, factors influencing driver opinion of bridge roughness are unknown. Research is needed to develop a method for measuring and criteria for determining acceptable maximum limits of bridge roughness.

Research Problem Statement Number 49

Periodic and Random Components of Road Roughness

The riding quality of pavements is related to road surface roughness. Research is needed to examine the periodic and random components of the road surface for a better understanding of why a road produces a poor ride. Included in the study should be theoretical laboratory determinations followed by field testing wave length analysis to isolate the components causing poor riding quality. Correlation between the objective measurements and passenger comfort will be necessary.

Research Problem Statement Number 50

Development of Non-Contact, High Speed Profilometer

The need for a profile measurement device which can travel at a speed high enough to work safely in evaluation of pavements will become acute as the Satellite Road Tests enter the full-scale testing phase. The problems inherent in the intimate contact-type profilometer can only be resolved by the development of a non-contact profilometer. Optical or audio type recording devices could be utilized in conjunction with a GEM (Ground Effect Machine) vehicle.

Research Problem Statement Number 51

Methods to Provide Smooth Concrete Pavements

The surfaces of the best laid rigid pavements contain irregularities which are measurable with existing road roughness equipment. This type of roughness appears to be independent of the construction methods on finishing techniques employed. The basic reason seems to be that rigid pavements have built-in random short wave irregularities that develop during the initial setting process. Research is needed to determine the causes of dimensional changes in the surface after the finishing operation is completed and to develop methods of minimizing them.

Research Problem Statement Number 52

Develop More Rapid and Reliable Procedure for Evaluating Pavement Conditions

If the need for manual measurement of such defects as cracking and patching could be eliminated from the current procedure for evaluating pavement condition, a great many more pavements could be evaluated than are now possible for most highway organizations with a corresponding increase in the usefulness of such data in decision making. Research is needed to develop a rapid and reliable procedure for evaluating pavement condition.

Research Problem Statement Number 53

Establish Subjective Rating Scale for Relative Riding Quality

Subjective rating procedures assume that raters are capable of making direct quantative judgments over linear or interval scale of measurement. For this assumption to hold true, leniency errors, central tendency effects and halo effects must be removed from ratings. This can be partially accomplished by suitable positioning of the rating categories on a rating scale. Research is needed to design and carry out a suitable experiment to evaluate the factors concerning scale format such as the errors described.

Research Problem Statement Number 54

Clarification of the Serviceability-Performance Concept

Since the concept of pavement serviceability performance was developed at the AASHO Road Test there have been considerable misunderstandings concerning it. There is need to delve deeper into this subject to clarify many of the aspects of pavement serviceability and how they can be related to performance of the pavement. The difference between this concept and the pavement or highway sufficiency rating should be clarified and spelled out. Study is needed to clarify the pavement serviceability concept, to develop the best way for evaluating serviceability or a method for determining performance of pavements, and to differentiate between the highway sufficiency ratings and serviceability ratings.

Research Problem Statement Number 55

Factors in a Pavement Profile Which Affect Passenger Ratings of the Road Serviceability

There are in current use several formulas for determining pavement serviceability from road roughness measurements. All of these formulas including those developed at the AASHO Road Test were developed in a more or less intuitive manner from available ratings of roughness measurements. Research is needed to relate human response to the riding surface in order to determine those characteristics which are mutually acceptable and those which should be excluded. The study should include:

(a) An evaluation of human response in an effort to evaluate the factors in riding quality which most influence the subjective rating of the ride.

(b) A detailed analysis of pavement profiles in an effort to break them into the many various components which are found to influence the subjective rating given to a riding surface by automobile occupants.

(c) From (a) and (b) develop a riding quality evaluation which will more accurately predict riders acceptance of the quality of the ride.

Research Problem Statement Number 56

The Effects of Environment and Time Variations on Roughness Equipment

Much of the equipment which is currently in operation for determining road roughness and fence road serviceability has shown in practice to be sensitive to environment such as temperature and humidity conditions. It has also been shown that equipment operated for a period of several months may show considerable variation over so-called standard sections during that time. In some cases these variations appear to be due to wear or lack of maintenance on the equipment. In other cases the apparent explanation is unclear. Research is needed to determine the effect of environment, particularly temperature and humidity, on the operating characteristics of roughness measuring devices used to establish pavement serviceability. Available data should be collected to establish control charts pertinent to the behavior of the various kinds of roughness equipment in current use and to evaluate the cause and effects of instrument variations throughout the operating life which may appear to be variations in pavement serviceability.

BRIDGE DESIGN

Research Problem Statement Number 57

Evaluation of Live Load Distribution Characteristics of Highway Bridges

Current design procedures for distribution of live load in slab, beam, and box bridges of various types have been developed over the years on the basis of independent, largely unrelated studies. Thus, there is some question concerning the consistency of the current design rules. Furthermore, the procedures in use are not capable of accommodating new types of structures nor do they reflect changes that have taken place over the years in traditional types of structures. This applies especially to skewed bridges which are being designed in larger numbers. Research is required to systematize the available information so as to develop a rational, up-to-date design procedure for the most common types of highway bridges and to provide a means of accommodating future developments.

Research Problem Statement Number 58

Effectiveness of Diaphragms as an Aid to Live Load Distribution

The use of diaphragms has always been in the realm of speculation. Live load distribution factors take no cognizance of the presence of, or absence of, diaphragms. If a diaphragm is to function effectively as an aid to load distribution, an investigation should be directed to determine the extent of this distribution.

Research Problem Statement Number 59

Effects of Curb and Railing Sections on Live Load Distribution

Bridge curbs and railings may have a substantial effect on live load distribution. Research is needed, both analytical and experimental, to establish the effect that curbs and monolithic rails play by providing various stiffnesses to slab, thereby altering live load distribution with various sections.

Research Problem Statement Number 60

Fatigue Studies to Aid in Determining the Life Expectancy of Steel Highway Bridges

To evaluate the life expectancy of a highway bridge it is necessary to first predict the expected strain history for the critical locations in the structure, and then to predict the life on the basis of the fatigue behavior of the details and materials employed in the structure. Only through a sound understanding of both aspects of this problem can adequate predictions be made of the life expectancy.

Research Problem Statement Number 61

Working Stresses for High Strength Steels

Substantial economies are often achieved by using higher strength steels in longer span bridges. This also applies to a lesser extent in medium span bridges. Many new high strength steels have been introduced in recent years. Since the ratio of yield point to ultimate strength for some of these steels is relatively higher than for lower strength steels, properties other than the yield point might need to be considered in arriving at allowable working stresses. Some of these properties are tensil strength, fatigue strength, buckling characteristics, ductility abilities and notch toughness. Research is needed to evaluate these properties and correlate them into realistic allowable working stresses.

Research Problem Statement Number 62

Design of Orthotropic Bridges

Design of orthotropic steel superstructures is gaining interest in the United States because it extends the capabilities of steel girder construction into ranges previously covered only by trusses. Most of the orthotropic design work in Europe has been done by private engineering firms who have not

published their design assumptions or calculations nor the results of their studies. The bases of design used in Europe are not directly applicable to the loads and design criteria used in this country.

The introduction of the orthotropic plate structure in the United States has created a need for developing design tools and procedures which would make its somewhat complicated analysis available to our use. Before any simplification of analysis can be achieved, however, it is necessary to know more about the complete behavior of this type of structure.

Research Problem Statement Number 63

Prestressed Structural Steel

It is possible to prestress continuous steel stringers by initially deflecting them prior to placing a composite concrete deck. In the final step, the release of the jacks will cause a more favorable state of stress in the steel while introducing a compressive stress in the concrete deck. The primary task is to develop a theoretical solution to the problem and to check this solution experimentally.

Research Problem Statement Number 64

Fatigue Effects on Reinforced Concrete Superstructure

Only a small amount of research has been done on the effect of repeated loading or fatigue effects on reinforced concrete members. Especially as it relates to bond strength and diagonal tension strength, the present evidence is that fatigue strength is considerably below static strength. Research is required to establish fatigue strength of reinforced concrete relative to static strength, particularly for bond and shear, but also for flexure.

Research Problem Statement Number 65

Allowable Bond Stress in Top Bars of Concrete Girder Bridges

It is well known that rising air and water from concrete (prior to the time it first sets) become trapped under reinforcing bars and result in a weakened bond resistance for those bars. Such information as is now available indicates that the strength loss increases with increasing depth of concrete placed below the bar. Continuous cast-in-place girder bridges are some of the deepest common members of reinforced concrete. There is some doubt that present design specifications treat this part of design in a safe manner. Research is needed to determine safe design stresses for top bars in bond, considering member depths and concrete consistencies in common use.

Research Problem Statement Number 66

Corrosion of Reinforcing Bars

Until the early 1950's few problems were observed in the serviceability of reinforced concrete in bridges. With the advent and widespread use of deicing chemicals for snow and ice removal cracking, spalling and other forms of deterioration increased, particularly in concrete deck surfaces. Subsequent to this, deterioration in the vicinity of cracks, stained with rust,

was observed on bridge substructures in various environments and on the under side of some superstructures beams. Many of the deterioration problems have been attributed directly to rusting of reinforcing bars in cracked areas.

Historically, structural cracking has been minimized by low design stresses allowed for reinforcing bars. The development and availability of high yield bars, however, requires increased allowable stresses to achieve maximum efficiency and economy. Increased stresses, as studies have shown, will result in increased concrete cracking and increased problems in deterioration. Research is needed to determine the influence of crack size, width and orientation with respect to the reinforcing bars and such variables as environment and chemical properties of steel and cement on corrosion and rate of corrosion of reinforcing bars.

Research Problem Statement Number 67

Fatigue Behavior of Composite Beams Bonded by Epoxy Compounds

For sometime the method of ensuring composite action between concrete bridge decks and the supporting beams has been through the use of shear connectors. Recently the use of epoxy compounds has been suggested as a simplified means of ensuring composite action. These compounds readily lend themselves to the construction of composite beam with precast bridge decks. However, before any extensive use of epoxies is advisable, the study of the fatigue behavior of beams with these compounds is required to determine the effects of repeated loads on the stability of the material.

Research Problem Statement Number 68

Fatigue of Reinforcing Steel

To utilize available high strength reinforcement and achieve potential economies in bridge structures comparable to those now achieved in building structures, the effects of fatigue must be considered. Research on fatigue properties of the reinforcing steel is available. Traffic load patterns have been studied. Certain details for hooks, splices and bending of reinforcing steel are known to reduce the straight bar fatigue limits. Tentative limits on safe stress range are known. The actual stress range in bridges where temperature, shrinkage and creep effects are present, as well as beneficial effects of long intervals between load applications need to be determined from tests on bridges under a variety of weather and traffic conditions.

Research Problem Statement Number 69

Shear and Fatigue in Concrete Girders Reinforced with High Strength Deformed Bars and Prestressed Tendons

High strength reinforcing bars are beginning to be used in bridge construction. Their use is limited primarily by considerations of serviceability; i.e., deflections and width of cracks. These problems could be overcome by combining with the high strength deformed bars a small amount of prestressed steel. Sufficient prestress would be provided to hold crack widths and deflections at service loads down to acceptable values. This would enable 75 or 90 ksi yield point deformed bars to be used as reinforcement with economic advantage.

The flexural strength of such a member under static load can be calculated. However, we lack information which would enable us to calculate its shear strength and its behavior under repeated loading.

It is proposed to investigate the shear and fatigue strengths of reinforced concrete beams reinforced primarily with untensioned high strength deformed bars and containing a small amount of prestressed reinforcement to control deflections and crack widths at service loads.

Research Problem Statement Number 70

Investigation of the Use of Precast Concrete Slabs in Bridge Decks

Precast slabs, if placed to span between adjacent stringers, might act as a form for casting in place a top layer of deck concrete or surfacing. The problem is to determine the integrity of the resulting composite section consisting of precast stringer, precast deck slab and situ-cast deck. It is proposed to investigate the behavior of existing bridges which utilize precast concrete slabs, to study all available reports on such bridges in the literature and prepare a report in which the most promising methods of utilizing precast slabs are described.

Research Problem Statement Number 71

Creep and Shrinkage Deflections on Hollow Box Concrete Structures

Deflections have been noted in concrete hollow box bridges that have gone beyond the anticipated and calculated ranges. It is proposed to study and, if possible, to reduce or eliminate the deflections in concrete hollow box bridges that may be due to the influence of long time creep and/or shrinkage.

Research Problem Statement Number 72

Behavior of Battered Piling

Many types of pile supported structures are subject to lateral loads applied at an elevation higher than the base of the foundation. Therefore, the foundation must resist not only lateral forces but also moment. These conditions can be resisted by vertical piling alone in areas where upper soil layers are dense. When the lateral load exceeds the value suitable for vertical piling, battered piling must be used to provide stability. Analysis of such pile groups is extremely difficult because of the complexity of this structural system and the soil support.

Research is needed to evaluate the effect of type of connection between piling and foundation, to evaluate the effect on piling due to translation and rotation of the foundation and to develop a simplified design procedure of pile foundations including battered piles.

Research Problem Statement Number 73

Effect of Environment on the Permanency of Piles

In pile design arbitrary allowances often are made for corrosion or rotting of piles and special precautionary measures are taken to protect

piles against potential damage to the structural material by soil, ground water, gases or insects. The long-term behavior of piles made of common materials, including timber, concrete and steel, requires investigation under various environmental conditions.

Research Problem Statement Number 74

The Lateral Capacity of Foundation Piles

There is a lack of specific evidence regarding the degree of resistance of the soil surrounding a pile to lateral movement of the pile. Lateral movement of piles could be caused by lateral loads, eccentric loads or moments applied to the pile. The pile could be partially embedded or fully embedded with a pile cap resting on the ground surface. The structural resistance of the pile in bending and shear should be taken into account.

Full scale field tests should be made on instrumented piles in typical situations described above in order to evaluate the lateral resistance of the soil surrounding the pile. Since experience indicates that the actual lateral capacity must be greater than predicted by conventional assumptions in use at the present time, results of this research are expected to lead to more economical design procedures.

Research Problem Statement Number 75

Determination of Load Carrying capacity for Piles

The determination of the load capacity of friction piles by other than test loads has been a stumbling block for years. Many pile driving formulas have been advocated which satisfy to some extent conditions in some particular area, but these do not meet the requirements for general use. This condition applies equally to the load capacity of a single pile or a group of piles in footings where the piles are closely spaced. Research is required to develop methods of determining the load capacity of friction piles using soils analysis and other presurvey data which can be secured in a field survey, and to determine load capacity of friction piles by means of data obtained from driving records of the piles.

Research Problem Statement Number 76

Estimating Bridge Life From Load-Strain Studies

In order to provide certain improvements in current bridge design practices, there is a need for acquiring data on the strain history at critical points in bridge members under representative highway traffic loads. Acquisition of this strain data together with predictions of traffic volume and load will make it possible to estimate the frequency of occurrences of strain ranges of various magnitudes in the life span of a structure. The immediate problem is a rather complete lack of information on the actual strain ranges in critical bridge members subjected to today's traffic. A study should include a broad representation of various bridge types with a variety of span lengths. The selection of bridges for testing which will span representative ranges in loading due to traffic volume and composition is also imperative.

Research Problem Statement Number 77

Instrumentation for Highway Bridge Research

A uniform instrumentation system to provide precise coordinated measurements of all aspects of the bridge-vehicle interaction on highway bridges in service under both regular and controlled traffic loading is a necessary prerequisite to the inception of comprehensive large-scale national programs of field bridge research into the life expectancy and the dynamic response of bridges. In order to permit the research to be concluded and put to practical use within a reasonable period of time, the anticipated large volume of collected data must be in a form susceptiable to rapid reduction, analysis and correlation. As a means of carrying out an effective national program of research on highway bridge problems, the wide variety of instrumentation presently used by researchers is this field should be improved, refinded and coordinated.

Research Problem Statement Number 78

Economic Considerations in the Design of Bridge Load Capacity

Bridge load capacity is currently determined by designing the bridge with a factor of safety for a standard truck intended to represent a load similar to current actual loading. Permissible axle loads in the various states vary widely. For some states, the Standard truck results in an overall load much smaller than the regularly permitted legally-loaded trucks. In addition, special permits are issued for truck loads which may greatly exceeed the legal load or the standard design load. Present design methods do not directly consider past experiences of increasing actual loads, increasing permitted legal loads and increasing frequency of loads, nor do present methods involve projections of these trends for the future. Proper selection of design load capacities for bridges as a result of valid predictions of future need, and basing this selection on an overall study of optimum economy, would be of tremendous benefit to highway agencies.

Research Problem Statement Number 79

Human Sensitivity to Bridge Vibration

Complaints by pedestrians and by passengers in vehicles (especially in vehicles stopped on a bridge) of "excessive" vibration of bridges are not infrequent and are considered by many highway bridge engineers and administrators to be a problem ranging from serious to annoying.

Research is needed to determine the extent of such complaints and the degree of seriousness with which they are considered by highway officials; to correlate such complaints with characteristics of the bridges and/or traffic; to study the reactions of vehicle passengers and pedestrians to the vibration of highway bridges and to relate these reactions to design parameters and actual vibration characteristics; and to consider possible remedial measures including design changes, vibration damping, education of the users and public relations.

Research Problem Statement Number 80

Effect of Roadway and Bridge Deck Roughness on the Life Expectancy of Highway Bridges

Both field tests and analyses have shown the marked effect of bridge roadway roughness or approach conditions on the dynamic increment of stress and deflection (impact) under vehicular traffic, with a consequent reduction in the life expectancy of bridges as a result of fatigue effects. The degree of roughness and the condition of the approaches can be controlled to some extent by changes in construction and maintenance procedures. The problem is to determine whether reductions in dynamic effects by such means is economically desirable in relation to the possible increase in bridge life.

Research Problem Statement Number 81

Analytical Studies of the Dynamic Effects of Vehicles on Highway Bridges

Analytical studies of the dynamic effects of vehicles on highway bridges are essential to the planning and interpreting of field tests intended to provide data for the prediction of life expectancy of bridges. Such studies have been made only for slab-and-girder bridges and box-girder bridges. Although these two types of bridges are popular and numerous, similar studies of other quite common types of bridges and bridge elements are needed.

Research Problem Statement Number 82

Dynamic Effects of Moving Vehicles on Skewed Bridges

Research is needed to extend existing studies of the dynamic effects of moving vehicles on right slab-and-girder bridges to skewed bridges of this type. Because of the mathematical complexity of the problem, the analytical studies made so far have been limited to right bridges. In order to provide data for comparison with the analyses, however, skew bridges are far too common to be ignored, and there is at present no basis for assuming that dynamic effects on them are the same as on right bridges.

Research Problem Statement Number 83

Alteration of Vehicle and Road Parameters to Reduce Impact on Bridges

The primary objective in previous field and laboratory research on the dynamic response of bridges to moving loads has been to determine the bridge parameters which might be altered to reduce the impact effect of vehicles. Another approach is a comprehensive study of vehicle and road parameters and the possible reduction in impact which can be achieved from a favorable combination of these characteristics. This is a natural extension of analytical studies of the Department of the Army, Purdue University, Cornell Aeronautical Laboratory and the analytical and experimental studies conducted at the AASHO Road Test. The primary emphasis should be to obtain experimental data on the dynamic effects of vehicle parameters for use with existing analytical approaches or modifications of them to fit the field data.

Research Problem Statement Number 84

Capacity of Highway Bridges for Infrequent and Emergency Loads

The materials of highway bridges usually remain elastic under the stresses produced by normal traffic. For this reason, practically all analytical studies

of dynamic effects (impact) have been based on elastic behavior. Similarly, most field tests have been caried out in the elastic range. However, under accidental, emergency or "permitted" overloads, or because of the presence of residual stresses, critical bridge elements may be loaded beyond the elastic range. The problem is to determine the effect of inelastic behavior on the dynamic effects under an overload and under subsequent normal traffic.