CENTER FOR HIGHWAY RESEARCH

THE UNIVERSITY OF TEXAS AT AUSTIN

RESEARCH STUDY 3-5-63-56

DEVELOPMENT OF METHODS FOR COMPUTER SIMULATION OF BEAM-COLUMNS AND GRID-BEAM AND SLAB SYSTEMS

Expanding highway programs, continuing shortage of engineering personnel, and consideration of maximum efficiency in design all point to a need to fully utilize the capabilities of high-speed digital computers in highway design.

This project has emphasized the continuing development of computer aided design and analysis techniques for the Texas Highway Department. The methods are presently being used by highway department and project personnel in several general areas for day-to-day design, analysis and research in highway pavements, bridges, and related structures.

Accomplishments. Thirteen comprehensive reports have been furnished. The computer simulations for all the procedures are closely related.

Specific accomplishments have been (1) working programs for girder and slab bridge systems over multiple supports, (2) a method of solution for slabs and pavements on yielding subgrade, (3) a direct solution for structural plane frames which can include sloping members, (4) dynamic programs for the study of beams and plates subjected to transverse vibrations, (5) a procedure for multiple-loading analysis for two-way floor slabs, (6) development of a general solution process for solving the types of equations common to most structural problems, and (7) a beam-column analysis to study combined axial and lateral nonlinear effects.

Implementation. Particular importance has been placed on the continuing implementation of the research results. Only through applications by design and research engineers can productive use be made of the completed computer programs. The feedback of ideas and suggestions is especially important in development of the analytical tools.

Applications. Numerous uses have been made of the developments in this project. The bent cap analysis program is in routine use. The completed beam-column programs have been used by highway department engineers for study of many special problems, among which are (1) overload capacities for existing structures, (2) railroad loadings on continuous girders, and (3) investigation of girders supported by rotating V-bents. One of the frame-solution programs has been used for box culvert design.

The completed slab and plate programs have been applied to problems such as (1) analysis of pavement stresses, (2) special pavement analysis for IH 45 in Walker County, (3) analysis of the two-way reinforced deck for the Houston Ship Channel Structure, and (4) analysis of steel plates in portable traffic scales for Project 108.

Five of the computer programs developed on this project are currently in successful use on the Texas Highway Department computer.

RESEARCH STUDY 3-8-63-73

DEVELOPMENT OF A SYSTEM FOR HIGH-SPEED MEASUREMENT OF PAVEMENT ROUGHNESS

This project is using a high-speed profilometer to develop a rapid, convenient method for measuring and evaluating riding quality of pavements. The instrument is being used to estimate the serviceability index (PSI) on Texas pavements. This is being done by running the instrument and a panel of 15 members over many different pavement sections at the same time and correlating the profilometer reading to estimate the panels opinion of the riding quality of the road.

Another important aspect of the problem is to evaluate the effect of roadway roughness on the dynamic load response of heavy highway vehicles. These measurements are being made in conjunction with Dr. Clyde Lee on Research Project 108.

With this new tool for evaluating riding quality, improved smoothness criteria can be established. The instrument is also useful in comparing quality of existing pavements for such purposes as establishing maintenance programs. The instrument is already being used on Texas highways. It was recently used for measurements in Corpus Christi and is presently being scheduled for use in the Atlanta, Dallas, Fort Worth, and Houston areas.

This research project presently supports three graduate students and three undergraduate students. Of the personnel costs expended, about 44% have gone to support graduate and undergraduate students; 26% to faculty and supervisory personnel; and 30% to supporting technical staff.

RESEARCH STUDY 3-5-65-89

SOIL PROPERTIES AS RELATED TO LOAD TRANSFER CHARACTERISTICS OF DRILLED SHAFTS

A drilled shaft is a cast-in-place concrete shaft with or without an enlarged base. The applied axial load is transferred to the soil through skin friction and point bearing. These types of deep foundations are widely used throughout the State of Texas.

This research program is aimed at developing a better understanding of the behavior of a drilled shaft under axial load, and utilizing numerical description of the foundation soils. The rational design procedure should allow drilled shafts to be designed with more economy than at present.

The general research plan consists of:

(1) development of long-term instrumentation,

(2) determination of the significant soil properties at the field sites by both field and laboratory testing,

(3) load testing of full-scale drilled shafts,

(4) correlation of soil properties with results of load tests, and

(5) translation of the research results into a usable design procedure.

A considerable effort has been expended on the development of instrumentation, (Item 1), and suitable axial load-measuring devices have been constructed and used. Work on Items 2, 3, and 4 is proceeding satisfactorily, principally in connection with field load tests of drilled shafts. The following tests have been performed:

SITE	DATES	SHAFT DIMENSIONS		PLUNGING LOAD, TONS
		DIAMETER, IN.	LENGTH, FT.	
Austin, Montopolis	10-66 to 3-67	24	12	150
San Antonio	6-67 to 5-68	30	28.5	1000
Houston 1	8-68 to present	30	23	140
Houston 2	3-69 to present	30 (with 7.5 ft. diameter bell)	23	537

Two additional research shafts are planned at Houston. In addition, a cooperative project is being undertaken with the urban district in Houston to test load a drilled shaft for design purposes.

The results obtained from the work accomplished give considerable insight into the problem. Some tentative design procedures have been proposed, and the development of rational design methods appears promising.

RESEARCH STUDY 3-5-66-92

PERFORMANCE OF CIRCULAR CULVERTS ON STEEP GRADES

The prediction of the hydraulic performance of culverts on steep slopes is one of the important design aspects of a highway crop drainage system. A satisfactory design should provide the adequate dissipation of fluid energy in addition to the prediction of the hydraulic behavior over a wide range of flows and geometric configurations. Furthermore, the design should ensure a safe and even velocity distribution at the end of the downstream wingwalls as a safeguard against scour and eventual undermining of the culvert structure. A design meeting these requirements should hopefully lead to minimum maintenance cost and efficient operation of the many culverts used by the Highway Department.

Research studies carried out to date have been concerned with the performance of broken-back circular culverts. This culvert configuration consists of three units, the center unit usually laid on steep grades with the first and third units on nearly horizontal slopes.

Past investigations have resulted in the prediction of the surface profiles, hydraulic jump locations and the amount of energy dissipation as related to the specific energy upstream of the jump. Experimental studies conducted on small and large scale models have indicated that the location and height of the sill required to cause the hydraulic jump to form within the Unit III portion of the culvert, can be related to the different flows and culvert configurations.

RESEARCH STUDY 3-5-66-94

STRUCTURAL MODEL STUDY OF SLAB AND GIRDER SPANS

This project consisted of a detailed study of the behavior at service load, moderate overloads, and at ultimate loads of typical concrete slab and girder bridge spans, using reinforced microconcrete structural models. The study concentrated on the behavior of the Texas Highway Department's standard pan-formed CG Series bridges. A number of highly accurate models were constructed and tested to obtain information concerning the actual distribution of load in bridges subjected to realistic vehicle loading patterns. The observed behavior of the models was confirmed at service load levels by full-scale testing of a prototype structure being built near Nolanville, Texas.

The results of the study indicated that accurate models of this type may be used to reliably measure load distribution at both service load and ultimate load levels. In addition, a comprehensive system of modeling practices was developed for use with highway bridge structures.

Study of the load distribution characteristics of the bridges led to a number of recommendations regarding the adequacy of present design provisions. Comparing the test results with present design practices based on AASHO specifications and BPR recommendations, it was concluded that the load distribution factors currently used are excessive for this type of bridge. A revised set of factors was recommended which would result in decreasing individual girder design loads approximately 25 to 33 percent, depending on the girder location and the type of bridge. The use of such revised distribution factors would result in appreciable savings in the amount of reinforcement required, even if the present standard pan cross sections are maintained.

Another result of the investigation was a recommendation that the bent cap should be designed considering its interaction with the end diaphragms as a non-composite beam. Such a design could materially reduce the required size of the bent cap.

RESEARCH STUDY 3-5-66-96

FATIGUE STRENGTH OF HYBRID PLATE GIRDERS UNDER SHEAR

Scope

The purpose of this final phase of the test program was to gather additional data on the fatigue strength of hybrid plate girders subjected to combined bending and shear. The end product of previous studies[1,2,3] and this study could readily be adaptable in the design of hybrid girders for highway bridges. The influence of aspect ratio on the fatigue strength of hybrid girders subjected to combined bending and shear is studied.

Test Program

Test program consisted of four hybrid girders with two different aspect ratios (α = 0.5 and 1.5). The maximum and minimum stresses used in the test were: (a) 25-40 ksi and (b) 25-50 ksi. Two girders, one with aspect ratio of 0.5 and other with aspect ratio of 1.5, withstood two million cycles without showing any cracks under a stress range of 15 ksi. The third girder (α = 0.5) under a stress range of 25 ksi showed type 3 crack after 670,710 cycles. Under the same stress range, the fourth specimen with α of 1.5 showed type 1 crack at 210,000 cycles.

Test Results

The analyses of the results are under progress. The final report will be ready shortly.

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[1]Kurobane, Y., Fielding, D. J., and Toprac, A. A., "Additional Fatigue Tests of Hybrid Plate Girders under Pure Bending Moment," Center for Highway Research Report No. 96-1, May 1967.

[2]Fielding, D. J, and Toprac, A. A., "Fatigue Tests of Hybrid Plate Girders under Combined Bending and Shear," Center for Highway Research Report No. 96-2, July 1967.

[3]Yinh, J., and Toprac, A. A., "Study on Fatigue of Hybrid Plate Girders under Constant Moment," Center for Highway Research Report No. 96-3, Jan. 1969.

RESEARCH STUDY 3-8-66-98

EVALUATION OF TENSILE PROPERTIES OF SUBBASES FOR USE IN RIGID PAVEMENT DESIGN METHODS

No rational method currently exists for designing layered pavement systems containing stabilized materials. In addition, no common method exists for designing or comparing asphalt-treated, cement-treated, and lime-treated base and subbase materials. At the present time, the design of such materials is primarily based upon experience.

This project is developing a test for evaluating the tensile load-deformational characteristics of stabilized base materials from which information can be obtained for the design of the stabilized mixture and for subsequent design of the pavement. In addition, this test will provide a method for comparing designs using all three types of materials and for choosing the stabilized material which is most satisfactory for a particular purpose.

The project is maintaining close coordination with Project 56, "Computer Simulation of Beam-Columns and Slab Systems" and Project 123, "A System Analysis of Pavement Design and Research Implementation," to insure that the findings of this project are put to use in new design procedures currently being developed for the Texas Highway Department.

RESEARCH STUDY 3-8-67-108

DYNAMICS OF HIGHWAY LOADING

The wheels of moving vehicles subject highway pavements and bridges to millions of repetitions of dynamic loads which vary in magnitude, duration, and frequency. Even though these service loads are dynamic in nature, present criteria for design loads are generally expressed in terms of static wheel loads, and virtually all material strength tests are performed under static loading conditions.

Engineers must have a better understanding of the relationship between static wheel weights and the maximum dynamic wheel forces which are imposed on highway structures if they are to select suitable materials and design structures which will safely and economically resist the applied forces without premature deterioration.

In this study, dynamic wheel forces produced by test vehicles and by normal traffic are being measured experimentally at twelve positions on the roadway surface. Transducers for these measurements were developed on Research Study 3-10-63-54 "A Portable Electronic Scale for Weighing Vehicles in Motion." Mathematical models which represent the dynamic wheel forces resulting from the interaction of several types of vehicles with various road surface profiles are being developed to aid in the interpretation and generalization of the observed data.

Results of this study will provide structural engineers with realistic dynamic wheel force parameters for use in improved pavement and bridge design procedures and will aid materials engineers in developing more representative tests for highway materials.

RESEARCH STUDY 3-5-68-112

CRACK WIDTH--CORROSION STUDY

Need

No well-controlled test data now relate reinforcing steel stress and bar cover to the corrosion hazard in a reinforced concrete member. Additional information on possible corrosion control by reducing the water-cement ratio of the concrete is also needed.

Procedure

A group of 26 beams with varying clear bar covers has been under load at various stress levels for nearly a year. An additional 13 unloaded members with differing water-cement ratios accompany the beams. Since June 1, 1968, all have been exposed to salt water sprayed on once a day. This wetting-drying cycle is already creating some corrosion. Further specimens are now proposed, along with continuation of the wetting-drying cycles.

Objective

To establish the influence of cover, water-cement ratio, and steel stress on corrosion of members in exposed locations.

Economic Implications

Corrosion of reinforced concrete in exposed locations is a major economic problem. Although this study is not directed to all phases of the problem, answers to the question of adequate bar cover, permissible bar stress, and necessary water-cement ratio will result in more economical and adequate designs.

4/21/69-PMF

RESEARCH STUDY 3-5-68-113

SPLICES AND ANCHORAGE OF REINFORCING BARS

Part A. Splices

Need

The joining of two lengths of bars to act as a single longer bar in a reinforced concrete member is frequently necessary. Although welding, the thermit process, and mechanical connections are possible, the lapping of the ends of two bars to form a splice held together by the concrete is the most common and least expensive splice form.

The AASHO Bridge Design Specification does not permit lap splices of #14S and #18S bars and for other bars provides a simple design rule recognizing neither the influence of lateral spacing of the splices nor the thickness of cover concrete. As a result some splices are forbidden, some are less safe than desirable, and some are of a wasteful length.

Objective

To continue the present study:

(1) To define adequate procedures for splicing very large bars (now prohibited).

(2) To define criteria which will eliminate hazardous splices and which in more common situations will reduce required splice lengths.

(3) To evaluate the deflection in slabs which results from creep in bond.

Economic Implications

(1) Lap splices of #18S and #14S bars are probably more economical than any other type. More importantly, lap splices do not interrupt normal construction processes; welded or mechanical splices do interrupt and are costly in themselves.

(2) For #11 and smaller bars, better design guides for splices will reduce costs when splices are not too closely spaced. Such guides will also eliminate certain hazards now only vaguely recognized.

(3) Alleviation of the problem of progressive slab deflection with time would reduce maintenance problems and costs.

4/21/69-PMF

RESEARCH STUDY 3-5-68-113

SPLICES AND ANCHORAGE OF REINFORCING BARS

Part B. Anchorage and Strength of Brackets

Need

The depth of a bent cap and a deck structure is reduced where bridge girders are supported near the lower face of the cap. Such construction is being used but it introduces stresses in the carrying bracket and the cap which have never been adequately explored. (Tests are already started.)

Objective

By laboratory tests to investigate full size specimens and determine whether economies of depth or materials are possible.

Economic Implications

If brackets and caps of less depth can be used, the overall height of overpasses can be reduced. Since many overpasses are at multiple levels, such economies can be cumulative, that is, the upper deck may be lowered by twice the individual reduction. This in turns means shorter elevated structures and substantial savings in construction cost.

4/21/69-PMF

RESEARCH STUDY 3-5-68-115

EXPERIMENTAL VERIFICATION OF COMPUTER SIMULATION METHODS FOR SLAB AND GIRDER BRIDGE SYSTEMS

The purpose of this project is to assist in the verification and application of computer simulation programs for typical slab and girder bridge systems. A comprehensive series of library searches and literature reviews has been carried out to obtain well-documented studies of slab and girder highway bridge systems. In areas where no information is available, such as for skewed prestressed bridges, physical tests are being carried out to obtain further comparative data. In all of these cases, studies are underway to verify the agreement between the output of the current computer simulation programs and the physical test results.

As a further purpose of this study and a natural outgrowth of the mathematical modeling of the physical test specimens, the most realistic ranges of input variables are being studied and suggested guideline procedures are being developed for the designer's use in initially setting up realistic slab and girder bridge analysis problems considering realistic material behavior. Such guideline procedures include methods for determining member stiffness at both service load and overload levels, methods for computing flexural and torsional parameters in nonuniform section bridges, and procedures for handling various types of boundary conditions typically found in slab and girder bridge systems.

This project has already resulted in an independent verification of the overall accuracy of computer simulation programs developed under Project 3-5-63-56 for many typical highway slab and girder bridge design conditions. The development of logical guideline procedures for various types of section and boundary conditions should be quite helpful to the designers in setting up problems. Difficulties encountered will lead to recommendations to the programming group of desirable changes in programs currently being developed to improve experimental correlation and to facilitate input of typical loading, material, or boundary conditions.

Preliminary results of the overall analysis and physical test verifications are leading toward recommendations to the Bridge Division for changes in analysis procedures to obtain more economical and safer structures.

RESEARCH STUDY 3-5-69-116

DEVELOPMENT OF RADIAL FLOW ENERGY DISSIPATOR FOR CULVERT OUTLETS

A major source of maintenance expense at highway culverts is the occurence of scour and erosion in the vicinity of the culvert outlet. High velocity flow from the culvert may develop a large scour hole extending downstream from the culvert or in some cases cutting back into the highway embankment. This has been a problem of long standing in many areas of the country and improved methods for reducing this lower scour and erosion will result in important reductions in the cost of building and maintaining highways.

Conventional methods of dissipating the high velocity energy of the flow from the culvert usually involves the conventional hydraulic jump or a series of baffles and walls. The effectiveness of both of these methods is limited because the flow leaving the energy dissipator is usually confined to a width about the same as the width of the culvert. The stream bed is usually of greater width and erosion may well result downstream from the dissipator until the stream has an opportunity to spread to the full width of the downstream channel. In addition, the energy dissipator using baffles and walls may catch drift which will block the structure and impair its operation.

The radial flow energy dissipator being developed is based on a new principle which makes use of vertical curvature of the flow to produce a pressure distribution causing the flow to spread rapidly to a width compatible with that of the downstream channel. In addition to the advantage resulting from the increased width of the flow the radial flow energy dissipator has two other significant advantages. 1. The geometry of the structure produces an inherent stability of the hydraulic jump permitting it to function effectively as an energy dissipator over a considerable range of tailwater depth and 2. The structure has no walls or blocks which can catch drift and impair its operation.

In developing the geometric design of the stilling basic an effort is being made to avoid, wherever possible, curved or warped surfaces which would add to construction expense in the field. To the maximum extent possible the stilling basin is formed from plane surfaces. It is expected that the radial flow energy dissipator will be most useful for culverts in moderately steep to steep topographic conditions.

RESEARCH STUDY 3-5-68-117

DEVELOPMENT OF METHOD OF ANALYSIS OF DEEP FOUNDATIONS SUPPORTING BRIDGE BENTS

In present day highway construction it is frequently necessary to found bridge bents on deep foundations. A complete analysis of a bent supported on deep foundations requires the consideration of complex loadings and geometry. The interaction of the foundation with the supporting soil is also a highly complex problem. Prior to the development of high-speed digital computers a great many simplifying assumptions were required in order to obtain a solution to the problem. In many cases the severity of the necessary assumption limited the usefulness of the solutions. Now that high-speed digital computers are readily available numerical techniques have been developed which reduce the number of simplifying assumptions necessary in order to obtain a solution.

The purpose of this research project is to develop a solution for a bent supported on deep foundations, which will take into account a number of factors previously omitted or approximated. This solution will be incorporated into a computer program. Necessary instruction manuals will be provided. The next step in the investigation is to run a series of load tests on two-inch diameter pipe piles embedded in sand, to check the validity of the proposed solution.

RESEARCH STUDY 3-8-68-118

STUDY OF EXPANSIVE CLAYS IN ROADWAY STRUCTURAL SYSTEMS

This is a long range project aimed at helping solve the problem of swelling clays in pavement subgrades. The service life and riding qualities of highway pavements throughout parts of Texas and other semi-arid sections of the world are often seriously altered by the uncontrolled shrinking and swelling of foundation soils. The consequent economic loss due to maintenance and replacement is enormous.

There is presently no adequate solution to this problem; however, work has been done recently in the areas of ponding, lime stabilization, and deep lime stabilization in attempts to control the problem. Much research and data collection is needed on this problem as there are very few cases of swelling clays where complete and accurate data were collected. Conferences have been held with representatives of several Texas Highway Department Districts who have intimate knowledge of the swelling clay probem in their areas.

We are currently conducting limited field testing in the Atlanta District on a deep clay cut which is expected to swell. Swell measuring devices have been installed, access tubes will soon be installed, and nuclear probes will be used to determine subsurface moisture and density changes. The data collected in Atlanta will be evaluated with the moisture movement and swell computer programs developed in this project. The ability to make rational prediction of swell should furnish a basis for better predictions of expected pavement life and would thereby assist in selecting economical design solutions for particular situations of swelling clay.

RESEARCH STUDY 3-5-69-121

DESIGN PROCEDURES FOR LONG SPAN PRESTRESSED CONCRETE BRIDGES OF SEGMENTAL CONSTRUCTION

The purpose of this project is to assist the Texas Highway Department in development of a new type of long span bridge to make feasible spans of 200 to 300 ft. for use in overcrossings and elevated freeways. The major emphasis is the development of a system which will permit significant improvement in both the aesthetics and the safety characteristics of highways by minimizing bridge columns, but still have reasonable construction times and costs.

The system being studied involves the use of prestressed concrete bridges in which a series of short span segmental units are precast and then assembled into a long span bridge by post-tensioning on site. In the initial year of the project a "state of the art" study has been made of this type of construction and its inherent advantages and problems. Several schemes for analysis are being studied and a usable design procedure is being developed. Studies of typical examples are being made to assess the economic feasibility and determine criteria for minimum cost design.

This research program should provide definitive information on the technical and economic feasibility of long span, segmentally constructed prestressed concrete bridges. If this goal is achieved, the following benefits should result:

(1) Economical increase in clear span lengths of highway bridges by using standardized elements.

(2) Enhanced highway safety and a more aesthetically pleasing design resulting from longer spans which allow the elimination of columns adjacent to roadways.

(3) Reduction of on-site construction time in long span construction.

(4) Obtainment of higher quality control through maximization of plant production.

(5) Reduction in design and construction costs by reduction in numbers of substruction elements in elevated expressways because of the increase in span lengths.

RESEARCH STUDY 3-8-69-123

A SYSTEM ANALYSIS OF PAVEMENT DESIGN AND RESEARCH IMPLEMENTATION

A need exists for the formulation of a computerized pavement design system that considers all physical variables affecting pavement performance and all economic variables influencing pavement design decisions.

The long range goal of this project is to develop for the Texas Highway Department a rational design system for all pavement types in partial fulfillment of this need and to provide for continued input into this system of the latest research developments and findings. The specific project objectives are as follows:

(1) Continue refinement of the flexible pavement design system developed in Research Project 32 and integrate it into use by the Texas Highway Department.
(2) Develop similar systems for rigid pavements and overlays.
(3) Incorporate into the system new research results and feedback from field usage.
(4) Delineate additional profitable areas of research in design, construction, maintenance, and economics of pavements.

The cyclic nature of this task dictates that the system be revised periodically. In future modifications, there are several items which will receive detailed attention. They are

(1) inclusion of skid resistance requirements for pavement into the FPS program,
(2) inclusion of stochastic concepts into design, and
(3) combining the FPS and RPS programs to provide a complete pavement systems analysis considering all pavement types.

At the present time, the project staff is assisting D-8 staff members with pavement design methods and in studying special design problems which are difficult to get approved by the Bureau of Public Roads.

RESEARCH STUDY 3-10-69-124

FUNCTIONAL CLASSIFICATION OF HIGHWAY SYSTEMS

This project is concerned with the current efforts of the Texas Highway Department in performing their portion of the National Functional Highway Classification Study as directed by the Congress. The study requires that Texas assemble and submit a vast amount of data to the Bureau of Public Roads by November, 1969.

The objectives of this research project are to examine the required data in detail and suggest to the Texas Highway Department how best they might use this data to their own advantage. The principal areas of investigation will include an attempt to develop a methodology for an equitable distribution of funds over the highway system and to propose a systematic program for maintaining the data in an up-to-date format.

It is anticipated that the results of the National Study will serve as a basis for future studies of National import and of direct concern to the State of Texas. The amount of funds and man-hours used in these efforts require that the State attempt to utilize these data in its own best interests rather than simply complying with Federal Legislation.