Structural Research and Testing in Florida

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At present, interest is increasing in the evaluation of existing structures and the development of new and economical types of construction. This is a direct result of the rapid change in the environment and scarce financial resources, which necessitate the development of better and safer structures and expansion of the life of existing structures. Also, spectacular developments in computers have provided engineers with a powerful tool for modeling and analyzing complex structures on the basis of a variety of assumptions. The verification of these computer models can only be done through field and laboratory testing, which is now more important than ever before. The Florida Department of Transportation (FDOT), recognizing the importance of structural research, undertook the creation of an engineering group dedicated to structural research and testing. The primary responsibilities of the structural research group are to conduct field and laboratory testing, evaluate existing bridges and structural components, and develop new design concepts and ways to cut construction cost and time. The state-of-the-art structural research laboratory therefore becomes an essential element in keeping FDOT in the engineering forefront. In this paper FDOT's current research program and available capabilities are described, and the necessary components for successful laboratory and field testing are discussed in detail. A brief description of research projects in which both laboratory and field testing were utilized to develop a new economical bridge system is given.

Historically, Florida's bridges have been among the least expensive in the nation, on the basis of cost per square foot. This low cost is due to many factors, among them favorable weather conditions and lower labor costs. However, the main factor has been willingness to adapt new construction techniques and design philosophies while still maintaining public safety as uppermost in importance. It is therefore essential to encourage structural research for evaluation of these new techniques and design philosophies before they are implemented.

Challenges from abroad have pointed out a general deficiency in research spending, which would inevitably lead to inferior products. Transportation research, although more difficult to compare with commercially oriented industrial research, has suffered even more. Nationally, in medium-sized industries, research expenditure has averaged approximately 1 percent of product cost. In some western European countries and Japan, this expenditure is 5 percent. Heavy dependence on engineering in the United States suggests that the level of transportation research should compare with the level of research in these medium-sized industries.

The Florida Department of Transportation (FDOT), recognizing the importance of structural research, undertook the creation of an engineering group dedicated to structural research and testing. The importance of structural research was brought to the forefront by several structural problems that occurred on the then recently completed Keys segmental bridges and other bridges across the state. It was decided that if FDOT was to continue as a leader in bridge and structures design, it would be essential to give proper attention to structural research.

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OBJECTIVES

The primary objectives of the structural research group were to (a) conduct laboratory tests to develop new design and construction concepts and (b) conduct field testing and evaluation of existing bridges. A brief description of these tasks follows.

Laboratory Testing

FDOT's research laboratory consists of a structural engineering laboratory with an attached office building that houses the researchers, support group, computer laboratory, and electronic workshop. The structural research laboratory has a 60- × 125-ft area served by two traveling cranes, each with a capacity of 20 tons. The primary component of the structural laboratory is a strong floor, which is a 3.5-ft-deep, heavily reinforced concrete mat with dimensions of 110 × 50 ft. The floor has a grid of one hundred and forty-four 150-kip anchor points at 6-ft centers. Each anchor point consists of four inserts anchored to channels at the base of the 3.5-ft-thick floor slab. All loading systems are driven by hydraulic power. This power is supplied by a 55-gal/min pump that serves two 55-kip, two 22-kip, and one 550-kip capacity actuator through a hard line network including five independent channels of controls.

The laboratory has two testing frames. One testing frame, covering an area of 10 × 58 ft, has a total static capacity of 1,000 kips in the vertical direction and 500 kips in the longitudinal direction. Details of the loading frame are shown in Figure 1. This frame allows the experimental testing of any structural component or bridge model up to 55 ft long and 12 ft wide. The loads are applied by eight 125-kip capacity hydraulic jacks. Jacks are mounted in pairs on a traveling frame that allows free movement of each jack in both the *X*- and *Y*-directions. The unrestricted movement of the jacks allows the application of any desired load combination to simulate actual field conditions. Details of the loading apparatus are shown in Figure 2. The second frame is a servocontrolled closed-loop testing system with static and dynamic capacity of 550 kips. Figure 3 shows a ½-scale bridge model during testing.

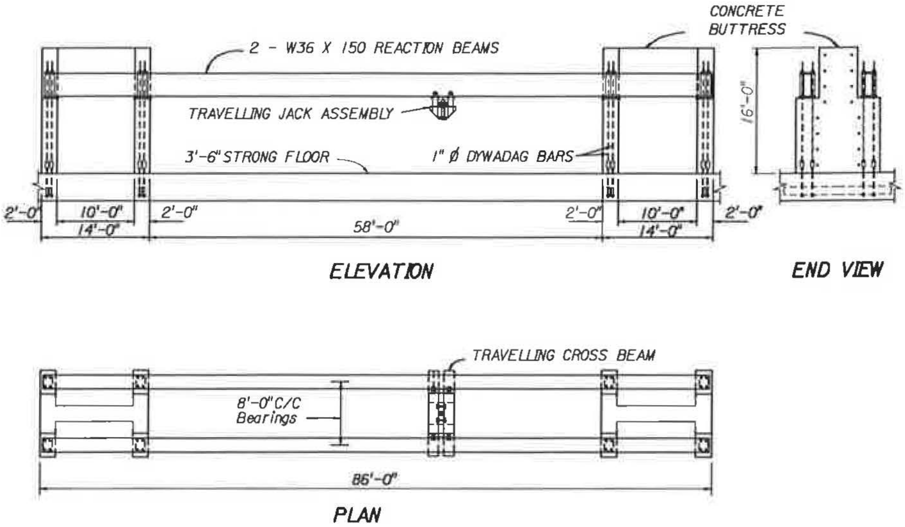


FIGURE 1 Dimensions of loading frame.

Two data acquisition systems are available. The first system is used to control and collect the test data from the 550-kip hydraulic testing frame. The second system is housed in a 23-ft motor home and is used for laboratory as well as field testing. The computer laboratory consists of a minicomputer with an extended memory and a graphic work station capable of handling large finite-element models. Also included in the laboratory are several IBM-AT and Hewlett Packard work stations with a large variety of software that provide the computational capabilities for the research group. FDOT's IBM mainframe computer is also available.

With its present capabilities, the structural research laboratory will facilitate static and dynamic load tests of large-scale bridge models and full-scale structural components. The results of such tests will serve in identifying serviceability and load capacity problems of highway bridges and in evaluating new concepts for inspecting and rehabilitating bridges and increasing their load capacity.

The research facility is one of a few in the United States and the only laboratory in Florida fully dedicated to structural research.

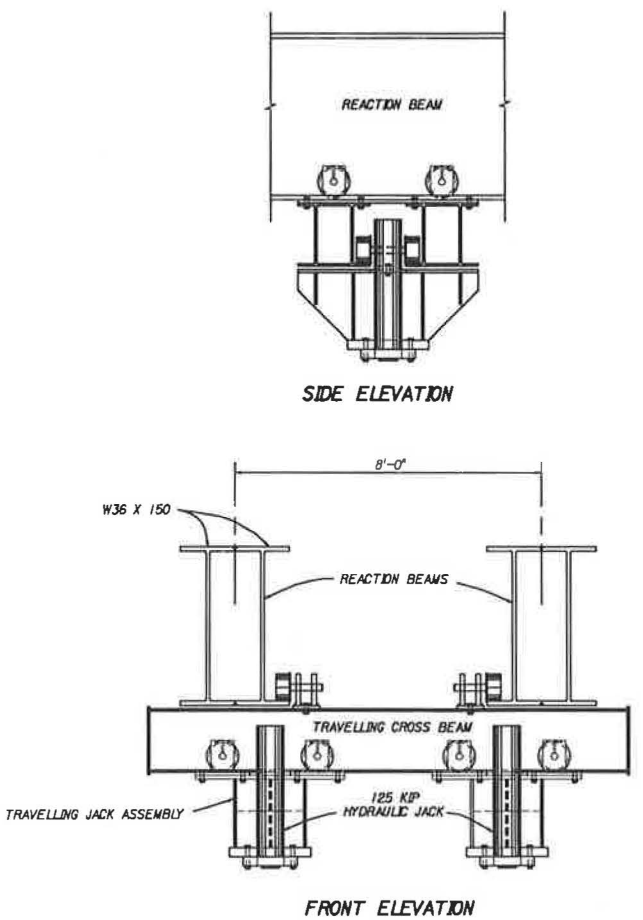


FIGURE 2 Details of loading apparatus.

Bridge Load Testing

It is estimated that of 500,000 existing bridges in the 50 states, nearly 105,000 are rated critically deficient (*1*,*2*). In Florida, thousands of the existing highway bridges are older than 20

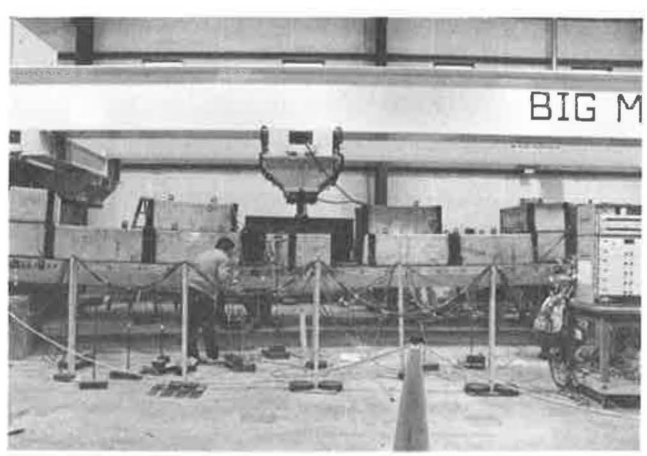


FIGURE 3 Half-scale model during testing.

years. Throughout the state, there are a number of bridges that, for one reason or another, are posted for loads lower than the original design loads. In many cases, the proper rating of a bridge cannot be achieved by the current methods of analysis. In most cases, the bridge is small and may be on an off-system road, so that it does not seriously affect commercial users. However, those that are on major systems and the resulting detours affect both the public and the commercial users.

Bridges of questionable strength that are posted for lower loads or scheduled to be replaced can be examined through a load test. The information collected from such a test can be analyzed to evaluate the true strength of the structure.

In bridge testing, various elements need to be examined. The strength of these elements is generally determined by placing strain or transducer gauges at critical locations along the elements. The bridge is then incrementally loaded to induce maximum effects. The data collected from the various instruments can be used to establish the strength of each component as well as the load distribution.

Testing Apparatus

The bridge load-testing apparatus consists of two testing vehicles, a mobile data acquisition system, and a mobile machine shop. The two testing vehicles were designed to deliver the ultimate live loads specified by the AASHTO code. Each vehicle is a specially designed tractor-trailer combination weighing in excess of 200,000 lb when fully loaded with concrete blocks. The detailed dimensions of the test vehicles are shown in Figure 4. Each vehicle can carry a maximum of 72 concrete blocks, each weighing approximately 2,150 lb. Incremental loading is achieved by adding blocks with a self-contained hydraulic crane mounted on each truck. Each truck contains a remote control system, allowing driverless operation when a bridge's strength is in question.

Testing Procedure

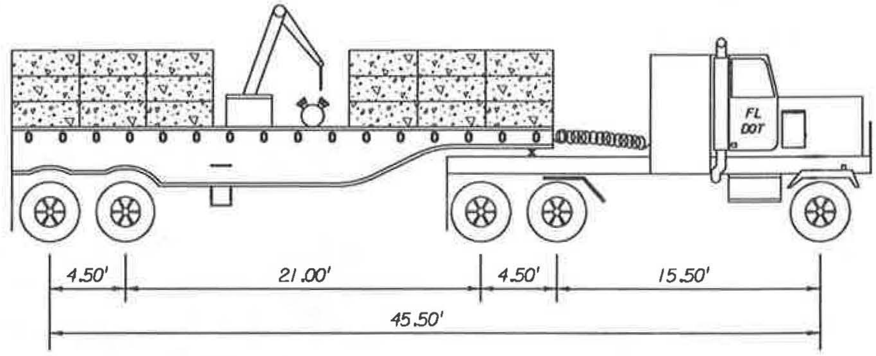
Once a bridge has been identified for load testing, a site survey and an analysis of existing plans and inspection reports give further information on the feasibility of such a test. The plans and details of instrumentation and loading locations are then established. The next step is to mobilize all testing equipment and personnel at the bridge site. The instrumentation [e.g., strain or transducer gauges, linear variable displacement transformers (LVDTs)] is placed at critical locations on the structure and tested for functional response.

The testing vehicles are loaded with an initial number of concrete blocks, established from the preliminary analysis of the existing structure. The vehicles are then driven to critical locations on the bridge while the data acquisition system monitors the instrumentation during loading. Figure 5 shows the two load-testing vehicles during testing. The data are immediately analyzed, displayed, and compared with the theoretical prediction to ensure the safety of the bridge, equipment, and testing personnel. After each load step, if the results compare favorably with the theoretical prediction, a specified number of blocks is added to the vehicles and the test is repeated until the ultimate AASHTO load is achieved. The data gathered can then be analyzed and a report of the findings prepared. Bridges that carry both vehicles without apparent distress are considered structurally safe.

RESULTS AND BENEFITS

One of the primary reasons for the establishment of the department's structural research program is the potential cost-saving benefits. In the short time that the laboratory has been in existence, the cost savings to the taxpayers have more than offset the expenditures.

Following are a few examples that show how Florida has already received significant cost savings and potential future savings.



WEIGHTS

72 ballast blocks	154,800 lb.
Equipment	8,200 lb.
Trailer	24,000 lb.
Tractor	17,000 lb.
Total	204,000 lb.

LOAD TRANSFER

5th wheel	82,350 lb.
Steering axle	15,630 lb.
Drive tandem	83,720 lb.
Trailer tandem	104,650 lb.

Note: All weights and dimensions are approximate and for information only.

FIGURE 4 Detailed dimensions of testing vehicle.

FIGURE 5 Load-testing vehicles.

Load Testing

The results to date have shown that load limitations imposed by theoretical analysis are not representative of the structure's real capacities. Design engineers and the existing codes have made conservative assumptions in the mathematical analysis of a bridge. This is not an unexpected finding. What has not been established, though, is a more accurate understanding of the extent of that conservatism and what it represents.

With higher loads expected in the future and the fact that, in spite of all attempts at policing these loads, overweight vehicles use the roads and bridges every day, what is needed is the knowledge of what these bridges can actually carry safely.

The bridge load-testing program will allow a satisfactory overall strength evaluation of any bridge under question. The information provided will greatly increase selective rehabilitation rather than the current practice of replacement of the entire structure. Proof loading has consistently indicated that structures have greater residual strength. It is estimated that about 85 percent of bridges with load restrictions do have adequate load-carrying capacity and subsequently do not need to be posted or replaced.

According to the department's program and resource plan, approximately $850,000,000 will be spent on bridge replacement and maintenance during the next 10 years. If this amount could be reduced by only 10 percent through the proof testing of bridges thought to be structurally deficient, the potential exists to save an estimated $85,000,000 during the 10-year period.

Florida Bulb-Tee Beam

The Florida bulb-tee beam was developed in house through extensive analysis and testing. The 72-in.-tall beam is the most effective ever designed or built in the United States. It was first incorporated in the Eau Gallie Bridge, which carries State Road 518 over the Atlantic Intercoastal Waterway, called the Indian River in Melbourne, Florida (*3*). The bridge consists of twenty 145.0-ft spans and carries four designated traffic lanes, two emergency lanes, and a 5.0-ft sidewalk. The bridge is subdivided into five independent structures, each continuous over four spans. Continuity was achieved by longitudinal posttensioning, which was carried out in two phases, one before and one after the slab was placed.

The development process included the physical testing of a full-scale, two-span continuous beam. The test beam carried the full AASHTO service load with no cracking. At ultimate, the beam carried 130 percent dead load and 490 percent live load, thus greatly exceeding AASHTO requirements.

The bridge was built in two stages. In the first stage, approximately two-thirds of the superstructure was constructed and opened for traffic. In the second stage, the old bridge was removed and the remaining part of the superstructure was built. Before the first stage of construction was opened to traffic, the bridge was load tested. The Eau Gallie Bridge won a certificate of special recognition from the Prestressed Concrete Institute in 1987.

In a competition for building the Howard Franklin Bridge over Tampa Bay, a design utilizing the Florida bulb-tee won, with a direct savings to FDOT of approximately $2,000,000. These savings, coupled with the estimated savings over conventional AASHTO or segmental beams on both the Eau Gallie Bridge ($800,000) and the Apalachicola Bridge, now under construction ($1,000,000), totals almost $4,000,000 in benefits already received by the department.

Isotropic Deck Reinforcement

The testing of both prototype and model bridge slabs showed that the mode of failure is not governed by flexure, as suggested by the AASHTO specifications, but by punching shear (*4*). Accounting for that fact in the design of bridge slabs will permit decreasing slab reinforcement by at least 50 percent. The research work is essentially complete. Adopting the new method of design will save approximately $4,500,000 a year for the state of Florida.

Transversely Posttensioned Double-Tee Bridges

The double-tee bridge system was developed through a cooperative effort between industry and the FDOT structural research group (*5,6*). The fully precast, prestressed double-tee beams are tied together by transverse posttensioning through simple grout-filled V-joints. The system provides for complete transverse continuity. This new system is aimed at state and Interstate highways with spans up to 80 ft.

In addition to analytical development, two series of physical tests were carried out. In the first (*5*), a half-scale bridge model was statically tested to investigate the overall behavior of the new system. In the second series (*6*), four fatigue tests were performed on a two-span 1:3.5 scale continuous bridge model at Florida Atlantic University. On the basis of both studies, a new design method was developed for short-span bridges.

The new design was utilized in the construction of two bridges for the city of Tallahassee. Both bridges were then load tested. The test results suggest that this new design is one of the most efficient for short-span bridges.

This new bridge type will save as much as $5/ft over current AASHTO designs for short-span bridges. It is estimated that a savings of $50,000,000 over the next 10 years may be possible using this new design.

CONCLUSIONS

Structural research is essential to transportation. Deficiency in research spending will only lead to inferior products. For many years, funding for transportation research in the United States has not been sufficient to support innovative product development as demanded by the public. The United States has become a copier and user of technology developed by others rather than a leader.

Increased research funding and long-term planning are critical for the United States to compete with other western European countries and Japan and to become once more a leader in this field. The Florida research program is only a small step in that direction and should be considered by other states in planning for the future. The benefits and the long-term cost savings are obvious.

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