Phase I

PROGRESS REPORT

for

DEVELOPMENT OF EVALUATION, REHABILITATION, AND STRENGTHENING CONCEPTS FOR LOW VOLUME BRIDGES

HR-323

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by

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1. INTRODUCTION

1.1 Historical Information

Numerous national studies have been completed detailing the substantial structural problems of high ADT highway bridges on the federal and state level. However, research and existing literature has virtually ignored the problems of local governments. Iowa is unique when compared to other states in their assignment of responsibility for bridge maintenance. An April 1989 Transportation Report (25) indicated that 86.4% of the rural bridge maintenance responsibilities in Iowa are assigned to the local level, i. e., the county and municipal systems, while only 13% are assigned to the state. The remaining 0.6% is assigned to the "other" which denotes private or a combination of custodial responsibilities. In the United States, Iowa has the highest percentage of rural bridge maintenance responsibilities assigned to the county level.

1.2 Purpose of Project

The primary objective of this project is to develop a design manual that would aid the county or municipal engineer in making structurally sound bridge strengthening or replacement decisions. The contents of this progress report are related only to Phase I of the study and deal primarily with defining the extent of the bridge problem in Iowa. In addition, the types of bridges to which the manual should be directed have been defined.

2. PHASE I ACCOMPLISHMENTS

2.1 Statistical Inspection

The Iowa Department of Transportation's Secondary Structures and Municipal Structures Computer Tapes for January 1989 were reviewed to compile statistical information related to Iowa's county and municipal bridge structural problems.

The number and types of bridges found on the county and municipal systems were determined. Figure 1 shows the ten most frequently occurring bridges on the secondary system. The percentage of each particular bridge type is also noted. Of a total of 20,882 bridges, these ten FHWA types represent 90% of all bridges on the secondary system; 60% of the bridges are in the first four categories. Table 1 provides a key for identifying the bridge types. Figure 2 shows similar information for the municipal system; these top ten bridge types represent 86% of all 1,308 bridges on the municipal system. Slightly over 44% of the bridges on the municipal system are in the first four categories shown in this figure.

Deficient bridges in the state of Iowa are characterized as either structurally deficient or functionally obsolete. These designations are based on the sufficiency rating of the National Bridge Inventory. Sufficiency ratings range between 0 and 100 percent. The three main variables used in the sufficiency rating are: 1) structural adequacy and safety; 2) serviceability and functional obsolescence; 3) and essentiality for public use. A bridge with a Structural Inventory and Appraisal (S.I. & A.)

sufficiency rating less than 50% is classified as structurally deficient and is eligible for replacement with federal bridge funds. A bridge with a S.I. & A. sufficiency rating between 50% and 80%, inclusive, is considered functionally obsolete and is eligible for federal rehabilitation funds.

Bridges were also reviewed according to the S.I. & A. sufficiency rating. Of particular interest were those bridges with values below 50%, or those bridges defined to be structurally deficient. Figure 3 shows the top ten structurally deficient bridge types on the secondary system. Of the total of 5,372 structurally deficient bridges on the secondary system, the first four types (FHWA 702, 302, 380, and 310), account for 92% of all structurally deficient bridges. Figure 4 shows the top ten structurally deficient bridges on the municipal system. Note that the top four bridge types on the municipal system are the same as on the county system, and make up 69% of 306 structurally deficient bridges. Based on this review, strengthening and/or rehabilitation procedures which apply to these four bridge types would be the most beneficial, since these types of bridges are the ones deficient on both systems.

Also reviewed for comparison were the functionally obsolete bridges. As Figure 5 illustrates, FHWA bridge types 302 and 702 were the top two functionally obsolete bridges on the secondary system, representing 69% of all functionally obsolete bridges. On the municipal system, more FHWA 302 bridges were found to be functionally obsolete than other types of bridges.

2.2 Literature Review

Minimal work has been performed on the general subject of strengthening and/or rehabilitating low volume bridges. Most of the research which has been reported has been on one specific type of bridge or set of circumstances. Although substantial research has been reported on essentially all types of bridges, this brief review concentrates on those bridge types that show the greatest statistical need for strengthening, i.e., timber stringer and steel stringer bridges.

The current AASHTO design specifications do not distinguish between low volume rural bridges and high volume urban bridges. It has, however, been suggested that a set of design specifications and procedures needs to be developed specifically for low volume bridges (12).

Previous research (16) has shown that methods of strengthening can be categorized in the following eight categories:

- Replace existing deck with lightweight deck.
- Provide composite action between the deck and the stringers.
- Increase transverse stiffness of the bridge.
- Increase the strength of existing bridge members.
- Add or replace members.
- Post-tension various bridge members.
- Develop additional bridge continuity.
- Strengthen critical connections.

2.2.1 Timber Bridge Studies

In recent years, there has been an increase in the use of timber in the transportation field. Construction of several timber bridges has developed significant interest; some of the techniques and procedures used in new construction can be also be used to strengthen existing timber bridges (3).

Throughout the United States, numerous short span timber bridges are in need of deck rehabilitation. The majority of these were nail-laminated. Due to traffic loading and the effect of the environment, these fasteners have loosened over the years. Until recently, the United States Department of Agriculture - Forest Service has been unsuccessful in attempts to rehabilitate timber bridges. Between 1965 and 1975, the Forest Service attempted to strengthen existing timber bridges with the application of transverse A36 steel rods. This procedure proved unsuccessful because the prestress force could not be maintained with the ordinary steel rods (19).

The use of lateral load distribution devices has generated significant research. These include distributor beams (26) or several methods of compressing longitudinal timber decks perpendicular to the grain. One method which has shown much promise is the use of high strength steel rods positioned perpendicular to the direction of traffic (21,27). These rods are tensioned against steel bearing plates along the outside edges of the bridge. The friction between the deck timbers induced by this tensioning eliminates inter-laminar slippage and provides substantial lateral load distribution. This transverse stressing has recently been approved by AASHTO as a new construction method.

Various types of parallel chord longitudinal deck systems have also been developed. Among these are plane trusses, multileaf trusses, and J-24 trusses. In place of diagonal wood members, the J-24 trusses have metal truss plates which are pressed into the timber (21).

2.2.2 Steel Bridge Studies

Steel girder bridges, which have a relatively small ratio of dead to live load, are especially sensitive to an increase in live load. Post-tensioning provides an excellent method of increasing the live load capacity of existing bridges. When the state of California increased the allowable legal loads on its bridges, many steel stringer bridges which were previously adequate became over stressed. In order to increase moment capacity, various tendon configurations were developed. The most effective of these were straight-tendon arrangements positioned above the bottom flange; in a few of the steel girder bridges, the tendons were positioned below the bottom flange with varying degrees of success.

The California Department of Transportation has recommended using straight-tendon arrangements to relieve relatively small overstresses, and using harped tendon paths to reduce regions of large overstress. This harped configuration can be developed by using king- or queen-post arrangements (14).

Iowa State University (I.S.U.), through research sponsored by the Iowa Research Advisory Board, has also developed post-tensioning strengthening procedures (5,6,7,13,14,15). The procedures developed by I.S.U. are more cost effective in that the procedure accounts for lateral distribution in simple span bridges and lateral plus longitudinal distribution in continuous span bridges. The California procedure post-tensions all girders of a given system while with the I.S.U. procedure, in most instances, only the exterior beams are post-tensioned - lateral distribution carries a portion of the desired stress reduction to the interior beams.

For the post-tensioning of simple span bridges, there was an initial laboratory feasibility study (HR-214, 13), a field study in which two bridges were strengthened and tested (HR-238, 5, 7), and a design manual developed for the practicing engineer (HR-238, 15). Several bridges in Iowa as well as in other states have been strengthened using this procedure.

The strengthening of continuous span bridges is following a similar sequence. Initially, a one-third scale laboratory bridge was strengthened employing various post-tensioning arrangements (HR-287, 6). Recently, a three-span bridge near Fonda, Iowa has been strengthened and tested (HR-308, 10). Within the next few months, a proposal will be submitted to the Iowa Research

Advisory Board proposing the development of a practical design manual for the post-tensioning of continuous span bridges.

The live load capacity of an existing bridge can also be improved by the reduction of the dead load of the bridge deck. Lightweight deck replacement is a viable option on bridges which have a overstress due to dead load, but which have undamaged girders and a sound substructure. Numerous types of lightweight bridge decks have been developed; among these are: exodermic, laminated timber, orthotropic plate (both steel and aluminum), and lightweight concrete (16,18).

2.2.3 Cost Effectiveness Studies

Several studies have been performed on the cost effectiveness of various bridge strengthening or rehabilitation methods. In 1985, Cady (4) developed a policy for the decision making process involved in bridge deck rehabilitation. An economic model was used based on the present worth of perpetual service, or the capitalized cost, of each alternative. This analysis may be extended to apply to any public works rehabilitation.

A study at Pennsylvania State University (31) developed a flow chart of rehabilitation methods for highway bridges. A survey of state bridge and maintenance engineers was made to determine the type and effectiveness of various maintenance and rehabilitation procedures. These procedures were subjected to a life cycle cost analysis to determine a range of expected unit costs for the various methods. A flow chart was developed which would allow a maintenance engineer to select the most cost effective rehabilitation method based on the amount of deterioration, etc. This type of solution manual was found to be very useful to local engineers.

The use of incremental benefit-cost analysis has been used by many agencies to aid in the decision making process. This method allows for the selection of the optimum alternative and prioritizes the projects. In public projects, measuring benefits in monetary terms poses a problem. One has to estimate the value of benefits, both for the agency and for the traveling public from available sources (23).

One difficulty noted in the literature was predicting the service life of various strengthening methods. This obstacle is somewhat mitigated by two factors: 1) as service life increases, variation in service life has a diminishing effect on calculated equivalent cost and 2) if the average service lives of relatively short-lived procedures are reasonably well known, rather large variations on an individual basis will have relatively little effect over the long run.

2.3 Advisory Panel Role

The advisory panel was formed to play a vital role in the determination of the project's practical focus. The advisory board is comprised of an Iowa Department of Transportation (Iowa DOT) Representative, a county engineer's panel, and a municipal engineer's panel. Larry Jesse is the Iowa DOT representative, from the Office of Local Systems. The county engineer's panel initially included Audubon County Engineer, Fred Short; Lucas County Engineer, Nick Konrady; and Poweshiek County Engineer, Moe Hanson. After the second county panel meeting, the Story County Engineer, Del Jesperson, was added to the panel. The municipal panel consists of the Cedar Rapids City Engineer, Dick Ranson and Iowa City Assistant City Engineer, Dennis Gannon.

The first advisory board meeting was with the county panel on March 15, 1990. Those in attendance were Larry Jesse, Fred Short, Nick Konrady, Moe Hanson and the research team. The project's objectives and the panel's role in the project were outlined and basic information was exchanged. After this meeting a draft of the proposed questionnaire was sent to the panel for their review and comments.

The second advisory board meeting occurred on April 26, 1990. Larry Jesse, Fred Short and the research team attended and discussed proposed modifications and additions to the questionnaire. The research team requested information on two bridges from Fred Short; one which needed strengthening and one which required replacement. Following this meeting Nick Konrady and Moe Hanson were contacted for the same information: a bridge that needed strengthening and a second bridge that needed replacement. Nick Konrady responded by specifying two bridges.

On May 24, 1990, the municipal panel, Dick Ranson and Dennis Gannon, and the research team, Terry J. Wipf, F. Wayne Klaiber, Deborah McAuley and Mike LaViolette met to discuss the municipalities concerns with rural bridges. The municipal questionnaire was discussed as well as the specific structural problems municipalities have.

The research team requested plans and any other pertinent information on an FHWA 302, steel stringer bridge, from Del Jesperson, on July 17, 1990, and he responded promptly.

While the county engineer panel is an essential and active part of this project, the concerns and problems of the municipalities may be beyond the scope of the project.

2.4 Questionnaire Responses

Each of Iowa's ninety-nine counties and seventy-seven of Iowa's municipalities with population's greater than 5000 were sent questionnaires (see example in Appendix A.) The questionnaires were developed to determine the perceived strengthening and rehabilitation needs of Iowa's county and municipal low volume bridges. The questionnaires were sent to the engineer in charge of each particular county or city. The county response rate was 88%; while the municipal response rate was 75%.

The initial questionnaire statement defined low volume bridges as those bridges with an ADT of 400 or less. In addition to answering the specific questions, the questionnaire encouraged comments and/or suggestions. Since county responsibilities are different from those of the municipalities, questionnaire responses from each were compiled separately. The questionnaire was divided into two sections. Completion of Section 2 was required only if the agency had strengthening or rehabilitation experience.

Section 1 of Questionnaire

The purpose of Section 1 of this two part survey was to determine the Iowa county's/municipality's experience with bridge strengthening and bridge rehabilitation. The questionnaire defined rehabilitation as including bridge replacement. As Figure 5 indicates, of the counties responding 43.6% had implemented at least one strengthening method; 81.4% had rehabilitated/replaced a bridge.

Fewer municipalities had attempted to strengthen bridges than counties. Of all municipalities responding, 14.3% had strengthened bridges, and 52.6% had employed a rehabilitation/ replacement method. It should be noted that 40% of all the municipalities either had no bridges, did not have any bridges with ADT's less than 400, or lacked a situation which could benefit from strengthening. The primary reason given by counties for not strengthening a bridge was that the deck geometries still would not meet state width specifications.

Figure 6 illustrates those reasons given for the lack of strengthening and rehabilitation/replacement by the various agencies. The indication here is counties, which are responsible for approximately 16 times as many bridges as municipalities, would benefit more from useful guidelines for bridge strengthening and replacement. Several respondents indicated that strengthening/rehabilitation had not been used because of the lack of appropriate expertise. Thus, this group would obviously benefit from the proposed manual.

Section 2 of Questionnaire

Section 2 questions were designed to identify the current bridge strengthening and replacement procedures most often employed by county/municipal engineers. Table 2 lists the number of responses to those questions which required a yes/no answer in Section 2.

When asked if any type of economic analysis was performed in making decisions, respondents noted that decisions were controlled by budget constraints, structural deficiency priority systems, and the needs of the public, thus making an economic analysis less effective.

Responses to question 2 of the questionnaire indicated five counties have developed their own bridge rehabilitation decision tools which included:

(1) a bridge rating sheet;

(2) graphs for beam spacing;

(3) tables for determining maximum spacing for various sized timber stringers to meet current legal load capacities for all wood bridges;

(4) a simple span bridge rating program used to assist in rehabilitation decisions; and

(5) charts indicating span lengths and stringer requirements for carrying fully legal loads.

A tabulation of the number of counties and municipalities which used services of structural engineering consultants along with the specific services used is presented in Table 3.

Of those responding to question 4 (see Table 2), county approval was 87% and municipal approval was 70% in favor of the development of decision making tools or rehabilitation/ strengthening design aids. Given a checklist of tools from which the agencies would most likely benefit, 81% of the counties listed computer software development; 52% requested nomograghs; and 23% requested flow charts. Other tools counties specified as being beneficial were plans, cost comparison calculations of rehabilitation versus replacement, a maintenance manual similar to the one used in Florida which outlines approved repair practices, and a design manual similar to the one used in California which outlines design values and techniques.

In the cases of the municipalities, of those in favor of a design tool, 67% were in favor of computer software, 52% were in favor of nomographs, and 52% were in favor of flow charts. One municipality noted a design aid is not necessary since they are a political entity and the insurance liability would be too great; another municipality noted they will always refer to a structural engineering consultant.

In order to determine the strengthening procedures with which counties/municipalities had experience, agencies were asked to check all procedures they had employed on the four most common structurally deficient bridge types considering the eight most commonly used strengthening procedures. The number of responses by counties were: addition or replacement of timber stringers - 50; addition or replacement of steel stringers - 31; and lightweight deck replacement of timber stringer bridges - 17. Municipality responses were: strengthening of existing members on steel pony and through trusses - 6; all other methods yielded fewer than 3 responses. Responses to "other" categories were also given very infrequently. The agencies which had employed strengthening methods were asked to indicate which of these methods were perceived to be cost effective and structurally effective. Counties noted the two most cost effective strengthening methods were 1) increased transverse stiffness and 2) providing composite action; the two methods perceived as the most structurally effective were the 1) addition or replacement of members and 2) strengthening of existing members. Municipalities noted the most cost effective methods were the 1) addition or replacement of various members and 2) strengthening of existing members and strengthening critical connections (equal number of responses for each.) The two structurally effective strengthening methods noted were 1) strengthening of existing members and 2) strengthening of critical connections. However, the addition or replacement of various members was also indicated as being very effective.

As expected, those methods which were not perceived to be very cost or structurally effective were the methods which have been employed the least. A possible explanation to be inferred here is that the engineers did not wish to endorse a strengthening method with which they had no experience.

It was suggested that if it were not cost effective to increase a bridge to current loading standards, a compromise could be reached where the bridge could be strengthened to a specified increased load. Counties specified in such a case the value they desire a bridge to carry is 19.1 tons; this value was obtained by averaging all reported values which ranged between 12 tons and 30 tons. The municipalities specified 16.4 tons (obtained by averaging reported values) as the desired capacity. Reported values ranged between 10 tons and 20 tons.

The National Cooperative Highway Research Program Report 293, Methods of Strengthening Existing Highway Bridges (16), reviews and describes current strengthening techniques used on highway bridges. Only 26% and 6% of the counties and municipalities, respectively, were familiar with this report.

Question 12 on the questionnaire asked the respondents to prioritize the top four deficient bridges into three categories: 1) those bridges which need to be strengthened, 2) those bridges which would most benefit from a combination of strengthening and posted weight/speed restrictions, and 3) those bridge types which are least likely to benefit from strengthening or rehabilitation methods. Responses by both counties and municipalities indicated that steel stringer bridges would benefit the most from either strengthening or a combination of strengthening and posted weight/speed restrictions.

In summary, a significant percentage of counties are currently employing strengthening methods, although a limited number of methods are being utilized. Replacement decisions typically tend to be sound economical and structural decisions based on current information available. It appears that part of the hesitation to strengthen a bridge results from a lack of adequate information and the bridge's inability to meet required deck geometries. Most importantly, both counties and municipalities indicated a rehabilitation/strengthening tool or design aid is desired.

The number of bridges per municipality is much less than the number of bridges per county. In addition, the high cost of liability insurance appears to be the reasons municipalities tend not to undertake their own strengthening and replacement designs. However, while counties also employ a great number of consultants, they are more likely to do some of their own engineering because of the large number of bridges for which they are responsible and budgetary constraints.

3. ILLUSTRATIVE EXAMPLES

3.1 Demonstration Project Objective

The purpose of the illustrative examples which follow was to demonstrate to the advisory panel the strengthening/ rehabilitation that can be implemented on various types of bridges; the illustrative examples really represent the initial steps of Phase II of the study. The use of specific examples together with input by the advisory panel will help the research team in developing guidelines which will be of greatest value to bridge engineers. Work in Phases II and III will involve the development of design aids, software, etc. which will assist engineers in designing the components of various strengthening/ rehabilitation system components.

Members of the advisory panel were each asked to provide two bridges, one which required strengthening and one which needed to be replaced. Lucas County identified a 4 span timber stringer (FHWA 702) which required strengthening and a combination steel stringer (FHWA 302)/timber stringer bridge (FHWA 702) which required replacement. The Story County member of the advisory panel provided plans and information on a steel stringer (FHWA 302) which required strengthening.

As a part of the analysis of these bridges, a review of the S.I. & A. sufficiency rating was performed. As previously mentioned, the structurally deficient or functionally obsolete classification is dependent on the S.I. & A. sufficiency rating. Additionally, since the federal bridge replacement or strengthening funding which may be requested is dependent on this rating, an analysis of the factors which comprise this number is obviously of interest. Table 4 outlines the most important of these items. An increase in the S.I. & A. sufficiency rating as high as 68% is possible when those specific points outlined in Table 4 are corrected.

3.2 Proposed Modification

The modifications proposed for strengthening the bridges submitted by the advisory panel are presented in the following sections. It should be noted that the procedure the research team visualizes developing for strengthening/rehabilitation or replacement design guidelines for deficient bridges involves three steps: 1) identification of alternatives, 2) analysis and design, and 3) evaluation of alternatives to determine the best procedure.

The first two steps have been illustrated in the two examples presented. Only a brief summary of those two steps is provided in this report. Separate appendices have been developed which illustrate the calculations performed in the analysis and design of the alternatives, but are not included in the interest of saving space. The intent of the research team is to develop design aids which would assist the bridge engineer in making these calculations.

First cost information has been provided for each alternative. This is given to provide a rough comparison and is not intended as the best way to compare alternatives. Developing a methodology for determining the best choice between two or more alternatives is a part of Phase II of this study.

The research team has not completed the replacement example for this report. The evaluation of alternatives for a replacement situation requires a similar analysis procedure as for strengthening: 1) identify alternatives, 2) analysis and design and 3) cost evaluation. The proposed design manual would contain this information in a format similar to that illustrated in the strengthening example.

3.2.1 Timber Stringer Bridge Strengthening

Figure 9 illustrates the bridge's configuration. A hand calculation of the computer generated S.I. & A. sufficiency rating was performed to determine which factors contributed to the bridge's 62% rating. (See Appendix B.) The low rating is due to the following losses:

26.7%: the Inventory Rating (#66) was 18.83 tons below the required 36 tons.

4%: the Structural Evaluation (#67) was assigned a low code of 3, reflecting basically intolerable conditions requiring high priority of corrective action.

4%: the Deck Geometry (#68) was assigned a code of 2 reflecting basically intolerable conditions requiring high priority of replacement.

5.25%: could be corrected if the bridge Roadway Width (#51) divided by the number of Lanes (#28) was >= 18.

2%: was due to the Vertical Clearance being coded as 0.

Five strengthening methods were considered:

1. Increase stiffness of bridge
2. Post-tension
3. Develop additional bridge continuity
4. Add or replace members
5. Improve strength of members

Alternative 1, increasing the stiffness of a bridge, in some instances can raise a bridge's strength by as much as 30%. However, in most instances, it is considerably less than this amount, thus this procedure is considered a secondary method. Therefore, this method was not given additional consideration.

Alternative 2, post-tensioning, is not a practical method for this bridge because of the large number of stringers which would require a sizable amount of steel (i.e. brackets, tendons, etc.) and manpower.

There are several reasons Alternative 3, develop additional bridge continuity, was not considered for this bridge: the overall effectiveness on a bridge this age is questionable; implementation of the theoretical assumptions of continuity is difficult; and analysis of the bridge with partial continuity or complete continuity is somewhat more involved than analysis of simply supported structures.

Time limitations did not permit a site inspection of the bridge in question. Therefore, no statement can be made of the usefulness of the second part of Alternative 4, replacement of members, for this particular bridge. Members which have sustained physical damage, excessive weathering, or pest destruction and can be easily removed and replaced are candidates for replacement. (See NCHRP Report 222 (28) for specific details.) The first part of Alternative 4, addition of a member, was an option considered. Appendix C summarizes the analysis which proved this to be a possible alternative.

Alternative 5, improve strength of bridge members, was the alternative given the most consideration.

Only the most critical span (Span 3 in Fig. 9) was analyzed. Attachment of steel plates to the bottom of one or more stringers is a procedure which can be used for the strengthening of timber stringers (see Fig. 10). This creates a composite beam with a higher section modulus thus allowing the bridge to carry greater live load moments. Spreadsheets were developed to determine the inventory and operating live load moments and horizontal shear capacity based on AASHTO truck line loading. These spreadsheets supplied the information needed for both the various plate/stringer combinations. Appendix C contains a summary of all combinations examined as well as example calculations. The additional stringer combinations were analyzed by assuming an average stringer size. As mentioned earlier, 26.7% of the deficiency could be corrected if the HS20-44 truck inventory moment could be raised to 36 tons. This was the criterion used in subsequent design calculations. A 0.25" thick plate attached to two adjacent stringers, thus creating a box beam, increased the stringer capacity to the desired 36 tons. The connection between the steel plate and timber stringers was designed and checked according to the timber National Design Specification (20). Using 0.5" diameter lag bolts, spacing of 5 inches on center is required.

This strengthening method raised the S.I. & A. sufficiency rating to 84.7% The structural evaluation (#67) number would also undoubtedly increase. After the vertical clearance coding was corrected and legal approach guardrails installed, an S.I. & A. sufficiency rating as high as 91% could possibly be achieved. Thus attaching a 0.25" thick steel plate as shown in Fig. 10 is the strengthening procedure recommended for this bridge.

The initial cost of adding steel cover plates to the Lucas County timber bridge was estimated with the assistance of the Iowa DOT. In addition to the cost of materials, the project would require the use of hydraulic jacks to reduce dead load stresses in the girders before the cover plates are bolted in place. It is estimated that the initial cost of the cover plating process described above is approximately $10,500. This cost has been developed with the thought of hiring an outside contractor to perform the work. Substantial savings may be realized if a county used its own forces on the project.

3.2.2 Steel Stringer Bridge Strengthening

The steel stringer bridge which required strengthening was from the V11 series. Other information provided which is related to this bridge included detailed site information, the county's copy of the Iowa Structure Inventory and Appraisal sheet, and the data from the Iowa DOT Secondary Structures Tape.

The length of the steel stringer (FHWA 302) bridge, which was built in 1967, is 80 ft; the horizontal clearance is 24 ft; the average deck thickness is 6.5 in. The bridge's four stringers are spaced at 7ft 8in centers; external stringers are W 33x118's and internal stringers are W 36x135's.

The bridge's S.I. & A. sufficiency rating is 80%. (See Appendix D.) The 20% deficiency is due to two factors: 18% to the bridge capacity which is 16 tons below the HS 20-44 truck loading and 2% to inadequate road/bridge guardrail transitions, approach guardrails, and approach guardrail ends.

Listed below are the five alternatives which were reviewed as possible strengthening procedures:

1. Increase stiffness of bridge.
2. Lightweight deck replacement.
3. Improve strength of bridge members.
4. Add or replace members.
5. Post-tensioning.

Alternative 1 was not considered for the steel stringer bridge for the same reason it was not considered for the timber bridge. That is, at most the strength of a given bridge can be increased 30%. Therefore, this method is generally only utilized as a secondary method in combination with another strengthening procedure.

It was determined from calculations for Alternative 2 that four of the seven lightweight deck replacements investigated would be structurally beneficial. They include an open steel grid, a timber deck, an exodermic 1/2 filled steel grid with wearing surface, and a timber deck with wearing surface.

The design chosen for Alternative 3 is illustrated in Fig. 11. The built up section increased the section modulus of the steel stringer, which increased the live load capacity of the member. A spreadsheet aided in the determination of the most economical sections. A combination of 2 - L 6x6x1 and a WT 12x31 were used for the exterior beam and 2 - L 6x6x5/8 and a WT 8x35.5 was used for the interior beam.

Alternative 4 was investigated but did not prove feasible for this particular bridge.

Initial calculations for post-tensioning the two external stringers resulted in a design which was 16% less than the strength desired. However, additional investigation of this method more than likely will result in a successful design.

The three methods which show definite promise are Alternatives 2, 3, and 5. Additional analysis would allow refinement in the design and a clearer connection between the strengthening procedure employed and its effect on the bridge's S.I. & A. sufficiency rating. This information along with step by step strengthening information and economical tools could prove to be a very powerful tool for county and municipal engineers.

As with the timber stringer bridge discussed previously, the initial cost of strengthening the Story County steel stringer bridge has been estimated with the assistance of the Iowa DOT. The initial cash outlay for the timber lightweight deck replacement options would be approximately $47,200, while the first cost of a similar deck replacement using a steel grid would be approximately $77,200. Increasing the strength of existing members by adding L and WT sections, Alternative 3, would cost approximately $52,000.

The initial cost of strengthening the bridge by post-tensioning is the most uncertain of the four methods. Due to the relative lack of bridge contractors experienced in strengthening by post-tensioning, the cost of such a procedure is highly situation dependent. The best available estimate of such a method, assumed to be performed by a bridge contractor, is approximately $24,000. This value assumes that one bridge is being post-tensioned. If more than one bridge in the area is being strengthened by post-tensioning, the cost would be less as the mobilization cost would be spread among all the bridges being strengthened.

These initial cost figures are intended only for comparison between the various methods and may differ significantly from the actual cost of a particular strengthening method.

4. CONCLUSIONS AND FURTHER STUDY

From the statistical review, four bridge types, steel stringer/multi-beam or girder (FHWA 302), timber stringer/multi-beam or girder (FHWA 702), steel pony truss (FHWA 380), and steel thru-truss (FHWA 310), were identified as the bridge types which require the greatest attention. The bridge types which would most benefit from strengthening were the steel stringer/multi-beam or girder (FHWA 302) and the timber stringer/multi-beam or girder (FHWA 702) by the questionnaire responses and from input given by the advisory panel.

Two illustrative examples were developed; preliminary investigation showed that the 3 alternatives previously noted are very viable strengthening methods for typical steel stringers; 2 possibilities previously discussed exist for timber stringers. The purpose of the examples was to show that alternatives exist for strengthening deficient bridges and to illustrate to the advisory panel the type of information that could be incorporated into a design manual. As a result of the successful completion of Phase I of the investigation, it is recommended that the project be continued as originally proposed. Previous documentation showed that 87% of the county engineers and 70% of the municipal engineers who responded to the questionnaire are in favor of the development of, and would find beneficial, a manual containing decision-making guidelines and strengthening/rehabilitation design aids.

Phase I also identified the most frequently occurring types of bridges on both the county and municipal systems. As has previously been shown (see Figs. 1 and 2) steel stringer (simple and continuous span), timber stringer, concrete continuous slab, and steel pony truss type bridges account for 66% of the bridges on the county and municipal systems. The remaining efforts of the project (Phases II and III) will concentrate on these types of bridges. However, many of the techniques may be applicable to other types of bridges with appropriate modifications.

As the original proposal stated, the majority of effort in Phase II of the investigation will be on Tasks 3 and 4. Task 3 involves determining strengthening/rehabilitation procedures that are applicable to the bridges identified in Phase I. In addition to consideration of the strength requirements, the simplicity, practicality and economics of a particular alternative will be given careful consideration. Although listed as Task 5 in the original proposal, initial steps will be taken on the development of design aids for the design manual as well. The other task (Task 4) which will be undertaken in this phase of the investigation involves the development and refinement of an economic model for evaluation and/or strengthening decisions. It is anticipated that a model which considers equivalent uniform annual costs will be investigated. All pertinent variables will be included to provide an accurate assessment of these decisions.

Upon the completion of Phase II, a second progress report will be submitted to the research advisory board.

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6. TABLES AND FIGURES

Table 1
Descriptive FHWA Bridge Type Names

F.H.W.A.#	Descriptive FHWA Bridge Type Names
101	Concrete slab
102	Concrete stringer/multi-beam or girder
104	Concrete tee beam
119	Concrete culvert
201	Concrete continuous slab
219	Concrete continuous culvert
302	Steel stringer/multi-beam or girder
303	Steel girder and floor beam system
309	Steel truss-deck
310	Steel thru-truss
380	Steel pony truss
402	Steel continuous stringer/multi-beam or girder
502	Prestressed concrete stringer/multi-beam or girder
504	Prestressed concrete Tee beam
702	Timber stringer/multi-beam or girder

Table 2
Summary of Section 2 Summary Questions

Questions:	Number of Responses Counties Yes	Counties No	Municipalities Yes	Municipalities No
1. Do you use formal methodologies (e.g. benefit/cost analysis, equivalent annual cost method, etc) when making management decisions?	21	55	10	23
2. Have you developed any design aids, nomograph, software, etc., that are useful in making bridge rehabilitation choices?	5	13	10	32
3. Does your agency hire any structural engineering consultants?	68	10	30	3
4. Would your municipality benefit from a design aid or decision making tool?	62	9	21	9
5. Are you familiar with the National Cooperative Highway Research Program Report # 293, Methods of Strengthening Existing Highway Bridges?	20	56	2	31

Table 3
Number of Agencies Which Employ Consultants

Consulting service	Number of Responses	
	Counties	Municipalities
Structural analysis	61	27
Bridge inspection	52	26
Strengthening or rehabilitation	24	20
New or special bridge designs	11	7
Construction inspection	3	17
Load rating	1	0
Culvert design	1	0
Underwater inspection	0	1

Table 4
Structural S.I. & A. Sufficiency Rating Criteria

ITEM	CRITERIA
1.	Superstructure Rating (S.I. & A. #60) must be increased to a value of 6 or greater. Code 6 denotes "major items in need of repair by maintenance forces."
2.	Inventory Rating (S.I. & A. # 66) represents the gross loading which must be met by the following vehicles (the largest gross weight controls):

Vehicle	Code load requirements
1. H truck	23.07 ton
2. HS truck	36.00 ton
3. Alternate interstate loading	23.07 ton
4. 3-Axle truck (type 3)	35.64 ton
5. 3-S Semi-trailer	46.75 ton
6. 3-3 Trailer	53.73 ton

Note: Currently the HS20-44 truck is the standard.

3.	Deck Condition (S.I. & A. #58), Structural Evaluation (S.I. & A. #67), Deck Geometry (S.I. & A. #68), and Under clearances (S.I. & A. #69) should be increased to a code 6 or better.

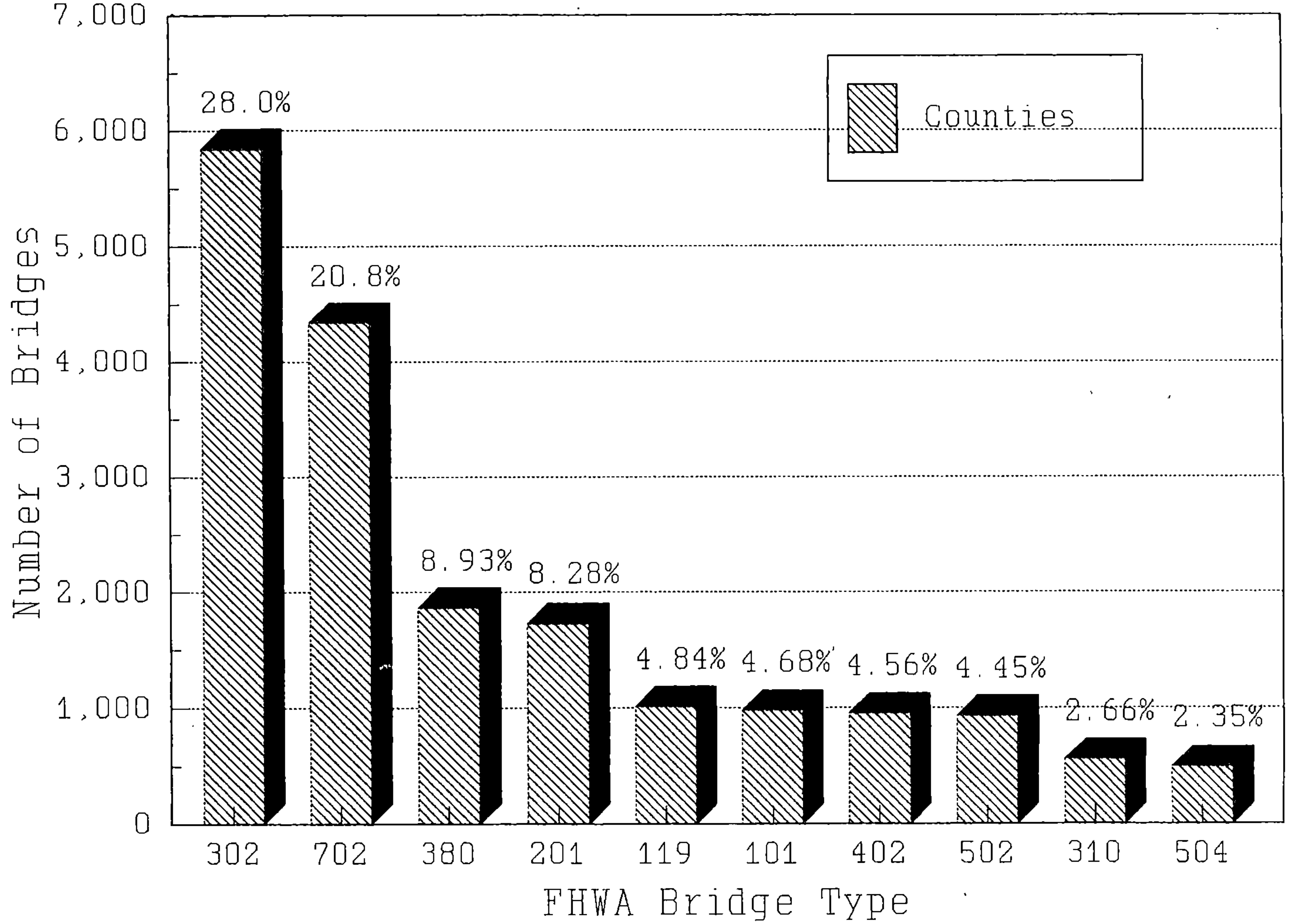

Fig. 1. Iowa County Bridges by Structure Type

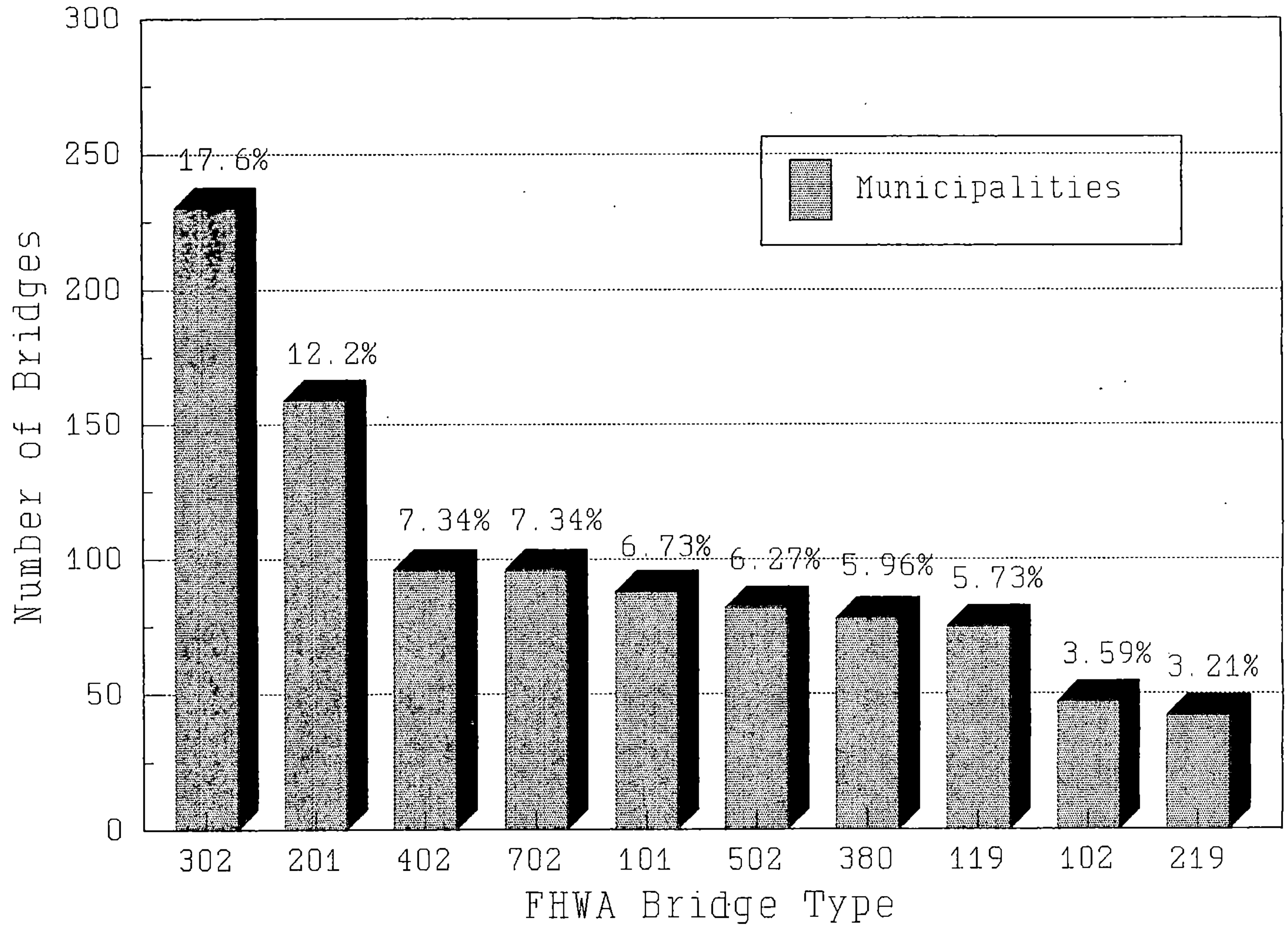

Fig. 2. Iowa Municipal Bridges by Structure Type

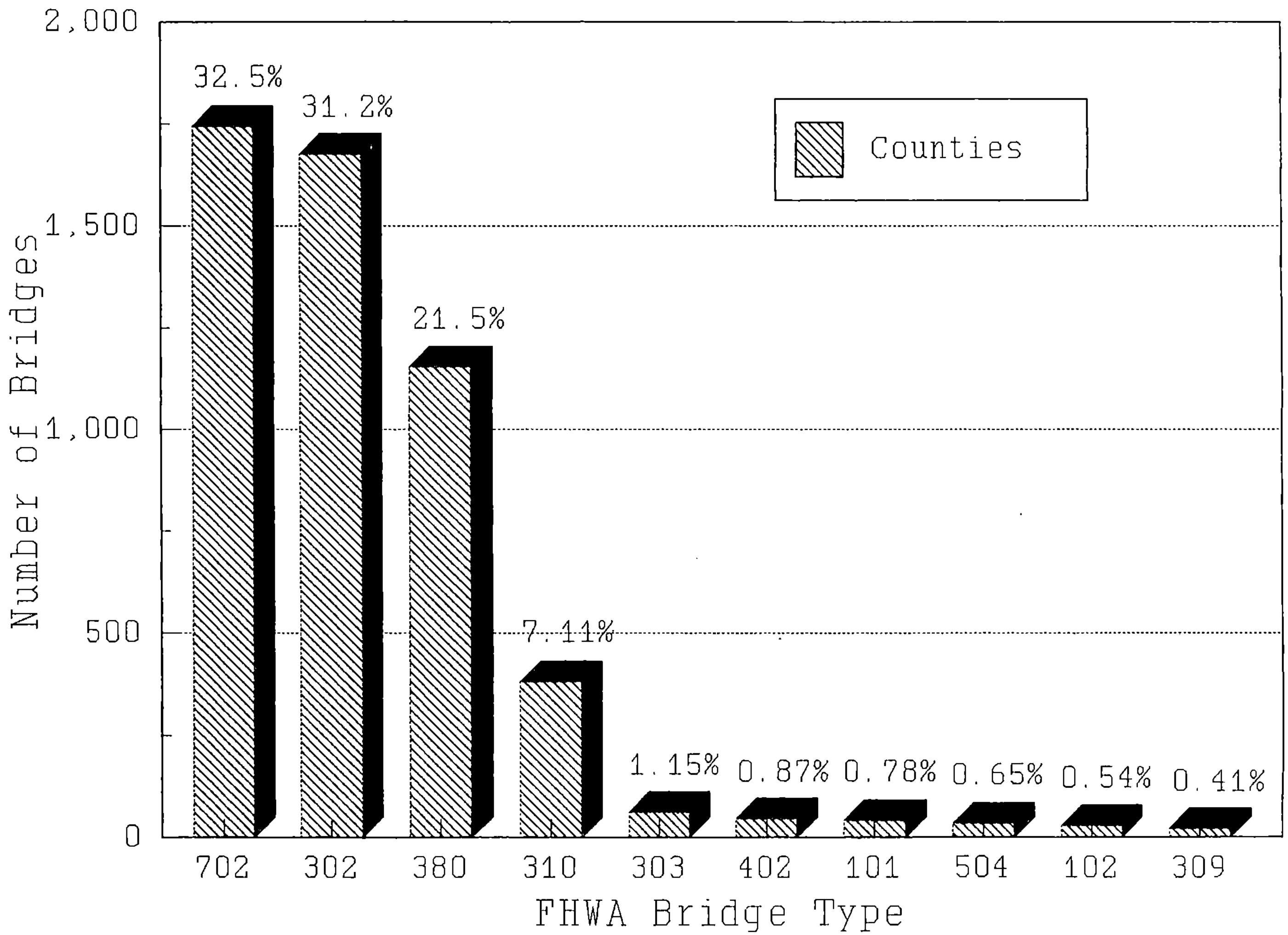

Fig. 3. Structurally Deficient County Bridges by Structure Type

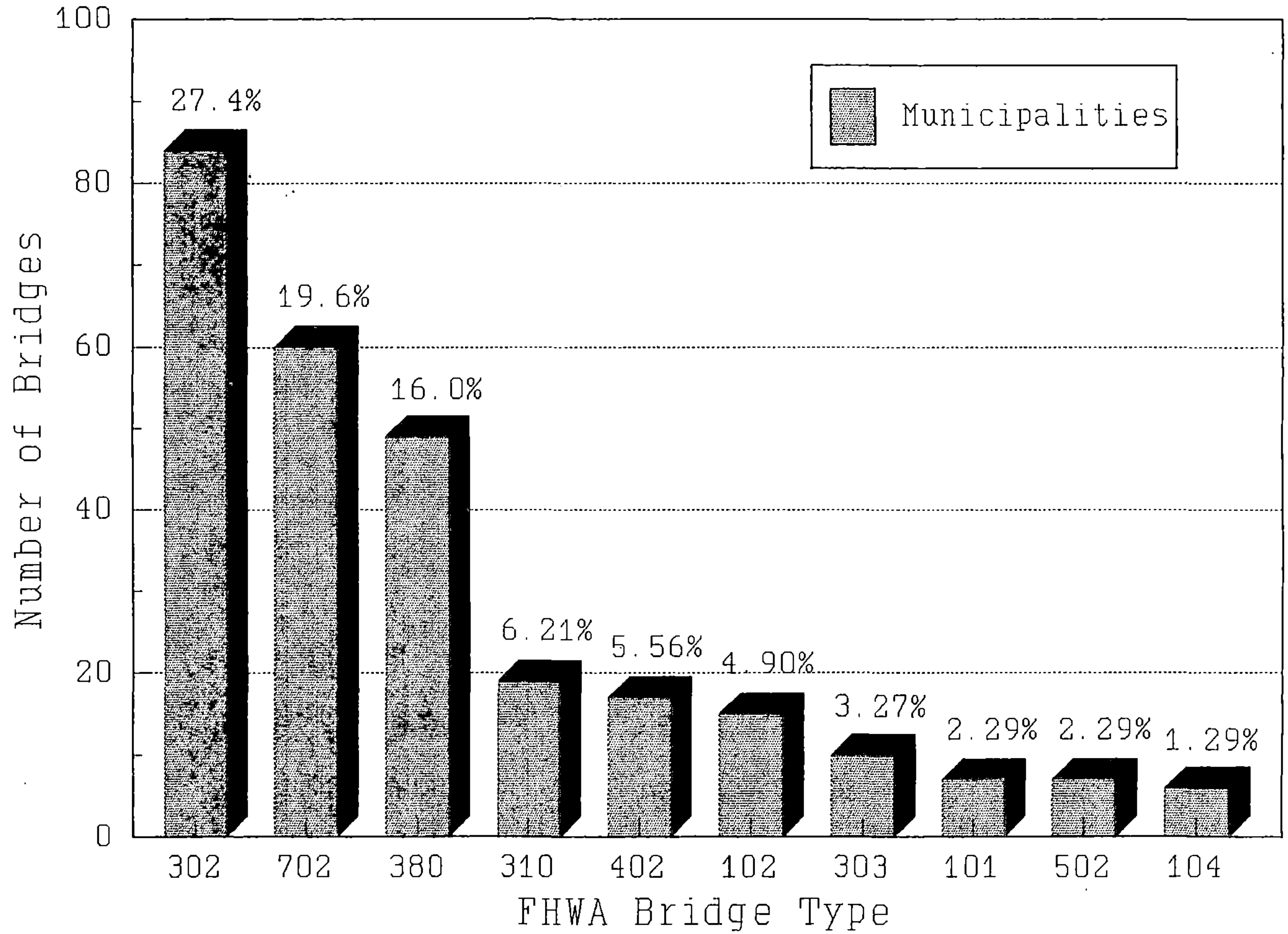

Fig. 4. Structurally Deficient Municipal Bridges by Structure Type

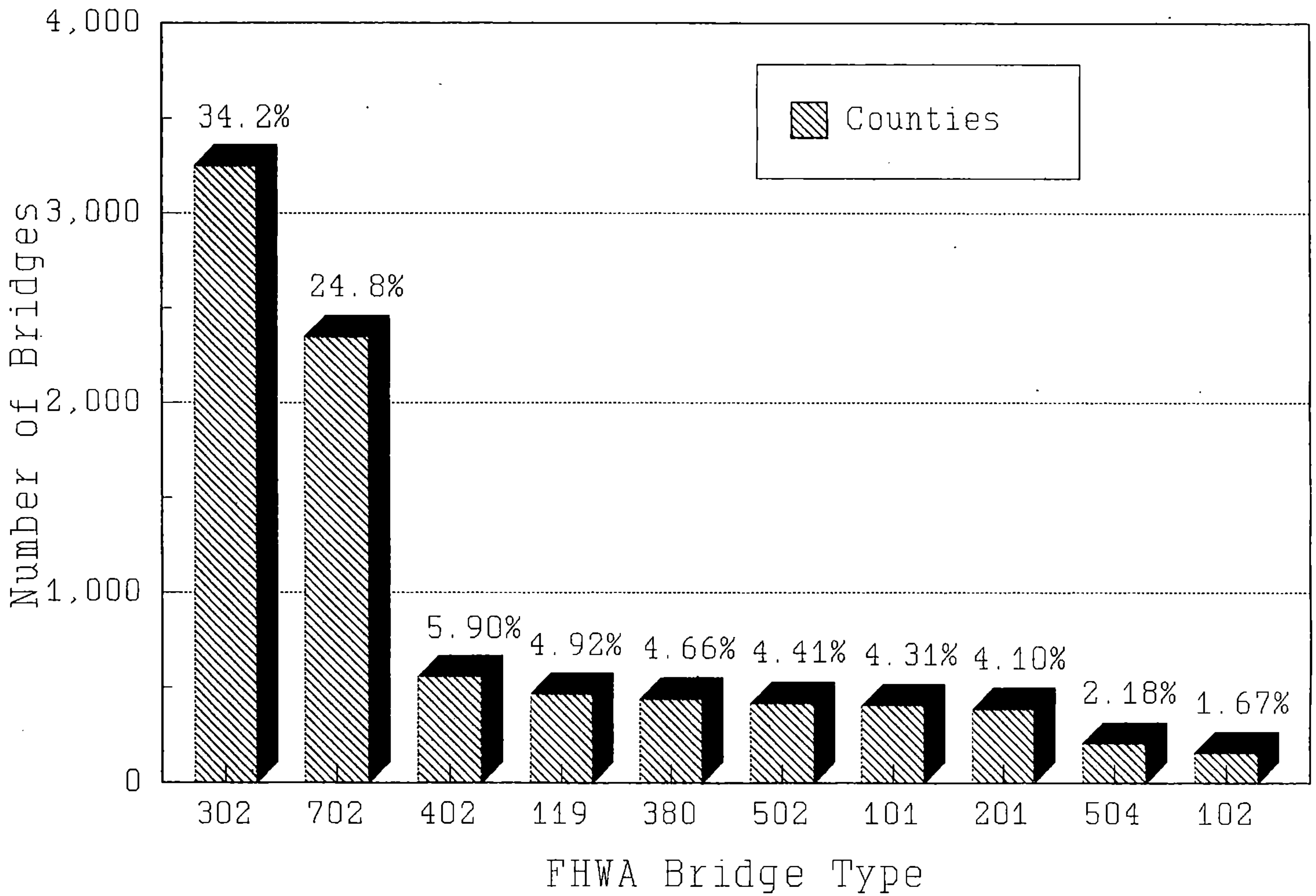

Fig. 5. Functionally Obsolete County Bridges by Structure Type

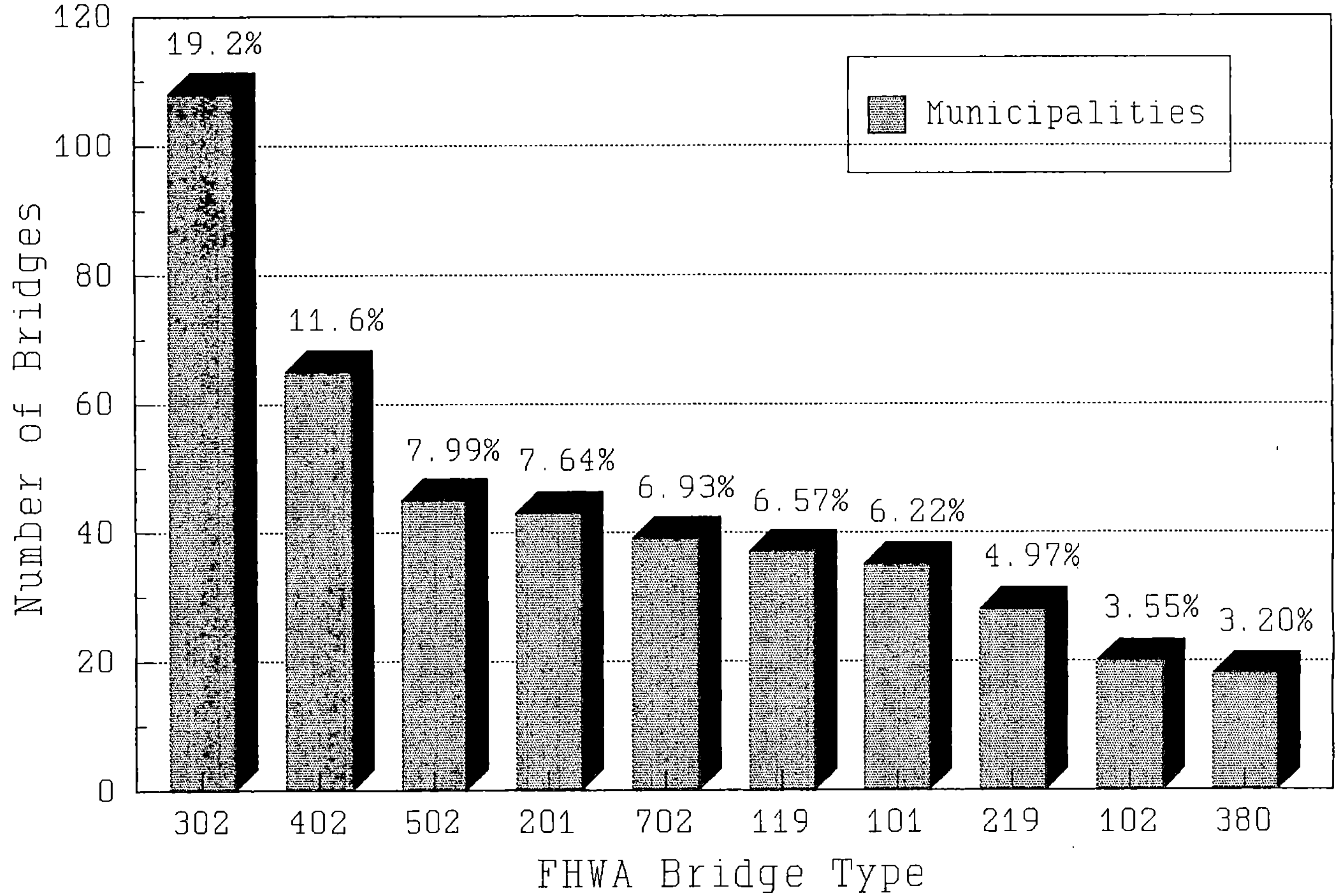

Fig. 6. Functionally Obsolete Municipal Bridges by Structure Type

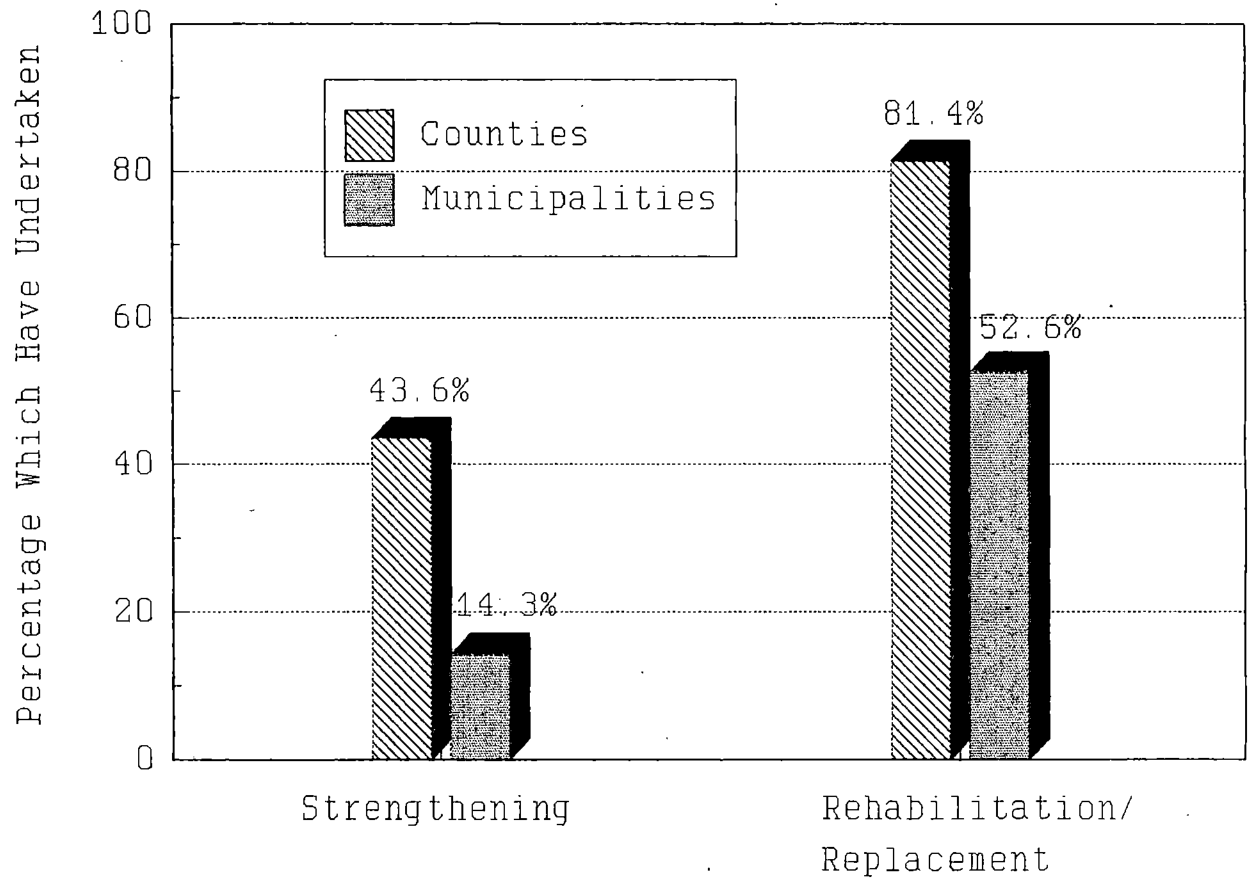

Fig. 7. Local Agencies Experience with Bridge Strengthening and Replacement

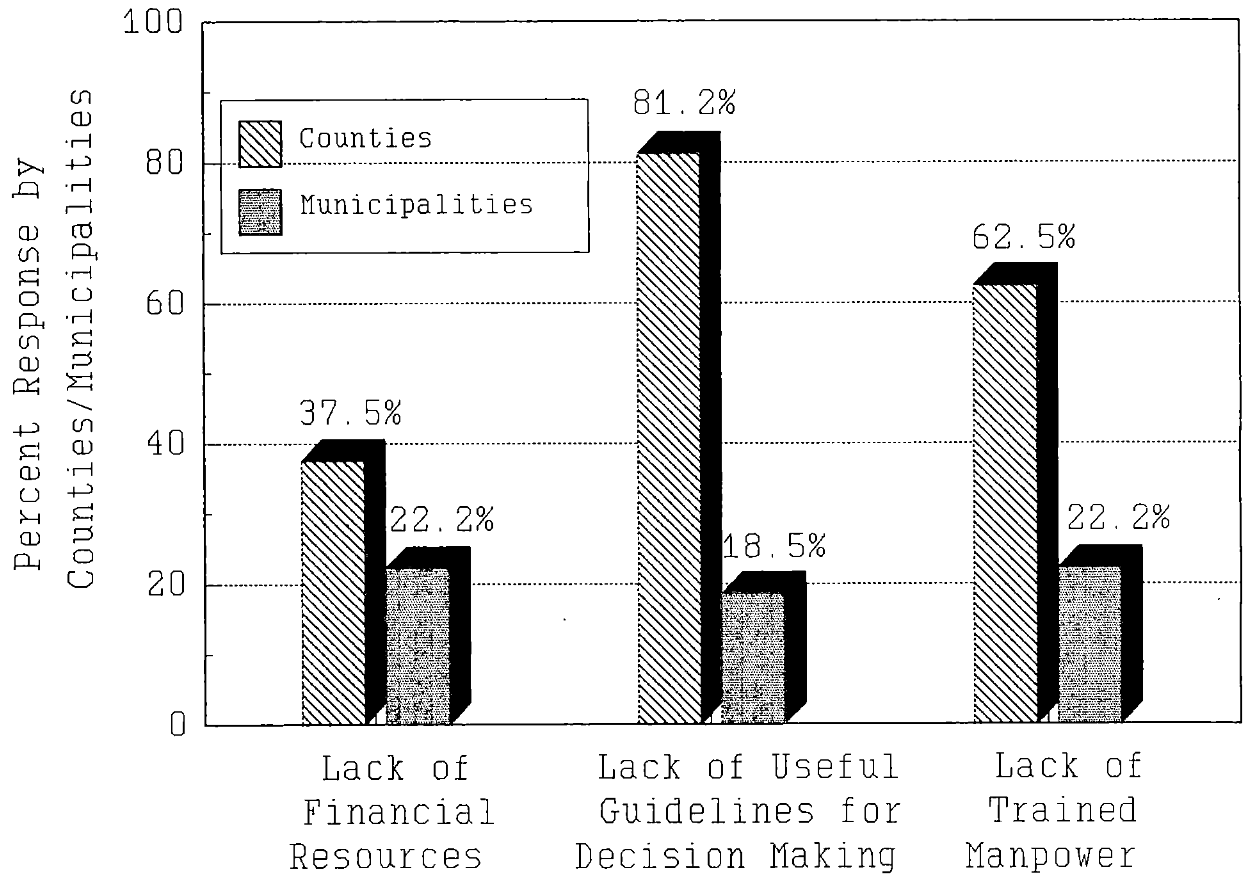

Fig. 8. Reasons for Not Implementing Strengthening

SPAN	STRINGER SIZE	# OF STRINGERS
ONE	4"x12"	16
TWO	4"x12"	18
THREE	4"x16"	13
FOUR	4"x12"	18

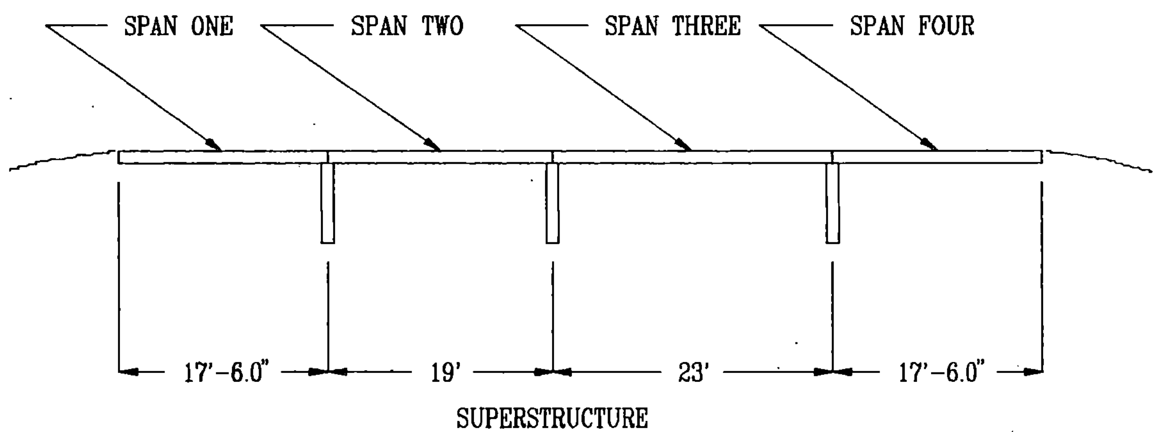

Fig. 9. Lucas County Illustrative Example

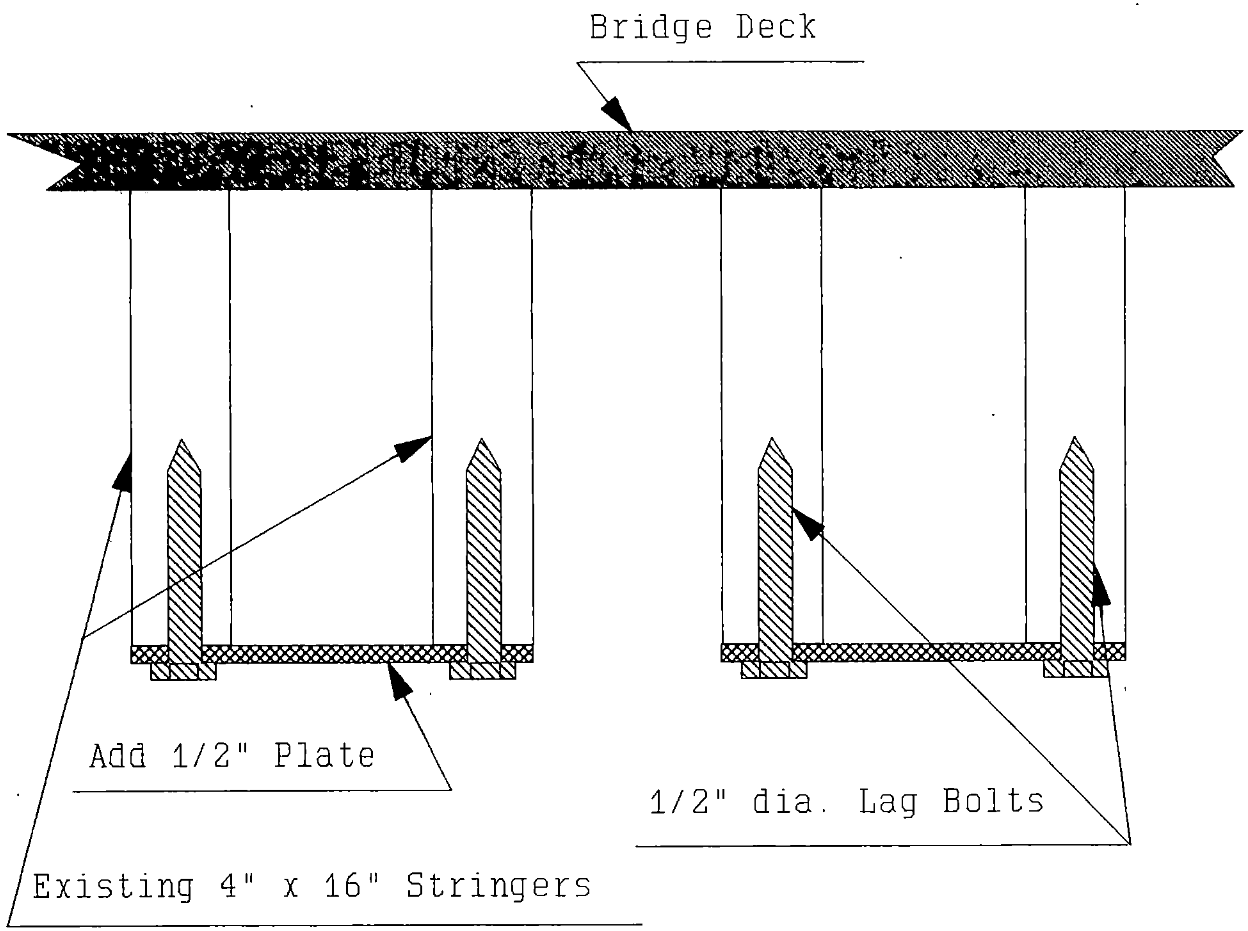

Fig. 10. Typical Steel Cover Plate for Timber Stringers

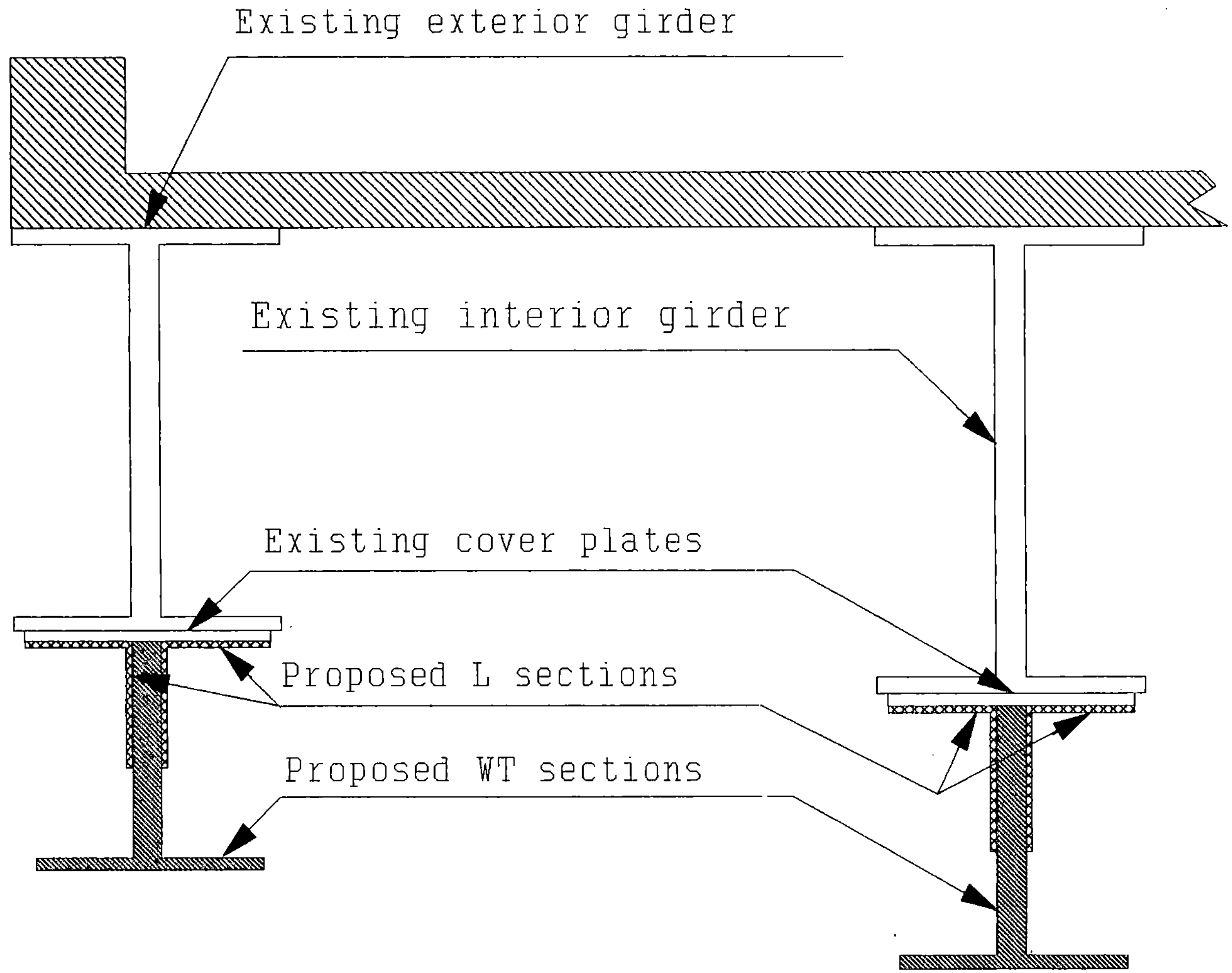

Fig. 11. Addition of L and WT Sections

Appendix A

The following is a sample questionnaire which was mailed to the 99 Iowa County Engineers. A similar questionnaire was mailed to 77 municipalities, with populations greater than 5000.

Iowa Department of Transportation
Highway Division
Research Project HR - 323

Strengthening/Rehabilitation of Low Volume Highway Bridges

Name of Respondent ______________________________

Organization ______________________________

Address ______________________________

____

____

The purpose of this questionnaire is to determine your experience and practice in the strengthening and/or rehabilitating of low volume highway bridges. For this investigation, bridges with 400 ADT or less are considered low volume. If you wish to comment on any questions or qualify your answers, please use the margins or a separate sheet of paper.

SECTION 1

1. Do you (or your county) have any experience with bridge strengthening?

   Yes _____ No _____

   with bridge rehabilitation (including replacement)?

   Yes _____ No _____

   If yes, please complete Section 2 of this questionnaire.

2. If you answered no to both parts of question 1, the reason bridge strengthening and/or rehabilitation has not been used is:

   - lack of financial resources _____
   - lack of useful guidelines for decision-making _____
   - lack of trained manpower _____
   - other (please explain) ______________________________

   Note: Check all reasons that are applicable.

____

SECTION 2

1. Recognizing that engineering judgement must be used to make many decisions regarding bridge management, do you typically use more formal methodologies for making management decisions (e.g. benefit/cost analysis, equivalent annual cost method, etc.)

   Yes _____ No _____

   If yes, which one(s) ? ____

   ____

   ____

2. Have you developed any design aids, nomographs, computer software etc., that are useful in making bridge rehabilitation decisions? If so, please describe them.

   Yes _____ No _____

   ____

   ____

   ____

   Would you be willing to share them with others?

   Yes _____ No _____

3. Does your county hire a consulting engineer(s) to perform any bridge related structural engineering work?

   Yes _____ No _____

   If so, which firm(s) have you employed? ______________________

   ____

   ____

4. If a consulting engineer is hired, what type of service is most commonly performed by a consulting engineer?

Check all that apply.

Structural analysis _____

Construction inspection _____

Strengthening or rehabilitation _____

Biannual bridge inspection _____

Other (please describe)? ______________________________

____

5. Could your county benefit from some sort of decision making tools or design aids for the rehabilitation or strengthening of existing bridges?

Yes _____ No _____

What sort of tools would be most helpful to your county?

Computer software ______

Nomographs ______

Flow charts ______

Other (please describe)? ______________________________

____

____

____

____

6. If plans or in-house reports are available for any of the strengthening or rehabilitation methods implemented, please indicate who we should contact to obtain copies.

Name/Title: ______________________________________

Organization: ____________________________________

Address: ____

7. With which types of strengthening procedures does your county have experience?

Bridge type (FHWA #)	Lightweight deck replacement	Provide composite action	Increase transverse stiffness	Strengthen existing members	Add or replace members	Post-tensioning various members	Strengthen critical connections	Develop continuity	Other (please describe):		
Timber stringer (multi beam) (702)											
Steel stringer (multi beam) (302)											
Steel pony (380) or thru (310) truss											
Steel girder & floor beam system (303)											
Other (please describe):											

The following question refers to the structural and cost effectiveness of various strengthening methods. The ratings requested are intended to be a subjective evaluation of the given methods. If a method has met your strengthening objectives, a high rating should be given. Likewise, if a particular method has been relatively inexpensive to perform, a high cost effectiveness rating should be given.

8. Based on your experience, please rate the strengthening methods you have employed. Use a scale of 1-10 (10 being the best.)

Strengthening Method	Cost Effectiveness	Structural Effectiveness
Lightweight Deck Replacement		
Provide composite action		
Increase transverse stiffness		
Strengthen existing members		
Add or replace members		
Post-tension various members		
Strengthen critical connections		
Develop continuity		
Other (please describe):		

9. If it is not possible to make an existing bridge structurally adequate to carry legal loads, but it is possible to strengthen it to carry an increased load, what load would you desire it to carry?

   ________ Tons

   Optionally, rather than specifying a weight which type of vehicle should the bridge be able to support?

   Dump truck _____

   Dump truck with pup _____ Garbage truck _____

   Farm vehicle _____ School bus _____

   Type of farm vehicle ________________

   Other (please describe) ________________________

10. Do you know of anyone who might be able to supply additional information regarding the rehabilitation and/or strengthening of low volume bridges (e.g. consulting engineers, highway officials, etc.)?

    Name: ________________________________

    Organization: ________________________________

    Address: ________________________________

    Name/Title: ________________________________

    Organization: ________________________________

    Address: ________________________________

11. Have you used, or are you familiar with the National Cooperative Highway Research Program Report #293, <u>Methods of Strengthening Existing Highway Bridges</u>?

    Yes _____ No _____

12. Previous studies have determined that the four bridge types listed below account for over 93% of the structurally deficient bridges on the secondary highway system in Iowa.

Please complete the table below.

Bridge type (FHWA #)	Indicate the bridge type for which you would most like to see strengthening methods developed.	Indicate which bridge types would most benefit from a combination of strengthening and posted weight/specd restrictions.	Indicate which bridge types would be least likely to benefit from strengthening or rehabilitation methods.
Timber stringer (multi beam) (702)			
Steel stringer (multi beam) (302)			
Steel pony (380) or thru (310) truss			
Steel girder & floor beam system (303)			
Other (please describe):			

Please return completed questionnaire
in the enclosed envelope by <u>June 25, 1990</u> to:

Dr. T. J. Wipf
Dept. of Civil and Construction Engineering
420 Town Engineering
Iowa State University
Ames, IA 50011

Appendix B

Bridge inventory and appraisal sufficiency rating calculations for Lucas County timber stringer (FHWA 702), Bridge number 225970. See Recording and Coding Guide for the Structural Inventory of the Nations Bridges (10) for further explanation.

1. Structural Adequacy and Safety

A. #59 Superstructure Rating OK
#60 Substructure Rating OK

B. #66 Inventory Rating = 417
AIT = 17 x 1.01
$I = (36-17.17)^{1.5} \times 0.2778 = 22.699$

S1 = 55 - 22.699 = 32.30

2. Serviceability and Functional Obsolescence

A.

a.	#58 Deck Condition =	>=6	OK
b.	#67 Structural Evaluation = 3	B=4	
c.	#68 Deck Geometry = 2	C=4	
d.	#67 Underclearances = N		OK
e.	#71 Waterway Adequacy =	>=6	OK
f.	#72 Approach Road Alignment =	>=6	OK

J = 4 + 4 = 8

B. Width of Roadway Insufficiency
X = 5 / 1 = 5
Y = 16.6 / 1 = 16.6

1. #43 = 02 <> 19 therefore
if (16.6 + 2) = 18.6 < 18′ No

G = 0

2. 14<= Y < 18 H= 15 * (18 - 16.6)/4 = 5.25

3. Does not apply.

4. Does not apply

C. #100 - Unknown but unnecessary

I = 2%

S2 = 30 - 8 - 5.25 - 2 = 14.75

3. Essentiality for Public Use

A. $K = (32.30 + 14.75) / 85 = 0.5535$

B. $A = [(5 \times 0) / (200{,}000 \times 0.5535)] \times 15 = 0$

C. #100 - Unknown but assume #100 = 0 which means the inventory route is not a defense highway. This assumption is made because the roadway is not paved. In the final analysis, this assumption is proven true.

S3 = 15

4. Special Reductions

A. $A = (0)^4 \times (5.205)(10^{-8}) = 0$

B. B = 0

C. C = 0

S4 = A + B + C
S4 = 0

Sufficiency Rating = S1 + S2 + S3 - S4
= 32.30 + 14.75 + 15 - 0

= 62 (This figure corresponds to the computer tape's S.I. & A. sufficiency rating.)

Appendix C

The following is a summary of the various strengthening methods investigated for the Lucas County timber stringer bridge (FHWA 702), bridge number 225970. The coding for the summary sheet is as follows: "S" is followed by a number which represents the number of stringers the plate covers; "P" is followed by a number which represents the thickness of the plate in hundredths of an inch. For example, S2P50 indicates a 0.50" plate which covers two stringers.

Following the summary sheet is an example of the spreadsheet output.

AASHTO BRIDGE ANALYSIS SUMMARY

HS20 - 44 LOADING

STRENGTHENING METHOD	LL Moment (tons)		LL Shear (tons)	
	Inventory	Operating	Inventory	Operating
Unstrengthened	23.05	31.69	23.64	31.91
S1P25	32.82	44.78	26.63	35.93
S1P38	35.58	48.48	26.91	36.32
S1P50	37.67	51.31	26.98	36.43
S1P75	40.74	55.47	26.91	36.37
S2P25	38.60	52.60	39.05	52.76
S2P38	41.08	56.00	38.52	52.13
S2P50	42.68	58.23	38.01	51.52
S2P75	44.68	61.11	37.21	50.61
S3P25	39.64	54.02	45.95	62.13
S3P38	41.92	57.18	45.14	61.16
S3P50	43.33	59.19	44.45	60.34
S3P75	45.02	61.70	43.41	59.16
ADD2X16	35.30	48.26	21.84	29.41
ADD3X16	41.43	56.55	25.55	34.38

S2P50

	Section Properties	Value
	Height (timber)	16.00
I N	Width (timber) (avg. if >1 size)	4.00
P U T	# Girders (timber) (>1 if composite)	2
	PL Thickness (in.)	0.50
	PL Width (in.)	20.32
	Neutral Axis (in. from top)	12.93
	Ix (in^4)	7945.42
	Sect. Mod. (in^3)	614.28

INPUT

Deck width	=	16.60 ft.
Span Length	=	23.00 ft.
Girder Spacing	=	2.72 ft.

Allowable Fb	=	1.600 ksi
Allowable Fv	=	0.128 ksi
Es / Et	=	18.75
Timber Density	=	50.00 lb/ft^3
Steel Density	=	490.00 lb/ft^3

Dead Load:

Deck		38.00	lb/ft.
Stringer	+	79.02	lb/ft.
Total		117.01	lb/ft.

Design Truck Values:

	LL Moment (ft. kips)	Loading Weight (tons)	LL Shear (kips)
HS20 Truck	92.00	36.00	16.70
H15 Truck	69.00	15.00	10.57
H20 Truck	92.00	20.00	14.09
Type 3 Truck	76.70	23.00	11.83
Type 3S2 Truck	77.10	36.00	12.52

MOMENT CALCULATIONS

	Inventory	Operating
Moment Capacity:	81.90 ft. k	108.93 ft. k
Dead Load Moment:	7.74 ft. k	7.74 ft. k
Available for LL:	74.17 ft. k	101.20 ft. k

Wheel Load Distribution: 0.68 wheel lines/stringer

Live Load Moment w/o Impact (per lane):

HS20 Truck	62.56 ft. kips
H15 Truck	46.92 ft. kips
H20 Truck	62.56 ft. kips
Type 3 Truck	52.16 ft. kips
Type 3S2 Truck	52.43 ft. kips

Rating (tons)

	Inventory	Operating
HS20 Truck	42.68 tons	58.23 tons
H15 Truck	23.71 tons	32.35 tons
H20 Truck	23.71 tons	32.35 tons
Type 3 Truck	32.71 tons	44.63 tons
Type 3S2 Truck	50.93 tons	69.49 tons

SHEAR CALCULATIONS

Q = 669.201 in^3
V = 12.16 kips
x = 4.00 ft.

	Inventory	Opearating
Shear Capacity	12.16 k	16.17 k
DL Shear	0.88 k	0.88 k
Available for LL	11.28 k	15.29 k

Wheel Load Distribution: 0.64 wheel lines/stringer

Live Load Shear w/o Impact (per lane):

	Inventory	Operating
HS20 Truck	38.01 tons	51.52 tons
H15 Truck	25.02 tons	33.92 tons
H20 Truck	25.02 tons	33.92 tons
Type 3 Truck	34.28 tons	46.47 tons
Type 3S2 Truck	50.67 tons	68.70 tons

Appendix D

Bridge inventory and appraisal sufficiency rating calculations for Story County steel stringer bridge (FHWA 302), bridge number 314650.

See Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges (10) for further explanation.

1. Structural Adequacy and Safety

A. #59 Superstructure Rating OK
#60 Substructure Rating OK

B. #66 Inventory Rating = 220
AIT = 20 x 1.00
$I = (36-20)^{1.5} \times 0.2778 = 17.7792$

S1 = 55 - 17.7792 = 37.2208

2. Serviceability and Functional Obsolescence

A.
a. #58 Deck Condition = 8>=6 OK
b. #67 Structural Evaluation = 6>=6 OK
c. #68 Deck Geometry = 8>=6 OK
d. #67 Underclearances = 6>=6 OK
e. #71 Waterway Adequacy = 7>=6 OK
f. #72 Approach Road Alignment = 7>=6 OK

J = 0

B. Width of Roadway Insufficiency
X = 50 / 2 = 25
Y = 24 / 2 = 12

1. #43 = 02 <> 19 therefore
if (24 + 2) = 26 < 26′ No

G = 0

2. Does not apply.

3. Does not apply.

4. H = 0%

G + H = 0

C. #100 - Unknown but unnecessary

I = 0%

S2 = 30 - 0 = 30

3. Essentiality for Public Use

A. K = (37.2208 + 30) / 85 = 0.7908

B. A = [(50 x 5) / (200,000 x 0.7908)] x 15 = 0.023709

C. #100 - Unknown but assume #100 = 0 which means the inventory route is not a defense highway. This assumption is made because the roadway is not paved. In the final analysis, this assumption is proven true.

S3 = 15 - 0.0237 = 14.97629

4. Special Reductions

A. A = $(5)^4$ x $(5.205)(10^{-8})$ = 0.0000 3253

B. B = 0

C. C = 2%

S4 = A + B + C
S4 = 0 + 0 + 2 = 2%

Sufficiency Rating = S1 + S2 + S3 - S4
= 37.2208 + 30 + 14.9763 - 2

= 80 (This figure corresponds to the computer tape's S.I. & A. rating)

Appendix E

Omitted due to length. Copies available upon request.