

# Bridge Strengthening Needs in the United States

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Large numbers of bridges in the United States are structurally deficient or are nearing the ends of their useful lives. Replacing these bridges in the near future is not economically feasible; therefore, rehabilitation and strengthening techniques are needed to extend the useful lives of bridges. Records from the National Bridge Inventory, responses from questionnaires to bridge engineers and other bridge specialists, and site inspections of load-restricted bridges were used to determine bridge types for which strengthening methods are most urgently needed. Steel stringer, timber stringer, and steel through-truss bridges have a particularly critical need for strengthening, because large numbers of these bridge types, if left unstrengthened, will have to be taken from service or retired in the near future. Other bridge types needing strengthening because of anticipated retirements are concrete slab, concrete tee, concrete stringer, steel girder-floor beam, and concrete deck arch. If strengthening and rehabilitation methods are not developed or made available for these bridge types in the near future, large numbers of bridge replacements will be required.

Many bridges in the United States have reached or are approaching the end of their useful lives. Design lane widths and design and legal loads have increased since most existing bridges were built. Since the 1940s, salt and other deicing chemicals have been applied to highways and bridges, and inadequate maintenance funding has led to deterioration of the strength of many bridges. For all of these reasons, the need for large-scale rehabilitation, strengthening, widening, and replacement of bridges has become critical.

In recognition of this problem, AASHTO has sponsored research through the NCHRP. NCHRP Project 12-28(4), "Methods of Strengthening Existing Highway Bridges," was specifically directed toward the strengthening alternative for coping with deficient bridges. A beginning task in the project was to determine which bridge types could be effectively and economically strengthened. For this task, strengthening was viewed as a means to extend the lives of bridges that are in fair to excellent condition but require additional load-carrying capacity to meet current design or legal load specifications.

Ideally, strengthening needs should be determined from a comprehensive bridge management system with consideration of such factors as actual bridge capacity versus required capacity for the route, functional adequacy, and long-term economic planning. Because such a comprehensive system is not available for the entire United States at this time, three approaches were taken to determine which bridge types could be effec-

tively strengthened. The collective experience and expertise of the bridge inspectors who have evaluated the nation's bridges were employed to examine the pertinent data contained in the National Bridge Inventory (NBI), current as of January 23, 1986. Needs perceived by bridge engineers and other bridge specialists in government offices and private consulting practices were solicited in late 1985 by means of a questionnaire, and the responses were tabulated. Site inspections of Iowa bridges, many of which were load restricted, were conducted in 1986. Each of these three approaches will be discussed in the following sections.

## NATIONAL BRIDGE INVENTORY

### Reliability of Bridge Records

The NBI, now essentially complete, contains records on more than 575,000 highway bridges having spans of 20 ft or greater, culverts of bridge length, and tunnels. The records are prepared according to a coding guide (1) from the FHWA, which often is supplemented by a guide from state or local authorities such as that of the Iowa Department of Transportation (Iowa DOT) (2).

Each NBI bridge record can contain up to 90 items, some of which may not be used because of local policies or lack of information. Those items judged most relevant and reliable for determining bridge strengthening needs are

- Year built, Item 27;
- Structure type—main, Item 43;
- Superstructure condition rating, Item 59;
- Substructure condition rating, Item 60;
- Estimated remaining life, Item 63;
- Inventory rating, Item 66;
- Structural condition rating, Item 67; and
- Type of work (proposed improvement), Item 75.

These items were further combined to determine bridge life (sum of age in 1985 determined from Item 27, and Item 63) and structural adequacy and safety (the S1 portion of the FHWA sufficiency rating formula, determined from Items 59, 60, and 66).

Questions that need to be asked with regard to such a large database as the NBI are "How reliable are the data?" and "How can interpretation errors be minimized?" A review of the first 50 bridge records from each state or reporting governmental unit showed few obvious coding errors but many blanks, often apparently as a result of state or local policies. In

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TABLE 1 FIFTEEN COMMON BRIDGE TYPES, NBI

NBI Item 43	Main Structure Type	Number of Bridges	Percentage of Bridges
302	Steel stringer	130,892	27.2
702	Timber stringer	58,012	12.0
101	Concrete slab	42,450	8.8
402	Continuous steel stringer	36,488	7.6
310	Steel through truss	31,206	6.5
104	Concrete tee	26,798	5.6
502	Prestressed concrete stringer	26,654	5.5
201	Continuous concrete slab	21,958	4.6
102	Concrete stringer	16,884	3.5
505	Prestressed concrete multiple box	16,727	3.5
303	Steel girder-floor beam	9,224	1.9
204	Continuous concrete tee	7,467	1.6
111	Concrete deck arch	6,245	1.3
501	Prestressed concrete slab	5,561	1.2
504	Prestressed concrete tee	4,687	1.0
	Total	441,253	91.8

order to avoid misinterpretations of the bridge records, all computer sort runs were programmed to reject any records containing blanks or unauthorized characters in items to be examined in a particular sort.

Those records containing correctly coded bridge types for Item 43 were examined by means of a matrix with row headings for the design material portion of the type and column headings for the construction design portion of the type. The number of masonry through-trusses, steel slabs, or other unusual or fictitious bridge types in the matrix were less than 1 percent. So that work was done with the most reliable portions of the data, only the 15 most common bridge types were selected as types for further study. Those bridge types are listed and ranked by number of records in the NBI in Table 1. The 15 bridge types represent approximately 92 percent of the more than 481,000 highway bridge records in the NBI. The remainder of the 575,000 NBI records are for tunnels and culverts.

A table prepared for the common bridge types and years built indicated either errors in the coding for some bridges or an inadequacy in the type classification for the NBI. Approximately 5 percent of the prestressed bridges are coded showing year built before the 1950s. Some of the apparent errors may be caused by insertion of 00 when year built was unknown; the category for bridges built in 1900 and earlier accounted for more than an average share of the 5 percent. It is also quite possible that older bridges, which have been recently widened

with prestressed concrete or which have had main spans replaced with prestressed concrete, were classified as prestressed concrete structures using original date of construction for the year built. No conclusions could be reached regarding the apparent errors, and those errors could pervade data for all bridge types. The data, therefore, were not screened to eliminate bridges with unusual year built coding.

Overall, the NBI data are relatively free of obvious errors. There are some definite and some probable coding errors, but those errors did not exceed 5 percent and often were less than 1 percent for the NBI items checked. So that the NBI records could be analyzed most accurately, records with obvious errors or with significant omissions were rejected.

### Bridge Strengthening Needs

The most direct approach to determining bridge types in need of strengthening from the NBI is to examine Item 75, the improvements recommended by the bridge inspectors. These inspectors' recommendations generally are tempered by local policies, consideration of functional obsolescence, knowledge of funding programs, and knowledge of rehabilitation and strengthening methods. In the 15 common bridge types, inspectors recommended some improvement for more than 49 percent of the bridges. For the bridges for which improvements were recommended, the types of improvements are ranked in Figure 1.

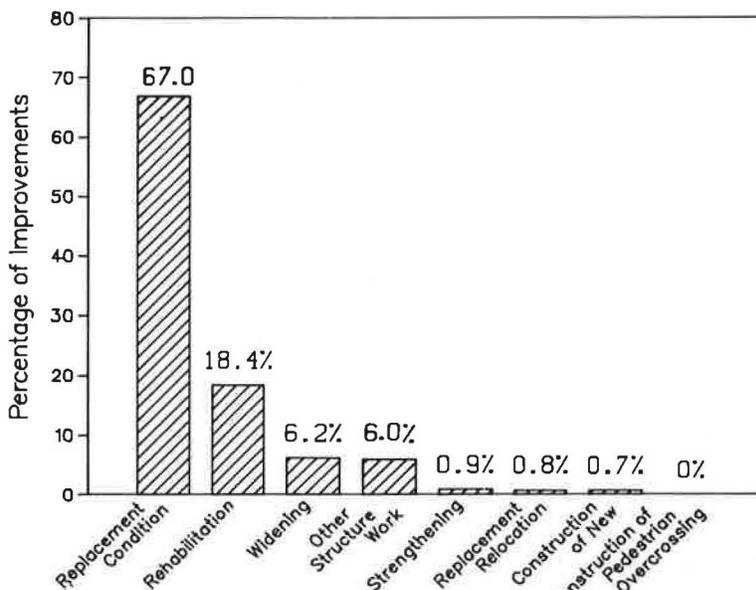


FIGURE 1 Bridge improvements recommended by inspector, NBI.

The overwhelming choice of improvement, accounting for two-thirds of the recommendations, was replacement due to condition, which, of course, means that one-third of the nation's bridges would be replaced in the near future if inspectors' recommendations were followed.

Figure 1 also shows that only 0.9 percent of the recommendations were for strengthening of bridges. There are probably several reasons for the few strengthening recommendations. Some inspectors may not recognize that strengthening is a means to prolong bridge life, and in some states inspectors may not have the option of strengthening. Another possible reason

that strengthening is seldom suggested could be the limitations in the NBI coding. An inspector cannot code both strengthening and widening, for example, and instead would be forced to code either replacement or rehabilitation. An additional reason for the large number of replacement recommendations could be the inspectors' intent to make known the urgency of bridge safety problems. Or, perhaps federal and state bridge funding programs are configured in ways that make replacement much more attractive than any type of strengthening or rehabilitation.

For those bridges for which strengthening was recommended, the responses are ranked by number, for bridge types

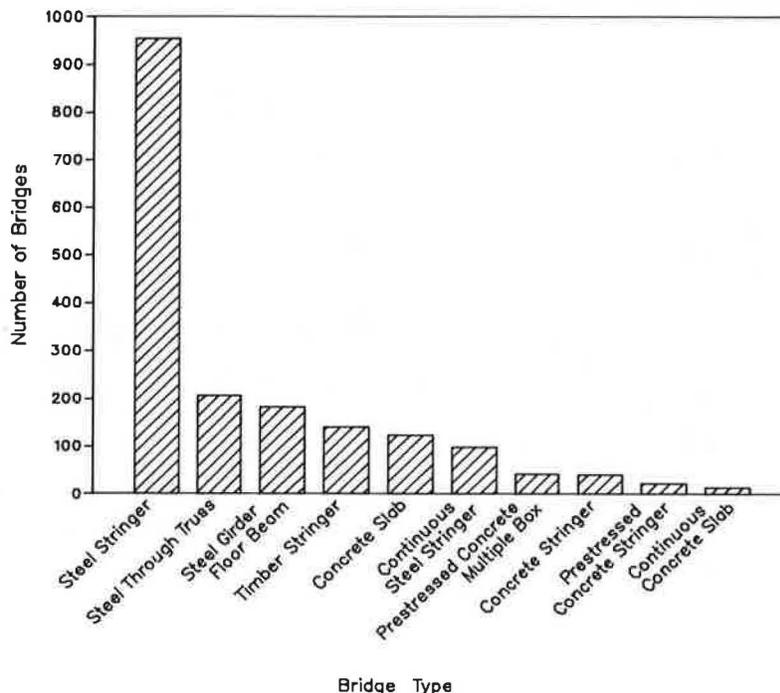


FIGURE 2 Strengthening recommended by inspector, ranked by bridge type, NBI.

in Figure 2. The recommendations for strengthening steel stringer bridges account for more than one-half of the recommendations. The next four bridge types in the ranking are steel through-truss, steel girder-floor beam, timber stringer, and concrete slab.

A less direct approach is to consider the bridge types for which some type of structural work—replacement, rehabilitation, widening, other structure work, and strengthening—was

recommended by the inspector. It is quite possible that strengthening could be used instead of replacement or as a part of rehabilitation, widening, or other structure work.

The bridge types for which some type of structural work was recommended are ranked by number of recommendations in Figure 3. If the bridge types ranked in the first five in Figure 3 are compared with the bridge types ranked in the first five in Figure 2, it is apparent that the rankings are similar. Four of the

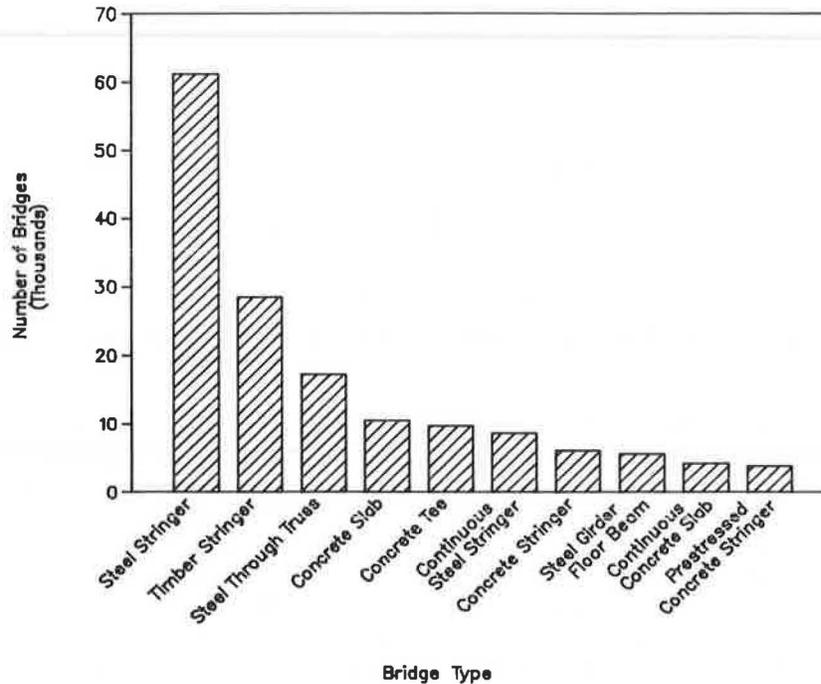


FIGURE 3 Structural work recommended by inspector, ranked by bridge type, NBI.

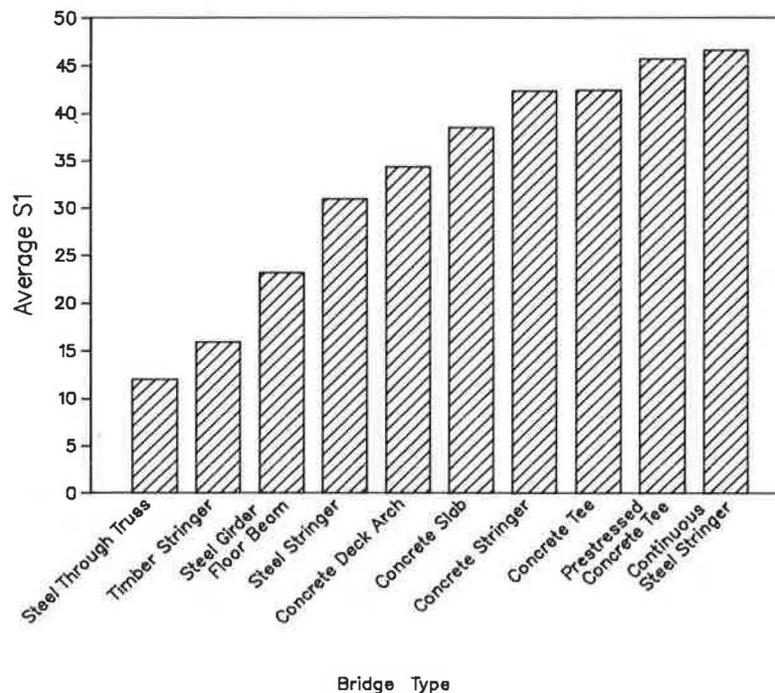


FIGURE 4 Average structural adequacy and safety ranked by bridge type, NBI.

first five in each figure are the same. The steel girder-floor beam type, included in the first five for strengthening, is replaced by the concrete tee type for structural work.

Another approach, which is more general and accounts for almost all of the bridges in the NBI, is to examine the structural adequacy and safety factor (S1) determined from the superstructure condition rating; substructure condition rating and inventory rating, as detailed in the FHWA guide for bridges (1);

remaining life; and anticipated retirement; all of which can be obtained directly or by simple computations from the bridge records. If the characteristics of bridges for which inspectors recommended strengthening are compared with the characteristics of average bridges, low structural adequacy and safety often correlate well with a need for strengthening.

The average S1 value then was computed for the 15 common bridge types, and the 10 bridge types with the lowest S1 values,

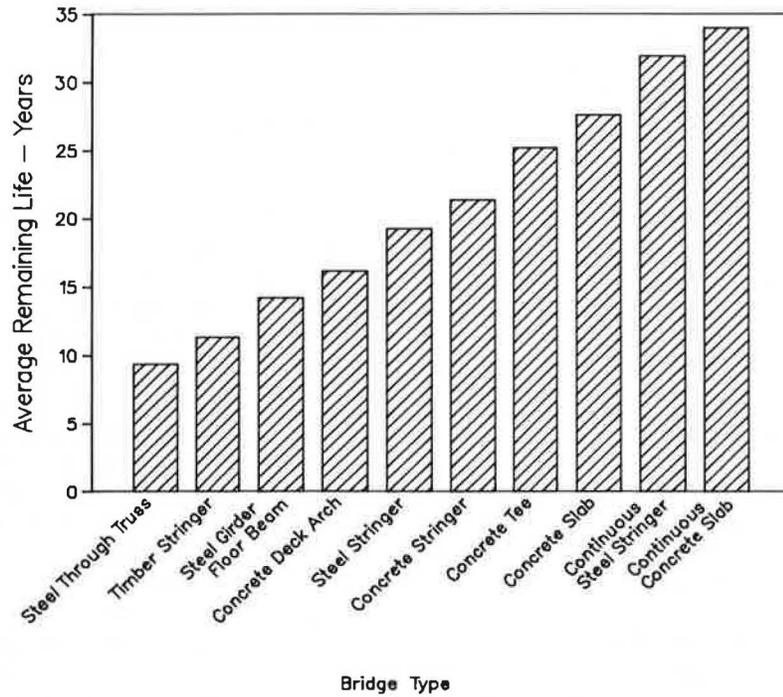


FIGURE 5 Average remaining life ranked by bridge type, NBI.

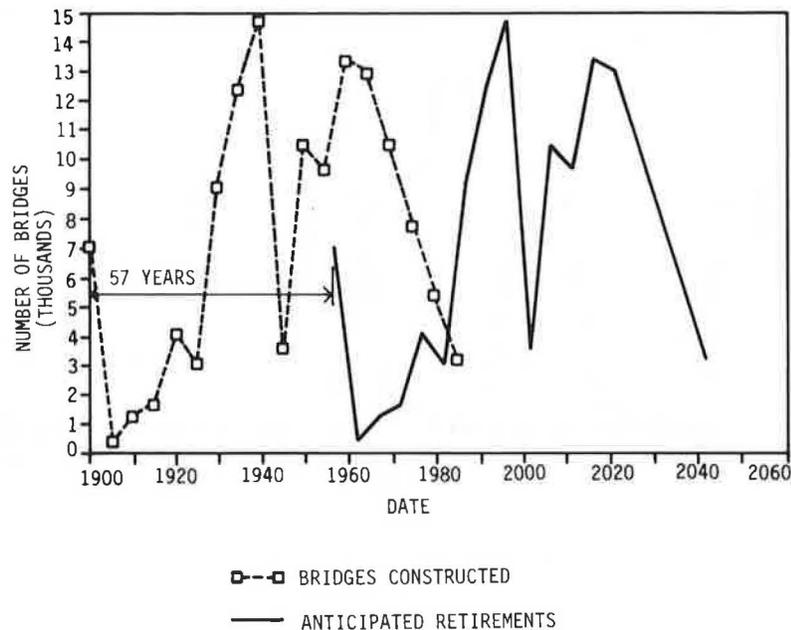


FIGURE 6 Numbers of steel stringer bridges constructed, and anticipated retirements by 5-year periods, NBI.

which indicate low-strength bridges, are ranked in Figure 4. The first five rankings based on S1 are similar to those in Figures 2 and 3 and are identical to those for structural condition, Item 67. The only new type in the first five is the concrete deck arch type.

Remaining life also can give some evidence of need for strengthening. Those bridge types for which inspectors estimated a relatively low remaining life are often candidates for strengthening. The average remaining lives are ranked for 10 bridge types in Figure 5. No bridge types different from those identified in previous figures appear in the first five rankings.

Either specific inspector recommendations or more general measures of the potential needs for strengthening point to the same bridge types. So that some concept of the urgency of the strengthening needs could be developed, the number of anticipated bridge retirements was examined for all of the 15 common bridge types.

In Figures 6–8, the numbers of bridges constructed in each 5-year period are plotted for steel stringer, timber stringer, and steel through-truss bridges, respectively. The first point in each figure is for the number of bridges constructed in 1900 or earlier, and the other points are for numbers constructed during 5-year periods such as 1901–1905. The average life was computed from NBI data for each bridge type, and a solid line was plotted in each figure by using the numbers for the construction points but extended into the future by the average life. The solid line in each figure, then, represents anticipated bridge retirements. For those bridge types having large numbers of anticipated retirements in the near future, there is a definite need for effective strengthening methods.

Those bridge types with large numbers of anticipated retirements in the near future, ranked in order by maximum number in any 5-year period, are steel stringer, timber stringer, steel through-truss, concrete slab, concrete tee, concrete stringer, steel girder-floor beam, and concrete deck arch. The graphs for

those bridge types are all similar to Figures 6–8, and all show a similar urgency. As of 1985, the number of anticipated retirements is either small with a large projected increase in the near future, or as in Figure 8, the number of anticipated retirements is at a high level that will continue in the near future.

The bridge records in the NBI are quite consistent in identifying steel stringer, timber stringer, and steel through-truss bridge types as the primary types for which strengthening, as a means to prolong bridge life, is required. Secondary needs involve concrete slab, concrete tee, concrete stringer, steel girder-floor beam, and concrete deck arch bridge types.

### Questionnaire

The NCHRP project research team (3) sent a questionnaire to FHWA offices, state departments of transportation, selected county engineers, selected bridge design consultants, and others considered to have expertise and experience in bridge strengthening. The questionnaire contained a variety of questions relating to the performance and economics of bridge strengthening. Responses to the following question were of interest: "For what types of bridges do you see a need for the development of a design procedure for strengthening?"

The responses are organized and plotted in Figure 9. Because the response format was open (not tied to the NBI), bridge types were not as accurately specified as in the NBI. General responses, which furnish little insight as to bridge type, are omitted from the categories in Figure 9, which gives results similar to those from the NBI. Obviously, many bridge engineers and management personnel see the need for strengthening methods for steel truss, steel stringer, and steel girder-floor beam bridges. Questionnaire respondents generally see less need for strengthening methods for timber and concrete

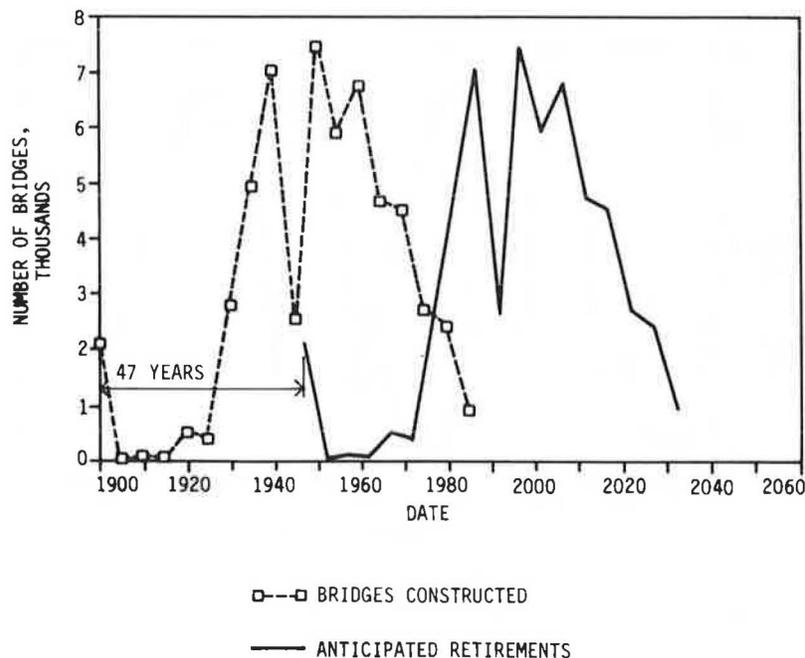
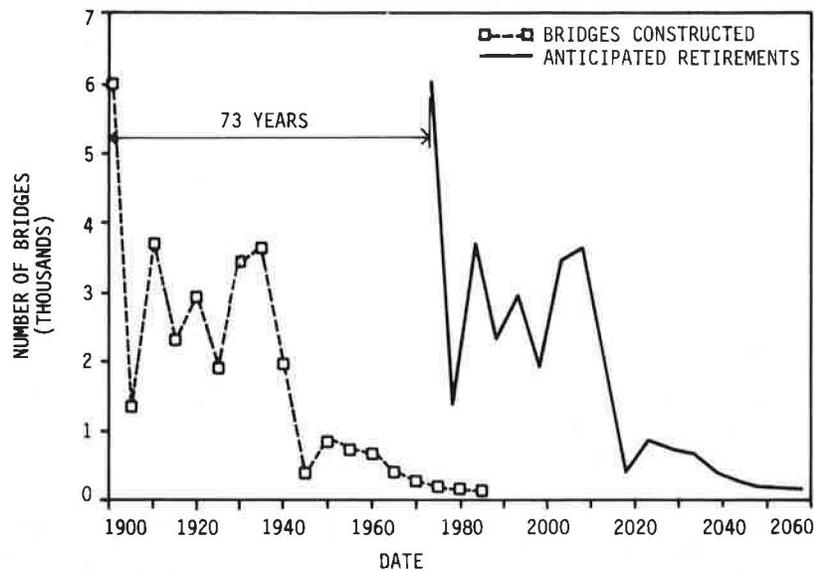


FIGURE 7 Numbers of timber stringer bridges constructed, and anticipated retirements by 5-year periods, NBI.



**FIGURE 8** Numbers of steel through-truss bridges constructed, and anticipated retirements by 5-year periods, NBI.

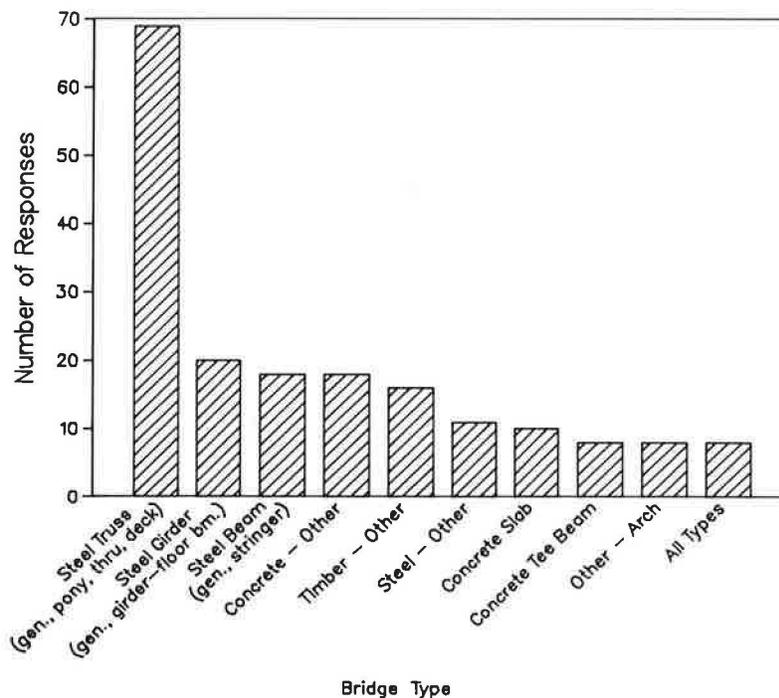
bridges. Concrete slab and tee bridge types were mentioned, but other timber and concrete responses related only to material and not to specific designs or constructions.

**Site Inspections**

The Iowa DOT regularly prepares the “Iowa Bridge Embargo Map” for load-restricted bridges on all federal and Iowa highways. The map was used as a guide for site inspections of more

than 40 bridges. About half of the 40 bridges were load restricted either by the Iowa DOT or by county or local authorities.

Of the load-restricted bridges, which would have a low S1 rating under the NBI, approximately one-third were in poor condition and obviously require replacement in the near future. Another one-third were in average condition and could be strengthened along with rehabilitation, if functional and economic considerations were favorable. The last one-third of the bridges were in good condition, well maintained, and good



**FIGURE 9** Questionnaire responses for strengthening needs ranked by bridge type.

candidates for strengthening without significant rehabilitation if functional and economic considerations were favorable. Most of the load-restricted bridges in average to good condition were steel stringer, continuous steel stringer, steel through-truss, or steel pony truss bridges. Even though the site inspections were quite random, they tend to support conclusions that can be drawn from the NBI records and the NCHRP strengthening questionnaire.

## SUMMARY AND CONCLUSIONS

Direct and indirect examination of NBI bridge records indicate that the bridge types with greatest potential for strengthening are steel stringer, timber stringer, and steel through-truss. If rehabilitation and strengthening cannot be used to extend their useful lives, many of these bridges will require replacement in the near future. Other bridge types for which there also is potential for strengthening are concrete slab, concrete tee, concrete stringer, steel girder-floor beam, and concrete deck arch.

Questionnaire responses from bridge engineers and bridge specialists strongly support the need for development of strengthening methods for steel truss and steel stringer or steel girder-floor beam bridges. There is less interest in strengthening methods for timber bridges, quite possibly because some engineers do not perceive timber as a permanent material. Questionnaire responses also support the need for strengthening of the concrete bridge types identified through the NBI, but the responses are not confined to the specific NBI classifications for bridge type.

Inspection of Iowa load-restricted bridges, even though these inspections were for a small number of the nation's bridges, tend to support previous conclusions for bridge types in need of

strengthening. Although some of the load-restricted bridges will have to be replaced, others could be strengthened, if functional and economic considerations were favorable, to extend their useful lives with minimal additional rehabilitation.

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