A Comprehensive Bridge Posting Policy

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ABSTRACT

The posting of bridges for maximum allowable loads should allow for the safe continued use of existing bridges without unnecessary restrictions. The mechanism for determining load postings must minimize risk to the structure and maximize the benefits for the user by considering economic as well as engineering factors. A rational policy is essential to maximize the remaining service life of existing bridges and to protect the bridge owner's capital investment. The method developed here to determine bridge postings will span the gap between current inventory and operating load levels of AASHTO. It will provide more than one stress level for evaluation and be flexible in the decision-making process by balancing risk and safety levels and taking structural redundancy, load variations, permit operations, load enforcement, and level of inspection into account. This method will help raise the load posting level of deficient bridges and at the same time reduce the risk of bridge failure. The method is equally applicable to reinforced concrete, prestressed concrete, structural steel, and timber. Equivalent load factors are identified for use with load factor method (LFM).

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In 1983 Byrd, Tallamy, MacDonald and Lewis, under contract with the Pennsylvania Department of Transportation (PennDOT) began a 21-month study of deficient bridges in Pennsylvania, which resulted in this paper. The objectives of the project were to develop a comprehensive bridge-posting policy, analyze bridges by both working stress and load factor methods, and evaluate the effect of bridge loads.

Specific tasks (Figure 1) were identified: (a) study the economic effect of the proposed posting policy; (b) conduct telephone surveys of several state agencies and all district bridge offices; (c) classify 6,000 deficient bridges by type, location, and traffic characteristics; and (d) compare typical posting values that result, using working stress (WSM) and load factor methods (LFM).

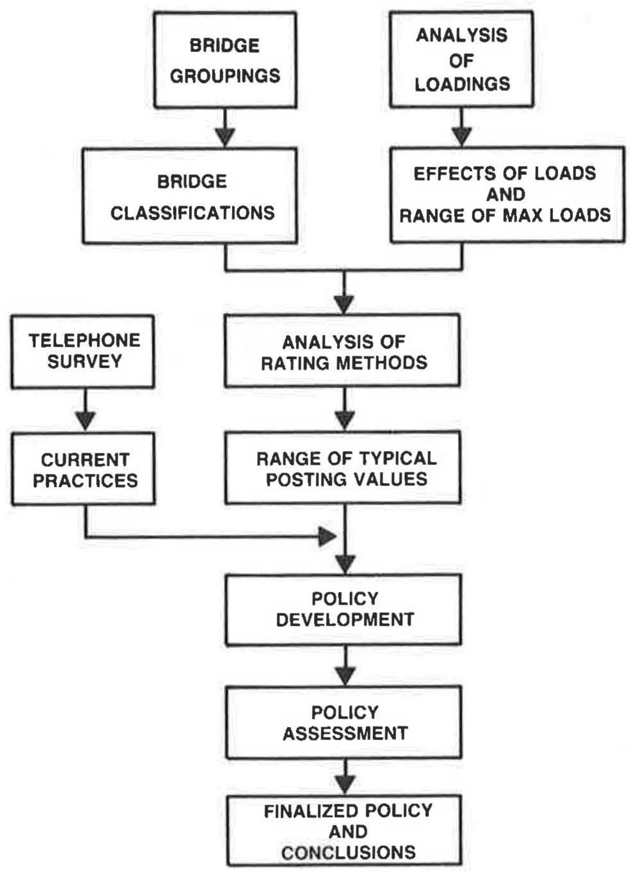

FIGURE 1 Task relationship.

FINDINGS

Telephone Surveys

The telephone surveys revealed that all states rate their bridges in accordance with AASHTO's Manual for Maintenance Inspection of Bridges (1). However, most states do not post their bridges in accordance with these specifications. Variations were found among states, reflecting the nation's geopolitical spectrum.

The telephone survey revealed that several states have their own posting policy. North Carolina's procedure was the most complete example found, consisting of 81 pages defining stresses, rating trucks, interpretation of AASHTO specifications, and specifying signs to be used (2). Illinois' policy defines lanes, stresses, and exceptions. New York's policy is actually a rating memorandum. Pennsylvania allows the use of stresses up to operating rating based on

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engineering judgment if (a) the bridge is in good condition, (b) the inspection frequency greatly exceeds the minimum required, (c) the load history of the bridge is closely monitored, and (d) the increase in stress is approved by the chief bridge engineer.

The policy also specifies the use of the AASHTO trucks but substitutes the state's 36.64-ton, four-axle dump truck, the ML-80 (Figure 2).

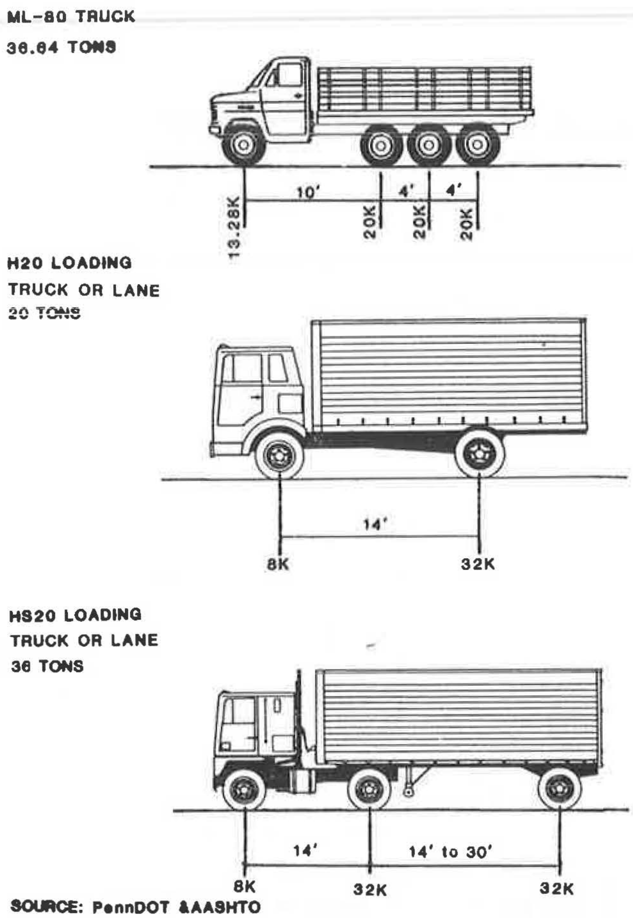


FIGURE 2 Rating vehicles.

Most states do not post for load using fatigue as a criteria because fatigue is more a function of stress cycles than stress range. These states include fatigue in the inspection-rehabilitation process. The surveys also revealed that most states do not issue overweight permits for posted bridges.

Deficient Bridge Classifications

It was decided that the research effort should concentrate on 6,000 structurally deficient bridges as defined by a sufficiency rating of 80.00 or less because these structures are either posted (presently 3,700 bridges) or candidates for posting. Both values include state and local owners. It was shown that the majority of structurally deficient bridges are older than the general population of bridges and are located on rural routes with an average daily traffic of under 2,000 vehicles per day and an average detour length of 5 mi. Five bridge types were selected for concentrated effort. These types, which account for most structurally deficient bridges, are steel I-beam spans, steel through truss spans, steel girder-floorbeam spans, reinforced concrete slab spans, and reinforced concrete T-beam spans. The types also account for most posted structures.

Prestressed concrete does not appear on the foregoing list because of the low number of such bridge types that are structurally deficient. It is speculated that this is because these structures are relatively young, made with dense concrete, and factory cured under a high degree of quality control.

Span ranges were obtained for each of the deficient structure types so that analyses of typical bridges could be performed. Figure 3 shows the span ranges for each type of structure considered.

Bridge Loads

Bridge loadings of various states were analyzed for their effect on structures. The legal loads in California, Michigan, and Pennsylvania were found to be among the highest in the nation. Figure 4 shows the relative effect of various bridge loads. The bending moment without impact was calculated and divided by the moment induced by the HS20-44 design truck. The resultant ratio is plotted versus the span length for which it was calculated. Based on this analysis 10 bridge loadings were selected for concentrated effort.

Comparative Analysis

A comparative analysis of WSM and LFM was performed on 15 sample bridges. For the five typical, structurally deficient bridge types, typical posting values were generated for short, average, and long spans at inventory and operating ratings for the 10 selected bridge loadings. The analysis was designed to compare variables affecting bridge postings. WSM versus LFM, inventory rating versus operating rating, truck configurations, original design load, and the effect of span length were examined. The results of the comparative analysis are summarized in Figure 5, which shows the number of bridges that require posting in each category.

WSM Versus LFM

WSM was used initially to design the nation's deficient bridges. The results of the comparative analysis demonstrate that postings are nearly the same, independent of the rating method used. The difference is that one sample bridge was borderline and would require posting using WSM. It was found during the comparative analysis that LFM was very time consuming. Much additional information is required to perform an LFM posting analysis.

The use of LFM for rating structural steel is not advantageous when the engineer is working with a noncompact section or a compression flange that is fully supported. Secondary stresses induced by beam curvature do not lend themselves well to rating by LFM. However, WSM is easily adapted to the rating task. The short span through truss in the comparative analysis also had the disadvantage of timber stringers that could not be rated using LFM. LFM for rating reinforced concrete is advantageous only for Grade 60 steel. Most deficient bridges were built using Grade 40 reinforcement, however.

Rating Vehicles

Single vehicle postings were controlled by either the H20 loading or by the four-axle dump truck. Com-

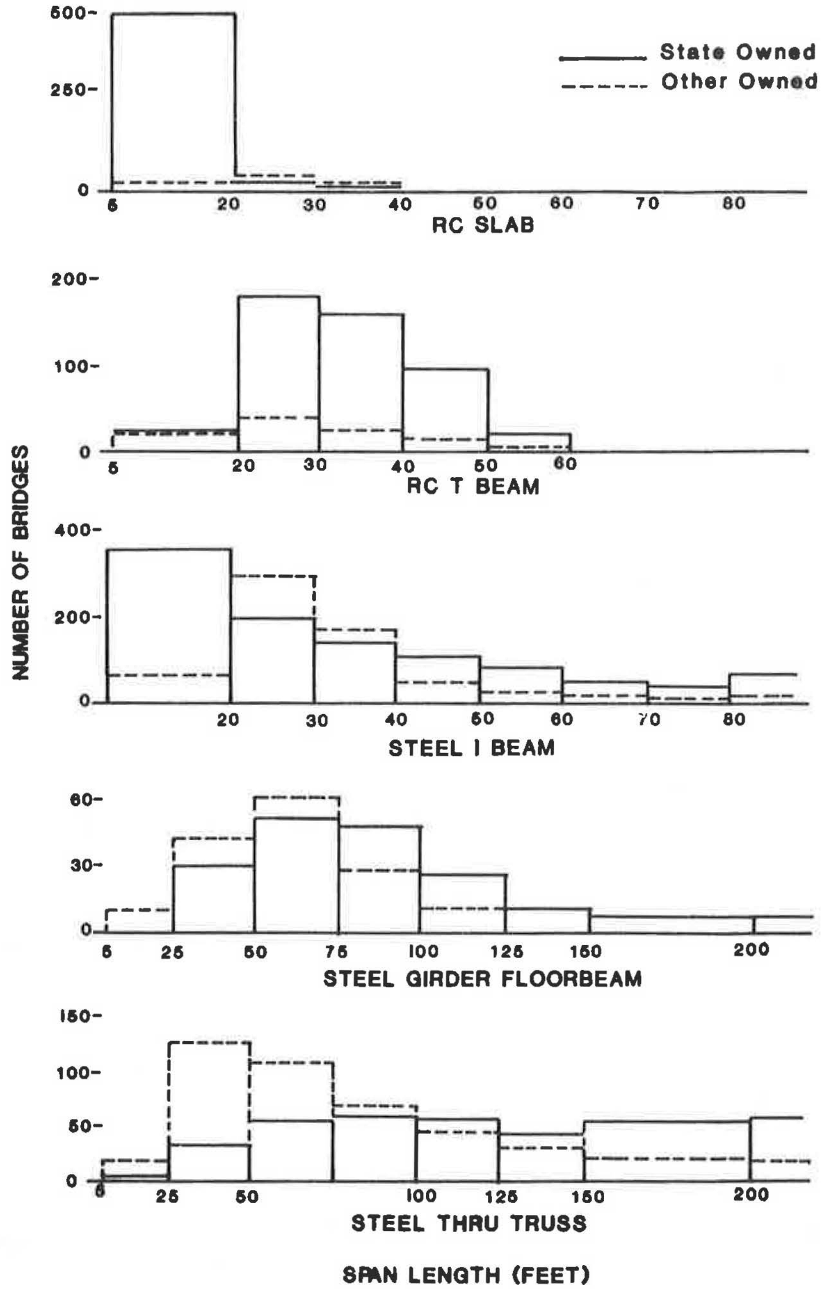


FIGURE 3 Span length distribution.

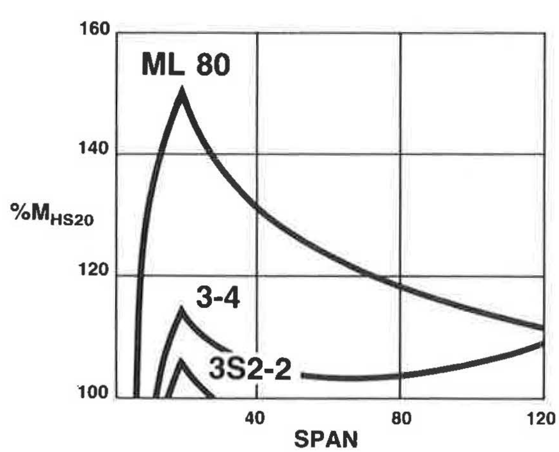


FIGURE 4 Effect of bridge loads.

bination vehicle postings were controlled by the HS20 loading in all cases except one borderline case where the Type 3-4 loading controlled. This vehicle is an Interstate loading and would probably not require posting.

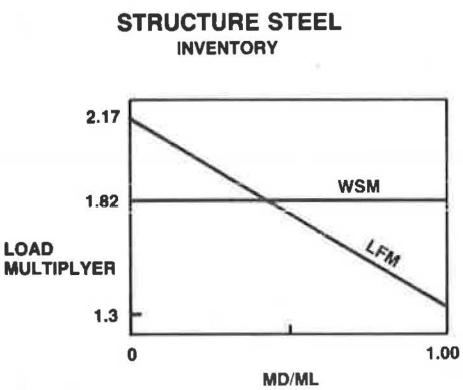
Span Length, Age, and Original Design Load

In all cases but one, the long span structures were designed for HS20-44. Most states have used this design load since 1944. It is plausible that the construction of ever-longer span structures was possible with a constantly advancing technology so that longer spans are of newer construction and design loads. This being the case, span length, age, and original design loads can be considered together.

In most cases the posting weight limit increases. This is partly a result of the effect described earlier and the fact that short spans, which are

	SHORT	MEDIUM	LONG
INVENTORY			
WSM	4	5	4
LFM	4	5	3
OPERATING			
WSM	3	2	1
LFM	3	1	1

FIGURE 5 Sample group profile.



	OPERATING
WSM	1.33
LFM	1.30

FIGURE 6 Load multiplier to first yield.

predominantly stressed by live load, will be posting prone, whereas long spans, which are predominantly stressed by dead load, will be, to a degree, relatively free of load posting (Figure 6).

POLICY DEVELOPMENT

Safe Load Posting Level Flowchart

The method developed to determine the safe load capacity will bridge the gap between current inventory and operating load levels of AASHTO. It will provide more than one stress level for evaluation. It will be flexible in the decision-making process, balancing risk and safety levels and taking structural redundancy, load variations, permit operations, load enforcement, and level of inspection into account.

This method of selecting safe load capacity should help raise the load posting level of deficient bridges and at the same time reduce the risk of bridge failure. The recommended method will be equally applicable to reinforced concrete, prestressed concrete, structural steel, and timber. Equivalent load factors that can be used for LFM analysis have been developed.

The 10 factors affecting the posting level previously identified are shown in Figure 7. The purpose of the safe load-stress level decision flowchart shown in Figure 8 is to quantify and document the input to solidify the logic for selecting the posting level to be used. A discussion of some of the various decision nodes in the flowchart follows.

Member Condition

Steel does not lose strength with age or deterioration because loss of section is used to discount corrosion of the metal, and because fatigue is not an issue here. Concrete actually gains strength with age, and even some heavily deteriorated concrete bridges have been shown to suffer no measurable loss of strength (3).

Based on these findings, the research team recommends that only members with material in critical condition, with an SI&A superstructure condition rating of 3 or below, should be rated no higher than inventory stress level (4).

Inspection Frequency

In order to minimize the need to post numerous bridges, AASHTO allows the rating agency to use load levels higher than inventory rating, for posting purposes. The research team recommends that posting levels greater than inventory rating should be allowed if the inspection frequency were reduced to once a year or less and if other pertinent factors do not prevail.

Level of Enforcement

Load levels higher than inventory rating for posting are acceptable only if the risk of overload is small. Enforcement of posting limits becomes more critical as the posting value decreases. Structures located on highways with permanent truck scales attain the highest level of confidence.

The level of enforcement was divided into three categories in an effort to quantify the enforcement factor. Enforcement Level 1, is assigned to structures on routes where truck load limits are vigorously enforced. Routes with a moderate level of enforcement are assigned to bridges with Enforcement Level 2. Other roads are assigned to Enforcement Level 3. Bridges with Enforcement Level 1 should be allowed higher posting levels, and bridges with Enforcement Level 3 should be posted at lower posting levels (Imbsen et al., 1983).

Incidence of Maximum Load

AASHTO (1,p.24) recognizes that the probability of having a series of closely spaced vehicles of maximum allowed weight becomes greater as the maximum allowed weight for each unit becomes less. Similarly, structures with a lower posting have a higher incidence of maximum load and, therefore, a lesser stress level should be imposed. On the other hand, structures with a higher posting have a lower incidence of maximum load due to a more distributed load spectrum and, therefore, are allowed a higher stress level.

Years to Replacement

Terminal rating is a procedure that allows a bridge scheduled for replacement to be posted at a higher level. The theory is that a condemned bridge may be allowed to deteriorate at an accelerated rate. The pitfall of using terminal rating is that the scheduling of replacement funds cannot be guaranteed.

Fatigue

Certain types of bridges need to be investigated for fracture-critical details, such as partial-length

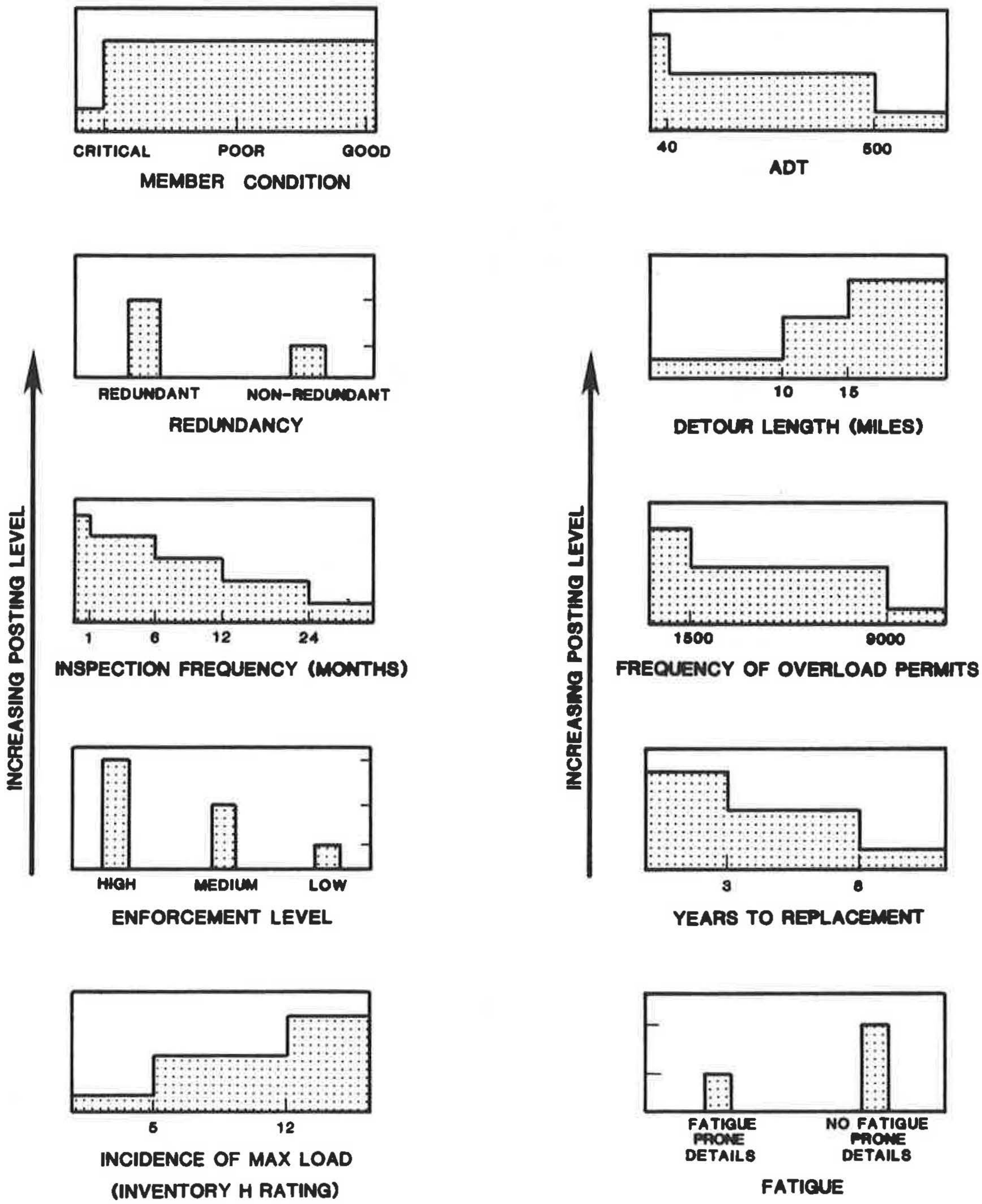


FIGURE 7 Factors affecting posting level.

cover plates. The detail must then be investigated to determine if it poses a fatigue problem. During the telephone survey, it was learned that one state limits its allowable strength to 129 percent of inventory. This was said to be done to reduce the risk of fatigue damage, which increases dramatically as the allowable stress is increased. This can be theoretically proven with a cumulative damage analysis. For example, a 10 percent reduction in the stress range will result in an increase of 10 to 30 percent in the fatigue life.

Detour Length

Of all the factors the research team considered in selecting a safe load posting level, the detour length around a posted structure is the only nonstructural consideration. It is recognized that the longer the detour, the higher the posting level required to offset the detour costs that will be incurred. It was found that most detour lengths are less than 6 mi. Breakpoints should be set high so that only exceptional cases are given special treatment. Breakpoints of 10 to 25 mi are chosen because 10 is near the arithmetic mean and 25 is at the 95th percentile.

Safe Load Posting Levels

The decision flowchart prescribes specific levels of posting that approximate even steps from inventory to operating rating. Actually the last step to

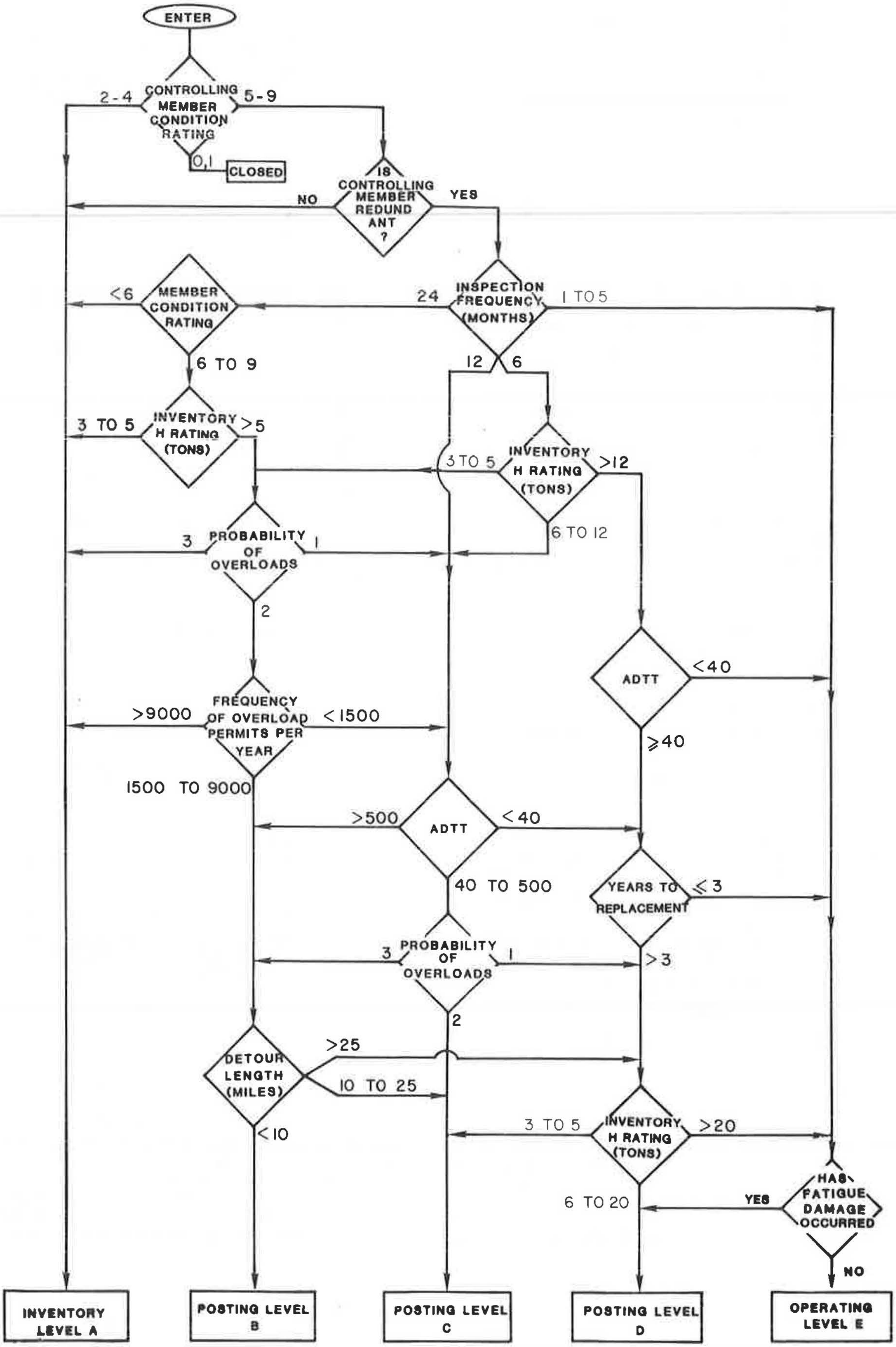


FIGURE 8 Safe load-decision flow chart for steel, timber, and concrete with plans.

operating rating varies, because operating as a percent of inventory differs for various materials. Figures 9 and 10 show the tabulation of the various posting levels. Figure 9 is for WSM and Figure 10 is for LFM.

POSTING LEVEL	CONC	STEEL	TIMBER
A	100	100	100
B	110	110	110
C	120	120	120
D	129	129	126
E	138	136	133

FIGURE 9 Safe load posting levels for working stress method.

POSTING LEVEL	SERVICEABILITY
A	$D + \frac{5}{3} L$
B	$D + \frac{4.5}{3} L$
C	$D + \frac{4}{3} L$
D	$D + \frac{3.5}{3} L$
E	$D + L$

FIGURE 10 Safe load posting levels for load factor method.

Safe Load Posting Level Decision Flowchart for Concrete Without Plans

A decision flowchart for reinforced concrete bridges where no plans exist is shown in Figure 11. The output of the flowchart is a posting value.

Signs of Distress

The 1978 AASHTO allows a bridge without record plans to be unposted when the structure has been carrying normal traffic for an appreciable length of time and shows no signs of distress. The researchers therefore recommended that bridges with an SI&A rating of 4 to 9 that show signs of distress should be posted for no more than 15 tons unless other circumstances allow for a greater capacity. Signs of distress are more fully defined in Figure 12.

Year of Design

The year in which a bridge was designed indicates the design load. Since 1944, most bridges have been designed with HS20 load. Before 1944, the majority of bridges were probably designed for a load somewhat less than HS20. Using this hypothesis, bridges built after 1944 showing no signs of deterioration should remain unposted. On the other hand, bridges built before 1944 showing signs of deterioration should be posted for a value of 15 tons unless other pertinent conditions prevail.

Rating

Analysis Method

The telephone survey showed that most states use WSM or a combination of WSM and LFM. Concurrently, many reasons were offered against LFM. From the comparative analysis of rating methods, the research team found that WSM and LFM yield nearly the same results, with LFM requiring notably more effort. Based on this observation, the policy should state that two levels of analysis be employed:

1. Analysis Level 1 would use WSM as the primary tool for bridge rating.
2. Analysis Level 2 would prescribe a second, more detailed analysis using revised rating criteria and the use of LFM, if deemed pertinent. The use of LFM should be reserved for instances when its use will be advantageous. These cases exist when a reinforced concrete span uses Grade 60 reinforcing steel or when a steel I-beam span uses compact sections and has laterally unsupported compression flanges.

Special Considerations

In cases where Level 2 analysis is performed, other factors in the analysis may be considered:

1. Use a three-dimensional computer analysis;
2. Use a more refined live-load distribution factor;
3. Reduce the impact factor in situations in which vehicle speeds can be effectively controlled;
4. Use the actual number of lanes that a structure carries, instead of design-lane loads;
5. Construct curbs to reduce the number of lanes or to place wheel loads in more favorable locations;
6. Erect signs or traffic lights to limit a bridge to one truck at a time;
7. Evaluate materials through sampling and testing; and
8. Use load testing to evaluate capacity.

Posting Limits and Rating Vehicles

The ML-80 truck, which has a gross vehicle weight (GVW) of 36.64 tons, was found to control single-vehicle posting in a significant number of the cases. For this reason it was decided that the ML-80 should be included as a rating truck and that the posting limit for single vehicles should be increased to 36 tons. Any state weighing tolerances will not be included here because the posting of bridges for a weight limit higher than that allowed by law would confuse the public.

Combination vehicles are allowed to have a GVW of up to 40 tons. As a result of the comparative analysis, it was found that the 36-ton HS20 truck controlled combination postings in all cases but one. The Type 3-4 truck controlled one posting. However, this vehicle is restricted to the Interstate system and to designated primaries only. In addition, the Type 3-S4 was also considered but rejected because it did not control posting.

It was recommended that bridges should be rated for the H vehicle and posted to a maximum of 19 tons, rated for the ML-80 vehicle and posted to a maximum of 36 tons, and rated for the HS20 vehicle and posted to a maximum of 35 tons. The exception is for the HS vehicle with a required posting greater than 35 tons when posting is required for single vehicles. In this

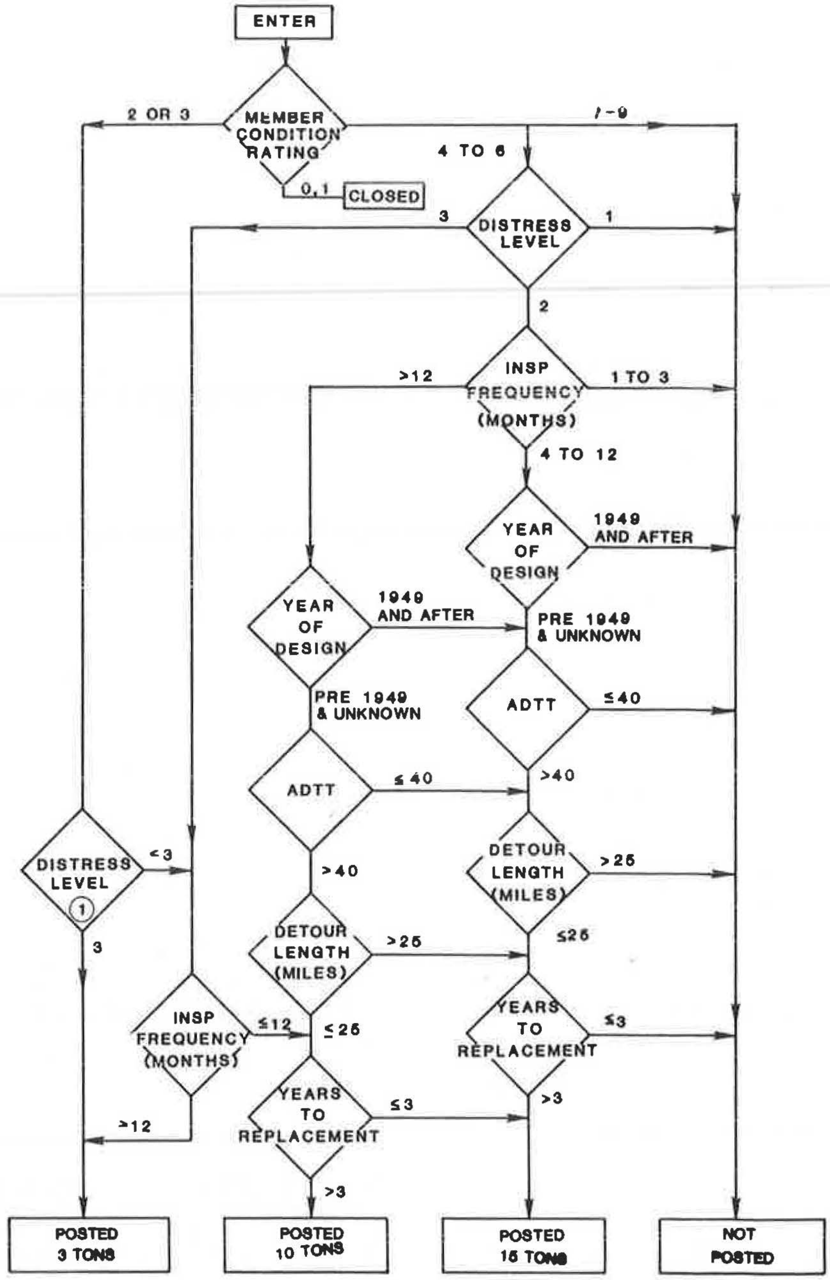


FIGURE 11 Safe load posting value decision flow chart for reinforced and prestressed concrete without record plans.

DISTRESS LEVEL PC	RC	DESCRIPTION
1	1	NO L.L. DISTRESS
1	2	HAIRLINE CRACKS
2	3	WORKING CRACKS
3	3	CRACKS PLUS VISIBLE L.L. DEFLECTION

FIGURE 12 Distress level.

case, the structure should be posted at the rated value for single vehicles and 40 tons for combination vehicles.

The Posting Process

General

Bridge management is a major activity of which the posting process is simply a part. The posting process begins with a field inspection. From the data collected, a load rating analysis of the structure can be performed for use in completing the FHWA structure inventory and appraisal data base. A load posting analysis--the focus of this study--can then be used to determine the maximum allowed load limit for posting. Finally, permit load rating analyses can be performed periodically to review overload permit applications.

Load Rating Analysis

The posting process, developed by the research team and shown in Figure 13, begins with the collection of data from the field inspection and with the load-rating analysis. It must then be determined if posting is required at the inventory rating. If not, the bridge remains in service unrestricted and is placed on a 2-year inspection cycle.

Load Posting Analysis Level 1

If posting is required at inventory rating, the decision flowchart can then be used to determine a safe load posting level. With this, the load posting analysis can be performed to determine if posting is still required. If not, the bridge is unposted, and the structure is scheduled for inspection every 12 months or less.

Load Posting Analysis Level 2

If posting is required at the safe load posting level, alternatives to posting are examined. These alternatives include an evaluation of posting criteria, such as wheel load distribution factor, impact factor, and the use of load factor method of analysis. The use of a more detailed analysis, such as three-dimensional computer modeling may be justified. If the evaluation reveals that criteria have changed, a second load posting analysis can be performed. The extent of this reevaluation depends on the posting value resulting from the Level 1 posting analysis and the minimum desirable posting criteria.

Operation of Posted Structure

The posting agency must now operate a posted structure. This includes notifying the public of the posted structure and detour routes. Examples of those affected include school and emergency services, the trucking industry (both local and long distance), and in some cases, local commerce. Other duties in operating a posted structure include maintaining signs, inspecting the structure every 12 months or less, enforcing posted load limits, and issuing overload permits.

Emergency Posting

Emergency posting as a routine part of the posting process was considered and rejected based on the conversations during the district field visits. Conditions rarely warrant temporary posting while emergency repairs are made. In addition, rapid reversals in the posted load limit before, during, and after emergency repairs only tend to undermine the user's confidence in the reality of bridge postings.

Most cases of emergency posting result from traffic accidents. This can be from an over-height vehicle striking an overpass or from river traffic striking piling. Emergency posting rarely results from the findings of a routine inspection. It was decided that if an emergency posting is truly an emergency, three options exist. The bridge should be (a) posted for 10 tons; (b) posted for no trucks, one-lane traffic, or both; or (c) closed to all traffic.

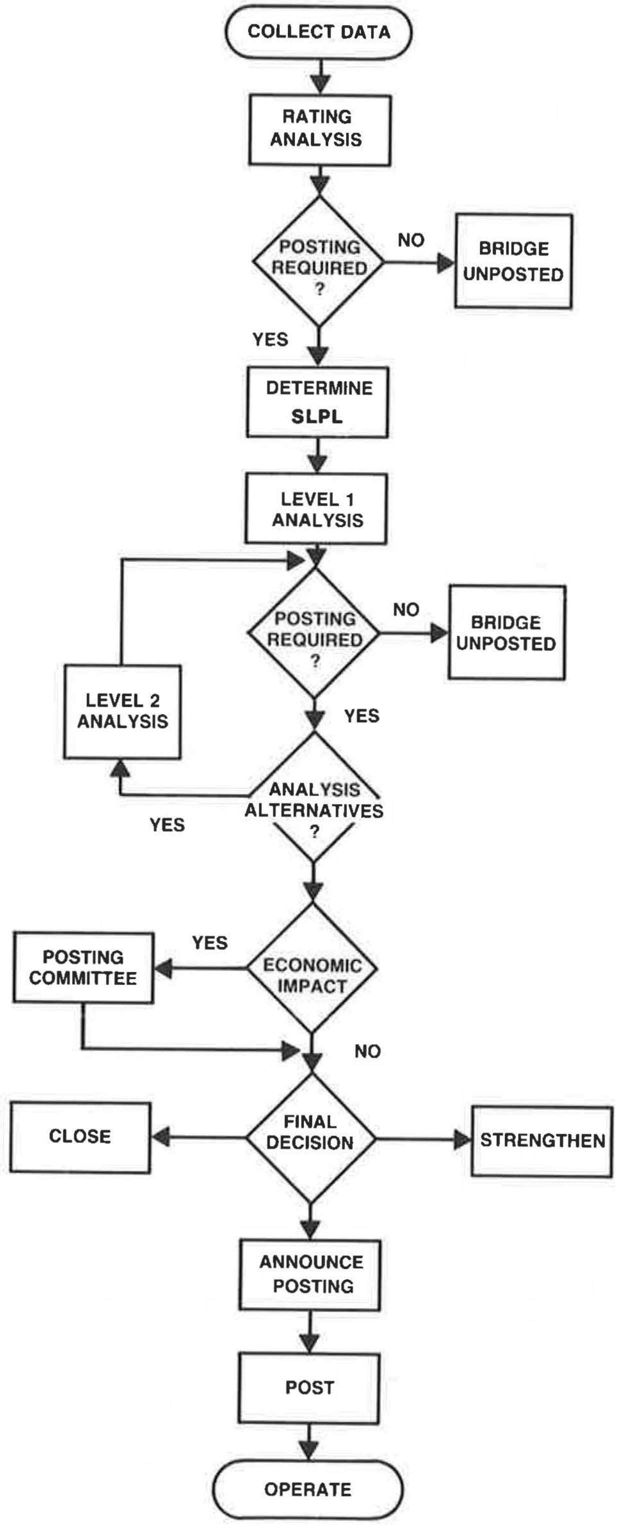


FIGURE 13 Posting determination process.

Time Limit

A time limit needs to be imposed on the posting process, so that a posting revision will not be held up in committees. The time limit from inspection to erection of the sign should be specified as a function of the percent reduction in the posting. This time limit should not exceed one month for a proposed posting reduction of less than 10 percent. A time limit of one week should not be exceeded for a posting revision of 10 to 50 percent. Beyond 50 percent, the time limit should be set at 24 hours. For example, if an unposted bridge is found to require a 12-ton posting, for an H-truck loading, a time limit of one week would be imposed, because the reduction in posting would be 8/20 = 40 percent.

Signs

During the district field visits, various sign types were discussed. These discussions aided the research team in selecting signs for the posting policy (Figure 14).

Type I: Weight Limit XX Tons

This sign specifies a single weight limit. As it is currently used, this sign restricts combination vehicles that generally accommodate more load because of the greater number and spacing of axles. This sign is best suited for structures with low weight limits where the difference between the two limits is small and the probability of there being a combination vehicle of low GVW is less. Otherwise, the Type I sign should be used in combination with Types II, III, or IV signs.

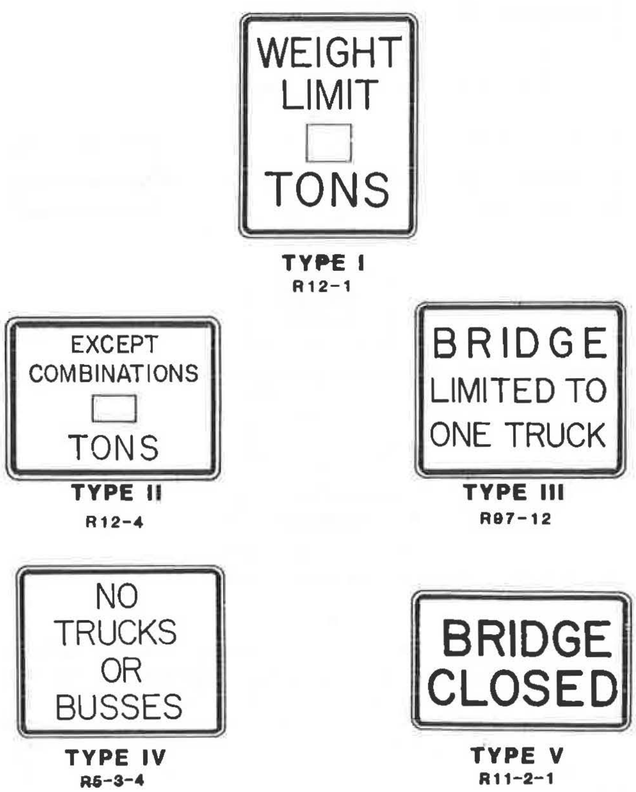


FIGURE 14 Posting signs.

The sign axle weight limit XXX lbs was also considered. This type of posting is more accurate than assuming that "each axle load maintains a constant relationship to the total load" (1,p.21). However, dual postings for axle loads and GVW will be more confusing. This sign also lacks a legal definition in the sponsoring state. For these reasons, the sign was rejected.

Type II: Except Combinations XX Tons

A bridge can be posted for both single and multiple vehicles when Type II and Type I signs are used, as they currently are in all districts. When the HS20 rating is equal to or greater than 36 tons and the Type I sign is required, this sign should call for a maximum limit of 40 tons to allow passage of all combinations.

Many states now use silhouette signs for multiple postings. Much information can be quickly grasped from these signs, which also lend themselves to the posting of double bottom combination vehicles. However, concern was expressed during the district field visits about the use of silhouette signs. These signs require a legal definition. Confusion by truck drivers was also anticipated concerning whether to count the number of trailing units or the number of axles. Word message signs are legally defined and understood by the user. Trends in other states and pressure for a uniform sign practice may eventually call for change in this policy.

Type III: Bridge Limited to One Truck

When special conditions warrant, the use of this sign along with the Type I sign will increase posting load limits.

Type IV: No Trucks or Buses

This sign is to be used with the Type I sign when the posted load limit is 3 tons. This sign will preclude the use of the bridge by trucks and buses and allow local officials to enforce weight limits without actually weighing them.

The sign Passenger Cars and Pick Ups Only was also considered for this application. This sign was ultimately rejected because it lists only two of many vehicles that are allowed to use the structure.

Type V: Bridge Closed

This sign is to be used when the structure must be closed.

CONCLUSIONS

The policy assessment was based on a small sample of bridges. The results of the analysis are tentative. However, the following conclusions are offered.

1. The proposed posting policy has the advantage over the existing policy of providing an objective decision-making tool for arriving at a desirable level of posting. The proposed policy does not eliminate engineering judgment but does provide a logical pattern for it.
2. The proposed posting policy will provide a uniform procedure for the selection of an optimum stress level with the use of the safe load posting-level decision flowcharts.

3. The proposed posting policy provides flexibility by allowing the engineer to perform a Level 2 analysis or inspect bridges at increased frequency.
4. The proposed posting policy protects the state's capital investment in its bridges. This is mainly a result of the protection from overloads provided by posting policy.
5. The proposed posting policy protects the public safety for the same reason as the aforementioned.

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Prescription for Steel Girder Bridge Rehabilitation

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ABSTRACT

Increases in design or permit live loads, coupled with material deterioration, currently require rehabilitation or replacement of many bridges. Current AASHTO live-load distribution criteria, originally developed for fully loaded structures, result in ultraconservatism when applied to overload vehicles occupying only one or two lanes. Indiscriminate use of these criteria may suggest needless rehabilitation. Application, even if time-consuming, of currently available, sophisticated, computerized analyses that treat such partial-width loadings accurately may effect significant economies by demonstrating structural adequacy. Plans for overlayment on a deteriorated concrete deck on steel girders at a California site and upgrading for a new live-load permit vehicle, based on AASHTO distribution criteria, will require auxiliary steel flanges, introduction of composite behavior and web posttensioning to carry increased dead and live loads. A grillage analysis with the CURVBRG computer program suggests questionable need for posttensioning. Further analyses with FINPLA and STRUDL finite-element programs demonstrate a method for assessing web stresses at the posttensioning brackets.

In 1975 the California Department of Transportation (Caltrans) upgraded its specifications for bridge loadings with the objective of producing initial designs commensurate with later ratings for overload (1). The revisions introduced a modular design vehicle called the Permit- or P-series vehicle, significantly longer and heavier than H-series vehicles used previously. Unlike H-series trucks, P-series vehicles are used singly or in conjunction with an HS20 vehicle in an adjacent lane, and load factors are significantly lower than H-series factors.

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