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COMMITTEE ACTIVITY

Committee on Dynamics and Field Testing of Bridges
Department of Design
Highway Research Board

BRIDGE VIBRATIONS
SUMMARY OF QUESTIONNAIRE TO STATE HIGHWAY DEPARTMENTS

Foreword

The committee on Dynamics and Field Testing of Bridges has as part of its scope the question of psychological and physiological reaction of vehicle passengers and pedestrians to vibrations of highway bridges. While this subject has been considered by various agencies a number of times in the past, it has never been clearly determined that the problem is real.

The committee concluded that it should attempt to determine the importance of the problem and if needed, to develop research projects aimed at its solution. In order to guide it in this study, a two-part questionnaire was developed and circulated to all State Highway Departments. This report is a summary and discussion of the results of the questionnaire.

ACKNOWLEDGMENT

This work was initiated by the Committee on Bridge Dynamics, under the Chairmanship of Dr. C. P. Siess and, as a result of the merger of two committees, was continued by the present committee, under the chairmanship of Mr. LeRoy T. Oehler. The major portion of the work was done by a subcommittee chaired by Dr. Kenneth H. Lenzen. The subcommittee members are noted on page ii. Dr. Lenzen is the author of the report.

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BRIDGE VIBRATIONS
RESULTS OF QUESTIONNAIRE TO BRIDGE ENGINEERS AND DISCUSSION BY AUTHOR

First consideration of the replies received on the Highway Research Questionnaire shown in Appendix 1 would seem to indicate that there is no significant vibration problem. Of forty-one replies received, only fourteen states reported having received complaints. Four of these replies indicate only one bridge that vibrates and two of these were corrected by deck repair. Four states indicate that they have had two problem structures in recent history. The remaining six states report sixty-two problem bridges and indicate more on which they have had no formal complaints.

However, the key to the existence of bridge vibration problems seems to be the definition of just what constitutes excessive vibration. Most of the survey definitions allude to structural damage as the primary criterion. If structural safety is taken as the only consideration in bridge vibration, then it is likely that there is little reason for research. The replies cited examples of deck cracking that were probably due to vibration, but in no instance was there any question of structural safety.

The replies on the twenty-seven questionnaires in which no complaints were recognized are interesting. Seven of the twenty-seven questionnaires state that research is needed on the vibration of bridges. Two of these state that no problem is experienced on their bridges since they allow no sidewalks and therefore have no complaints. Another states that there have been no formal complaints.

Many of the replies in which bridge vibration was recognized defined bridge vibrations as that which could be felt either by occupants of vehicles or pedestrians. One reply cited pedestrian insecurity as the determining factor. Of the fourteen states that acknowledged or recorded complaints of bridge vibration, only four recommended no further research on this problem. Two of the four stated the reason was mainly that they had nonurban control of bridges.

By far the majority of the complaints stated that the vibrations were in continuous or continuous-composite structures. Other than these types included in the list of vibrating structures are two deck girders, a truss, and a suspension bridge. Further, the vibrations in general were thought to be due to a single truck, either in the span or in an adjacent span. Three replies indicated that the maximum vibrations are felt after a single heavy vehicle leaves the span. One pedestrian bridge was acknowledged as vibrating and here the cause of vibration was, of course, pedestrians. In only one case was an automobile indicated as the source of vibration.

Apparently in all of the bridges that were noted as vibrating, there has been only one formal complaint made. This complaint was filed by "a bum sleeping on the under truss-work of the bridge on pine boughs." Complaints from citizens are usually made and answered by telephone and not recorded. Most of the complaints received were by engineers and highway workmen. In only one recorded case was the complaint made by a person in a vehicle. All other cases were by pedestrians.

It is apparent that the importance of the vibration problem is directly related to the importance of alleviating pedestrian concern. Research might well lead to more economical design, but its prime effect would be to keep the pedestrian from feeling vibrations. On this basis it appears that metropolitan areas would be more interested in the problem than the predominately rural areas. The extent of the problem is not clear. There is too little information from the metropolitan areas. One chief engineer recognized this. In investigating further he found that the metropolitan areas all indicated definite objections by pedestrians. Again, no formal complaints were made. His rural area engineers had no complaints whatsoever.

Historically(1) it appears that the primary purpose of specifying depth span ratios was to limit live load deflection. The deflection limitations were introduced into the specifications to reduce vibration in highway and railway bridges. At that time they were not restrictive for the materials and allowable stresses in use. Observations through the years have cast doubt on the optimum level or even the effectiveness of deflection limitation. This and the increasing restrictiveness of such limitations when applied to design with high-strength materials have led to reappraisal of the causes, effects and control of the bridge vibration.

Extensive and varied field and laboratory tests as well as theoretical studies have shown that the causes and effects of bridge vibration are very complex. Objectionable vibration cannot be consistently prevented by a simple deflection limitation alone. On the other hand, little if any damage to the structure can be attributed to vibration, except when the bridge has been previously damaged due to other causes such as a badly cracked or loosened concrete deck. The objection to vibration arises only from the response which it induces in persons on the bridge or in stationary vehicles on it.

A perceptible vibration is set up when a smoothly rolling load passes across an elastic beam. This may be considerably amplified if the relation of speed to span is such as to cause resonance or sub-harmonic excitation of a natural mode of oscillation of the bridge. Further excitation may be caused by roughness of the deck or approaches, resonant oscillation of the sprung and unsprung parts of the vehicle, and other factors. Investigators at the University of Illinois [2] and at the Massachusetts Institute of Technology [3] have studied this problem and are able to predict these vibrations with engineering accuracy, both theoretically and with models.

Specification writers have tried to minimize the vibrations by limiting the deflection. When the stiffness of the bridge is increased, there is less deflection per unit load. At the same time, the increased stiffness results in a greater impact factor or dynamic amplification.

D. T. Wright[4] showed that if the total stiffness of the bridge exceeded 200 kips per inch deflection (load placed and deflection measured at mid-span), the median amplitude factor was about 0.00050 inches per kip of live load. Increased stiffness above this value reduced the mean amplitude factor very little. (Fig. 1).

Frequency and damping are parameters which affect the human response to the vibration as well as the amplitude. The general range of frequency at which a bridge vibrates is from 2 to 7 cycles per second. The damping is usually 1 to 2% od the critical damping (logarithmic decrement of 0.06 to 0.13). In this range of frequency, Janeway [7] has indicated that the human responds directly to the change in acceleration or "jerk" rather than to amplitude, velocity, or acceleration. Reiher and Meister [6] and Goldman[8] have shown results of subjective tests on humans which are in reasonable agreement, and indicate the response to change of acceleration previously mentioned is correct. This would indicate that a bridge designed with a total stiffness of above 100 kips per inch would probably have perceptible vibrations when a vehicle weighing 20 kips passed over if all axles or wheels were responding together. Increasing the stiffness of the bridge would not decrease the amplitude of vibration sufficiently to remove it from the perceptible range.

The vibration is sensed by a standing or sitting subject looking for the vibration. The question of the use and location of the bridge then must be evaluated. Moving pedestrians would probably not sense the vibration. Passengers in moving vehicles would not feel the vibration. People in parked vehicles would probably sense the vibration only if the frequency of the bridge was close to the natural frequency of the vehicle. Thus, it would seem that the use of the bridge should control specifications in regards to vibration. Vibration will probably be sensed only on bridges with pedestrian traffic.

Unfortunately, coupled with the sending of the vibration is a psychological effect. The human tends to exaggerate any movement or vibration. Engineers who have investigated blasts, sonic booms, and bridge or building vibration feel that this magnification factor seems in the order of 100 to 1.

The response of humans to vibration can be reduced if sufficient damping is present[5]. If a vibration is damped to a small amplitude in less than 10 cycles, the human will respond at a reduced scale. With amplitudes of about .010 inches, the human will not sense them if they are damped to about .001 inches in 5 cycles or less. This requires damping of 7.5% or more of the critical, but there normally is only 1 to 2% of critical damping in a bridge.

Successful vibration dampers have been devised but usually the cost has been considered too high for most installations. Recent work with viscoelastic material [9] in buildings have indicated an acceptable method of introducing the necessary damping. Thus, vibration can be eliminated when it is economically feasible to do so.

Janeway[7] states there are three regions in which the human responds differently to vibrations. Above 20 cps the reaction is to the velocity of the vibration. From a about 5 cps to 20 cps the human responds to the acceleration. Below 5 cps the human being responds to the change in the acceleration or "jerk" as Janeway has termed it. If a bridge has a vibration with an amplitude "A", then the maximum velocity is "A" times the circular frequency. The maximum acceleration is "A" times the circular frequency squared and the maximum jerk is "A" times the circular frequency cubed. A reduction of the frequency should then make the vibration which is present in all bridges, much more tolerable to the occupants. T. Y. Lin in an oral presentation pointed out that his prestressed concrete pedestrian bridge in Los Angeles had no vibration problem. The frequency was so low, one quarter of a cycle per second, that the users did not feel the large vibrations. Most bridges are in the region of a critical human response since the natural frequency is about 5 cps. It would be well to contemplate designing and building a span in a rural region where all present specifications are disregarded as to L/D ratio and span to deflection ratio. This bridge should incorporate the highest strength steels with hybrid-composite construction. It obviously must have the same structural integrity that our present design specificiations require. A bridge would result with a low natural frequency, probably below 1 cps. This low frequency would reduce the human sensation by the cube of the reduction based on Janeway's conclusions. Thus, such a bridge may well be suitable for pedestrians.

The amplitude would increase but at a reduced rate compared to the moment of inertia since the impact factor would decrease with so flexible a structure. Sensation is only dependent on the first power of amplitude.

From the previous discussion it is suggested for consideration that the specifications for the deflection limitation and depth to span ratio of bridges might be altered to reclassify bridges in three categories with the following restrictions:

1. Bridges restricted to vehicular traffic should have stress restrictions only. The bridge need not be designed to minimize vibrations for the occasional emergency stop or for workmen.

2. Bridges in urban areas with moving pedestrian traffic and parking should have a minimum stiffness of 200 kips per inch of deflection to practically minimize the vibrations.

3. Bridges with benches, fishing, or other loitering pedestrian traffic should have a minimum stiffness of 200 kips per inch of deflection, plus damping of 7.5% critical damping of the bridge, to eliminate vibrations.

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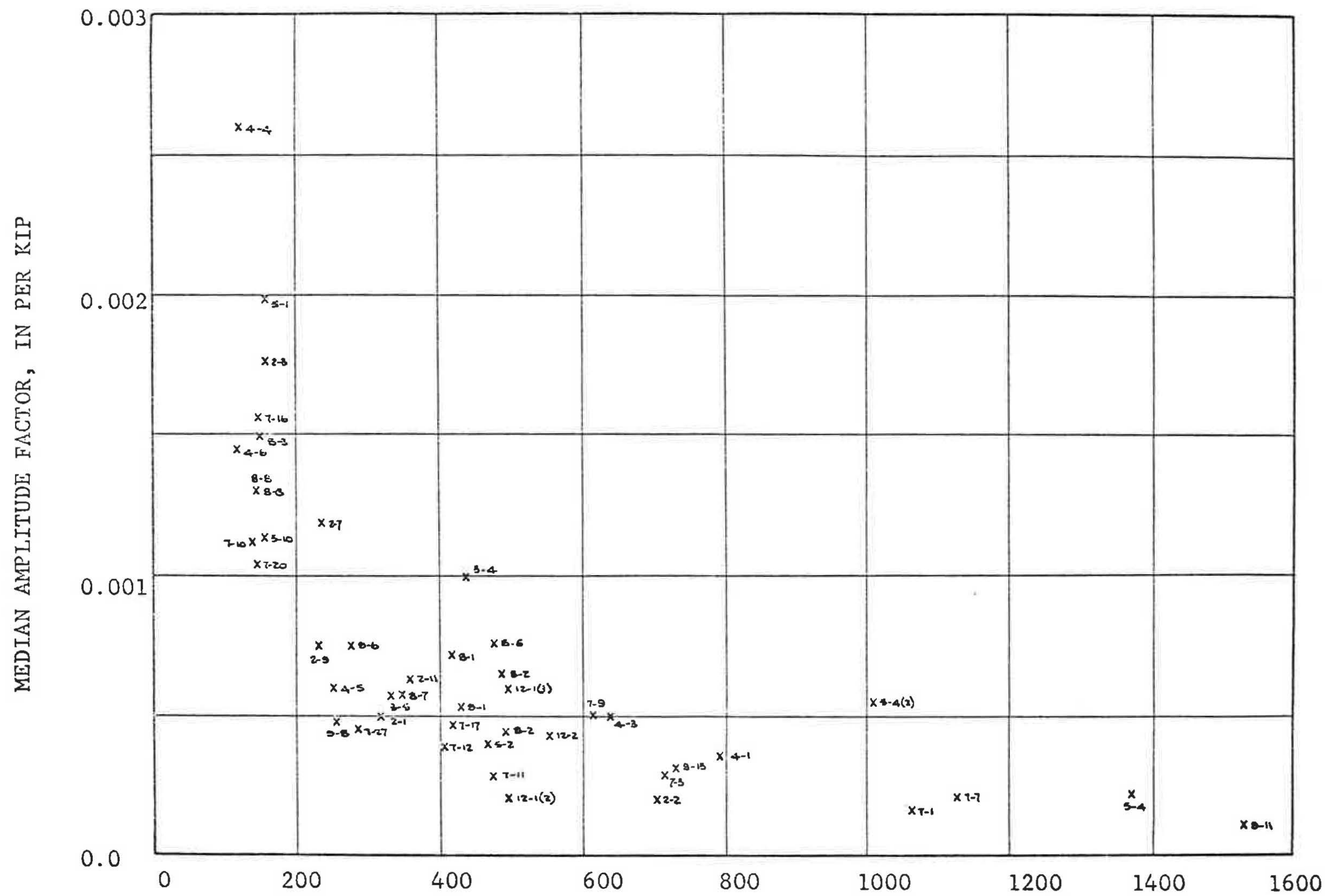

FIG. 1 RELATIONSHIP BETWEEN MEDIAN AMPLITUDE FACTOR AND OBSERVED STIFFNESS

Highway Research Board
Committee D-C6, Bridge Dynamics

QUESTIONNAIRE

Please return to:

Dr. K. H. Lenzen
Department of Mechanics and
Aerospace Engineering
University of Kansas
Lawrence, Kansas 66045

Indentification

State of ______________________
Department ______________________
Prepared by ______________________
Title ______________________
Date ______________________

If you desire that your replies to this questionnaire be held in confidence, please check ☐

SUMMARY QUESTIONNAIRE

1. How many bridges are under your jurisdiction? ______________________

2. How many bridge vibration complaints do you recall having received in the past two years? ______________________

3. How many individual bridges were involved? ______________________

4. Who usually makes complaints?

   a. Highway department workers maintaining the bridge ____________
   b. Other highway department personnel ____________
   c. Pedestrians using the bridge ____________
   d. Automobile or light commerical vehicle occupants ____________
   e. Truck or heavy vehicle occupants ____________
   f. Other (state) ____________

5. What is done about complaints? ______________________

____

____

____

6. How would you define excessive vibration? ______________________

____

7. How many bridges under your jurisdiction actually exhibit excessive vibrations? ______________________

8. List factors you believe cause excessive vibrations. ____________

____

____

____

9. What is the loading condition for excessive vibrations? ________
(single vehicle, fully loaded, after vehicle is off span etc.)

____

____

10. Is one type of bridge more prone to excessive vibrations than others? ___

If so, what design? ______________________________

11. Do you suspect structural damage due to vibrations? ____________

What part of structure? ______________________________

12. Have you tried to minimize vibrations? ______________________

13. In your opinion is vibration of highway bridges a problem which warrants research? ______________________________

14. Other comments. ______________________________

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____

PRELIMINARY BRIDGE LIVE LOAD DEFLECTION SURVEY

1. Your identification of bridge.

Bridge Name	Dist. Co. Rte. Sec.	Br. No.	Yr. Const.

Location	State

Type of Bridge	Span Length

Check one or more appropriate classifications below:

2. Material

a. concrete ___
b. steel ___
c. composite ___
d. other ___

3. Description of deflection or vibration

a. pronounced ___
b. moderate ___
c. perceptible ___

4. Are the deflections or vibrations objectionable? yes ___ no ___

5. Magnitude of deflection:

a. By (visual estimate) (measurement) the approximate maximum deflection was

______________________________.

b. Where did this deflection occur? span ___ hinge ___

c. Under what loading? heavy truck ___ passenger car ___ span empty-loaded

6. Was the vibration more noticeable while a vehicle was on the structure or after it had left the bridge? before ___ after ___

7. Reaction to vibration (check one).

a. none ___
b. mild complaints ___
c. numerous strong objections ___

8. Who reacted to vibration?

a. public ___
b. maintenance ___
c. engineer ___
d. other ___

9. Structural damage possible caused by live load deflection. ___________

____

10. Other comments. ______________________________

____

11. Name and address of the person to be contacted for further information about the bridge.

____

____