DYNAMIC STRESS STUDY OF COMPOSITE-SPAN BRIDGE WITH CONVENTIONAL AND ELASTOMERIC BEARINGS

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This paper describes an experimental study of the effects of dynamic loading on the vertical compressive deflections of elastomeric bearings and the influence of the flexible bearings on the response of the supported span. The primary test structure was a steel-beam, composite-span, highway bridge dynamically loaded by a test vehicle closely simulating an AASHO HS20-44 standard truck. The bearings investigated included 1 set of conventional steel rocker plate assemblies and 5 sets of elastomeric pads representing a wide range of practical design parameters.

Although the accepted compression-deflection relationship for elastomeric pads was verified experimentally in the subject study for both static and dynamic loading, it was concluded that deflections of full-sized bearings under either type of loading would be less than those predicted by the standard design curves. Analytical and model studies indicated that elastomeric bearings would reduce both the frequency of vibration of the supported span and the flexural stress in the structural members at resonance. The effect of the bearings in reducing the frequency of vibration of the span, however, was found to be slight; and under the realistic loading condition utilized, no practical advantage was indicated in reduced flexural stresses or increased damping of vibrations. However, a trend toward increased deflections of the span on elastomeric bearings was noted at all speeds of the test vehicle.

•ELASTOMERIC bridge bearings—pads of natural or synthetic rubber on which a beam rests and which deform to allow rotation, expansion, or contraction at the ends of the beam—are widely used in conjunction with both concrete and steel girders. The main advantage of elastomeric bearings lies in the economy resulting from low materials cost, ease of fabrication and installation, and little or no requirement for maintenance. The use of properly designed elastomeric bearings in lieu of more complex steel assemblies has resulted in cost savings in highway bridge construction, and field experience has generally confirmed their effectiveness.

There is a considerable body of research literature concerning elastomeric bearings, most of it concerned with laboratory tests to evaluate the performance of bearings fabricated of various compounds under conditions of static and cyclic loading at a practical range of temperatures. Little information is available on the response of bearings on an actual structure to dynamic loading or on the effect of the flexible bearings on the behavior of the supported span.

This paper reports the results of field tests of an actual highway bridge span supported on steel bearings and on 5 sets of elastomeric pads having a wide range of practical design parameters. The span was loaded during the tests by a 3-axle test vehicle that closely approximated an AASHO HS20-44 standard truck. The 2 primary purposes of this experimental investigation were as follows:

1. To determine the effects of a realistic dynamic loading on the vertical compressive deflections of the elastomeric pads included in the study and to compare the ex-

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perimental results with the empirical compression-deflection relationship on which the design of elastomeric bearings is largely based; and

2. To investigate the effects of the flexible bearings on the response of the supported span to dynamic loading and to compare the results, where applicable, with those of an analytical study reported by Zuk (1) and a model study performed by Emanuel and Ekberg (2).

The full-scale field tests can best be introduced by a brief discussion of the conventional compression-deflection relationship for elastomeric bearings and a review of the findings of the analytical and model studies.

COMPRESSION-DEFLECTION RELATIONSHIP FOR ELASTOMERIC BEARINGS

Perhaps the key factor in the design of elastomeric bearings is the vertical compressive deflection, which is generally held below a specified maximum value. The vertical compressive deflection is generally predicted on the basis of empirically derived standard curves that relate percentage deflection at a given load to the shape factor of the bearing and the hardness of the elastomer (3, 4).

The shape factor of an elastomeric bearing is defined as the ratio of the loaded area, which conventionally is the entire top face, to the area of the sides, which are free to bulge, as shown in the following for a rectangular pad:

$$\text{Shape factor} = \frac{l_p w_p}{2t_p(l_p + w_p)}$$

where

l_p = length of the pad;
w_p = width of the pad; and
t_p = thickness of the unloaded pad.

Hardness refers specifically to the relative resistance of an elastomer to surface indentation as measured by a durometer, a device with a spring-loaded probe that is pressed into the elastomer. The durometer indicates the hardness of the elastomer on an arbitrary scale from 0 to 100 for soft to hard materials. There is general agreement that durometer hardness does not provide an accurate measure of the stiffness of the compound, which is the property of interest (3, 4, 5). A general relationship does exist, but wide scatter is to be expected in a correlation of compressive stiffness and durometer values (3).

Most of the research on elastomeric bearings has been concerned, at least in part, with the compression-deflection relationship, and the standard curves have generally been verified within acceptable limits under laboratory conditions (2, 5, 6, 7). Thus, as indicated by the standard curves, the compressive stiffness of a bearing increases with higher shape factors and hardnesses, but tests of full-sized bearings have generally shown the pads to be stiffer than they were indicated to be by the standard curves.

ANALYTICAL AND MODEL STUDIES OF EFFECTS OF ELASTOMERIC BEARINGS

A theoretical study of the effect of flexible bearings on the vibration characteristics of a simply supported span has been reported by Zuk (1). Assuming that the vertical oscillations of a crossing truck would be equal to and in phase with those of the span at resonance, he developed an expression for the fundamental frequency of a beam on elastic supports with the vehicle at midspan. Equations for the ratios of amplitudes and stresses of the span on flexible bearings to those of the span on rigid bearings were also presented, as were sample computations based on sectional properties of typical bridges. Zuk's rather involved expressions will not be restated here; instead the results of the sample computations will be compared with the results of the model study by Emanuel and Ekberg (2).

Emanuel and Ekberg utilized a 25-ft steel-beam span that approximated a one-third scale model of a highway bridge span. The span, supported in various tests on curved steel sole plates and neoprene pads of 64 and 49 durometer hardness, was loaded by means of a counter-rotating eccentric weight oscillator at its center.

In general agreement with the theory developed by Zuk, Emanuel and Ekberg found the natural frequency of the model span to be lower when it was supported on elastomeric bearings, the softer bearings yielding the lower natural frequency. However, the difference between the experimental frequencies of the beam on the various bearings was always considerably less than that predicted by theory.

In both the analytical and model studies, maximum lower flange strain, that occurring at the respective natural frequencies, was less for the span on elastomeric bearings than on rigid bearings. This effect is shown graphically in Figure 1 (2, Fig. 1, p. 162), a plot of strain versus frequency for the 3 sets of bearings employed in the model study. The strain-frequency curves are similar in shape, but the curves for the elastomeric bearings are shifted to the left, which indicates the lower natural frequencies. The difference in maximum strain between the beam on steel bearings at its natural frequency and the beam on the 2 sets of elastomeric bearings at their natural frequencies is indicated by the relative ordinates of the peaks of the curves.

One point of contention existed between the analytical and model studies. Zuk's sample calculations indicated that deflections at the respective natural frequencies would be greater for the span supported on elastomeric bearings; however, the model study generally found the reverse to be true.

FULL-SCALE FIELD TESTS

Test Structures

The test structure, a typical highway bridge shown in Figure 2, was composed of a series of simply supported, rolled-beam composite spans, including 4 identical interior spans, two of which (spans 3 and 5) were chosen for instrumentation. The steel and

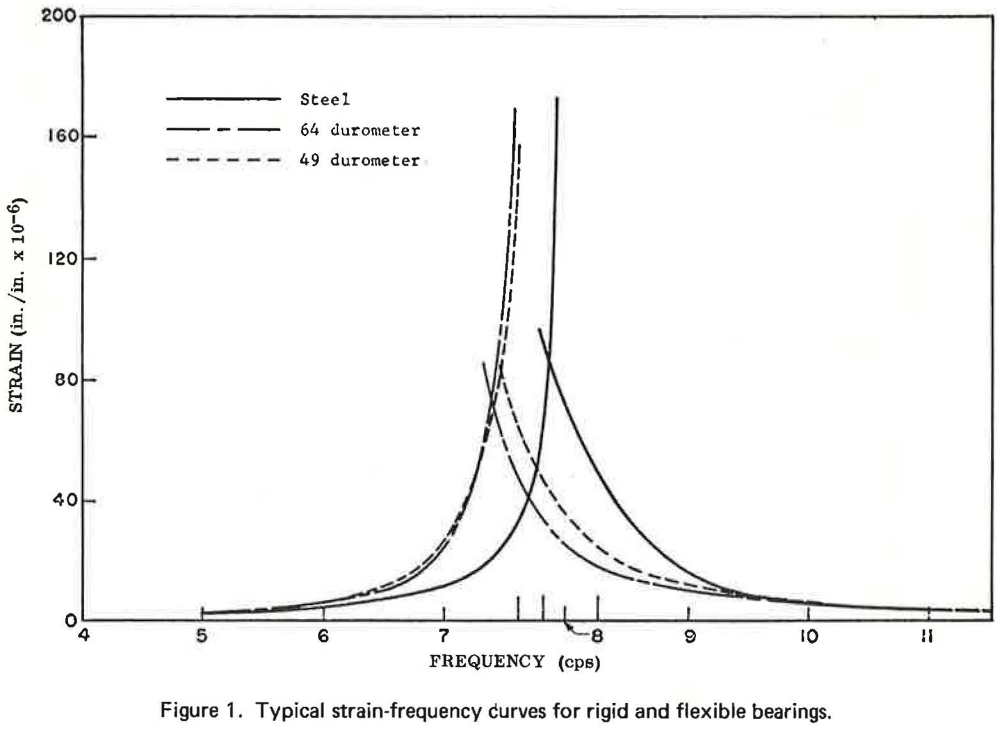


Figure 1. Typical strain-frequency curves for rigid and flexible bearings.

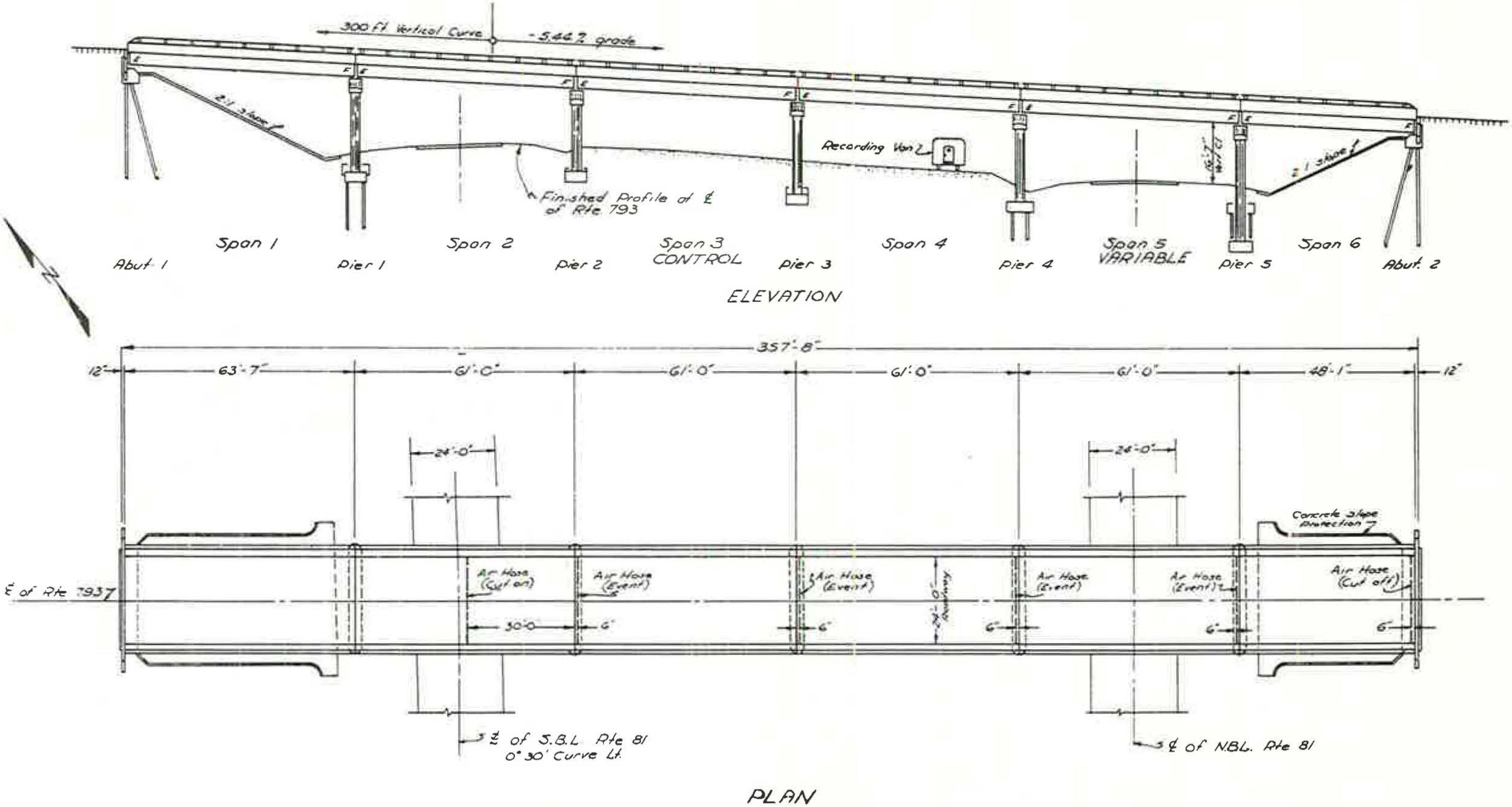


Figure 2. Plan and elevation of test structure indicating control and variable spans.

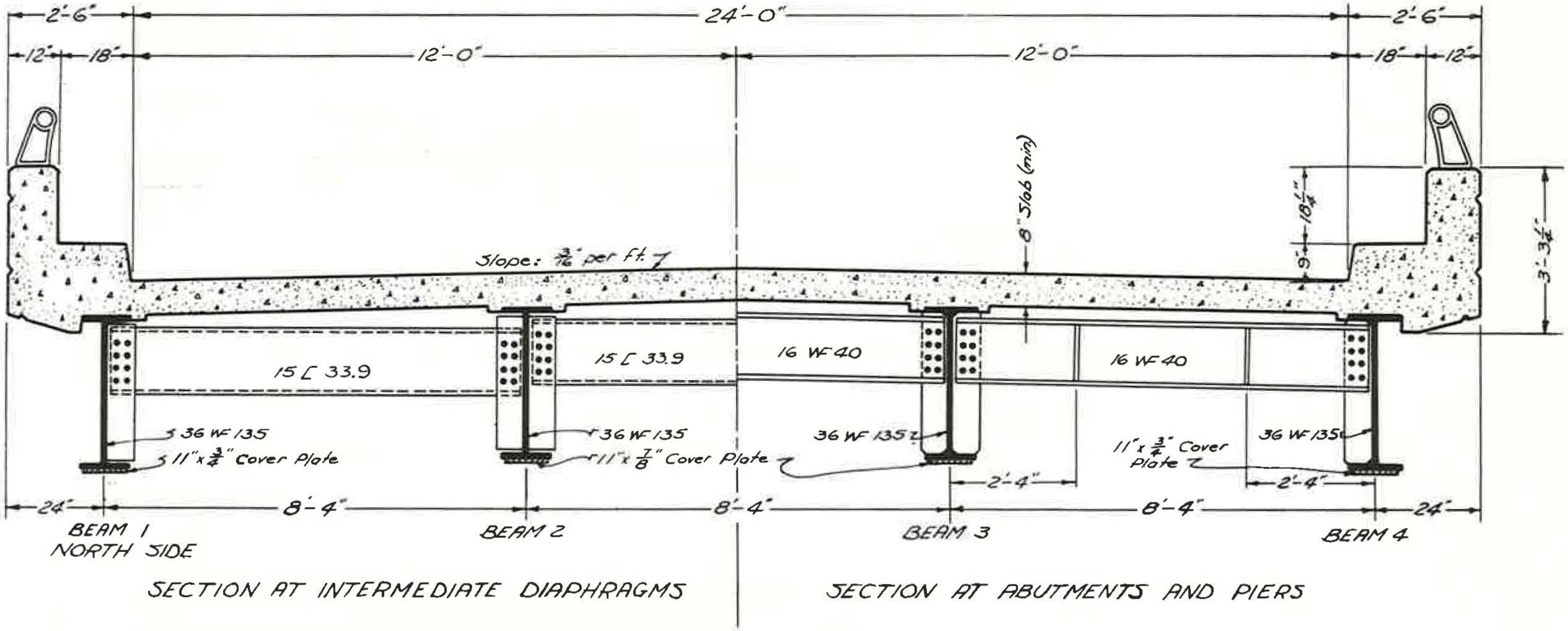
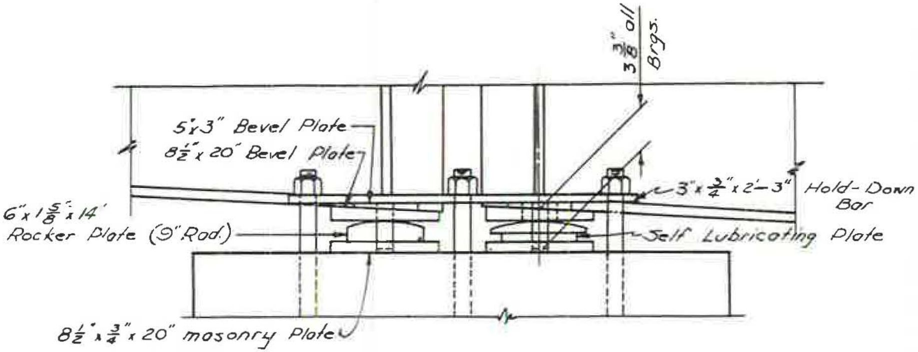


Figure 3. Typical transverse sections of test structure.

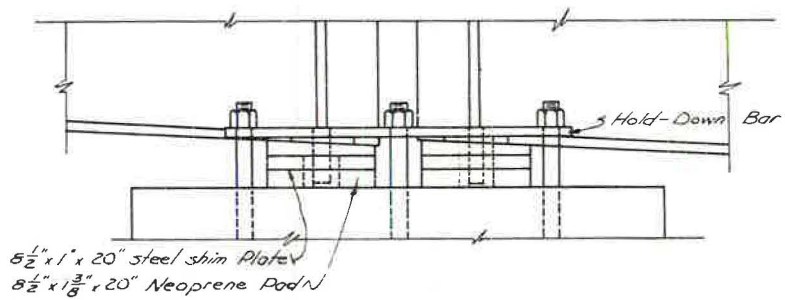


FIXED EXPANSION

STRUCTURAL STEEL BEARING

PROCEDURE FOR CHANGING BEARINGS

1. Remove anchor bolt nuts.
2. Jack span off bearings (1/4" max.)
3. Remove hold-down bars.
4. Remove masonry plates and rocker plates.
5. Insert neoprene pads and steel shims.
6. Align bearings and replace hold-down bars.
7. Release jacks and replace anchor bolt nuts.



NEOPRENE BEARINGS

Figure 4. Details of bearing assemblies with conventional steel bearings and original neoprene bearings and procedure for changing bearings.

elastomeric test bearings were interchanged on span 5, designated in Figure 2 as the variable span, while span 3, the control span, was supported on steel bearings throughout the study. The test spans had an identical cross section shown in Figure 3; stud shear connectors ensured composite action between the deck and the four W36 by 135 beams, which spanned 60 ft, center to center of bearings. The structure was designed for the HS20-44 standard loading in accordance with the AASHO 1961 Standard Specifications for Highway Bridges.

TABLE 1

DESIGN PROPERTIES OF TEST BEARINGS ON VARIABLE SPAN

Test Series	Type of Bearing	Approximate Shape Factor	Nominal Hardness
I	Elastomeric (bridge contractor)	1.7	70
II	Elastomeric	3.5	50
III	Elastomeric	8.4	50
IV	Elastomeric	3.5	70
V	Elastomeric	8.4	70
VI	Steel	–	–

Note: Steel bearings were used on control span for all test series.

A unique feature of the test structure was its specially designed bearing assemblies shown in Figure 4, which allowed the interchanging of steel rocker plates and elastomeric pads with a minimum of effort.

Bearing Details

The conventional steel bearings used on the control span throughout the tests and on the variable span during the final series of runs are also shown in Figure 4. These bearings allow for rotation of the end of the beam by means of the rockers and for expansion or contraction through sliding of the rocker plate on the self-lubricating plates in the expansion bearings.

In addition to the conventional bearings, 5 sets of neoprene pads were utilized in the field tests. The elastomeric bearings, of varying shape factors and hardnesses, included pads supplied by the bridge contractor according to the original design by the consulting engineer and 4 additional sets of bearings specially designed and fabricated for inclusion in the test program. The properties of the bearings for each of the 6 test series are given in Table 1.

The original elastomeric bearings supplied by the bridge contractor, series I, were solid neoprene rubber pads slotted to accommodate the studs on hold-down bars of the bearing assembly. Details of the pads are shown in Figure 5, and an average experimental compression-deflection curve based on static load tests of 2 pads is shown in Figure 6, as is the standard curve for a shape factor of 1.7 and a hardness of 70. In accordance with the findings of research cited previously, the experimental curve shown in Figure 6 indicates the full-sized pads to be 16 to 32 percent stiffer than the standard curve indicates them to be.

The bearings prepared specifically for the field tests, shown in Figure 7, are of a laminated construction and are smaller than the original neoprene bearings. Experimental compression-deflection curves based on laboratory static load tests of 1 bearing from each of the 4 groups, series II through V, are shown in Figure 8. In contrast to the theoretical effect of hardness, the 50-durometer pad with a shape factor of 8.4 appears stiffer than the corresponding 70-durometer pad. The cause of the discrepancy is impossible to explain with certainty, but it appears likely that the behavior of the sealing ribs that encompass the top and bottom of the pads might have affected the deflections in the single tests on which the curves are based.

Figure 5. Details of elastomeric bearings for test series I.

Instrumentation and Experimental Procedure

The instrumentation included (a) strain gages on the top and bottom faces of the lower flanges at midspan on all beams in the 2 test spans and (b)

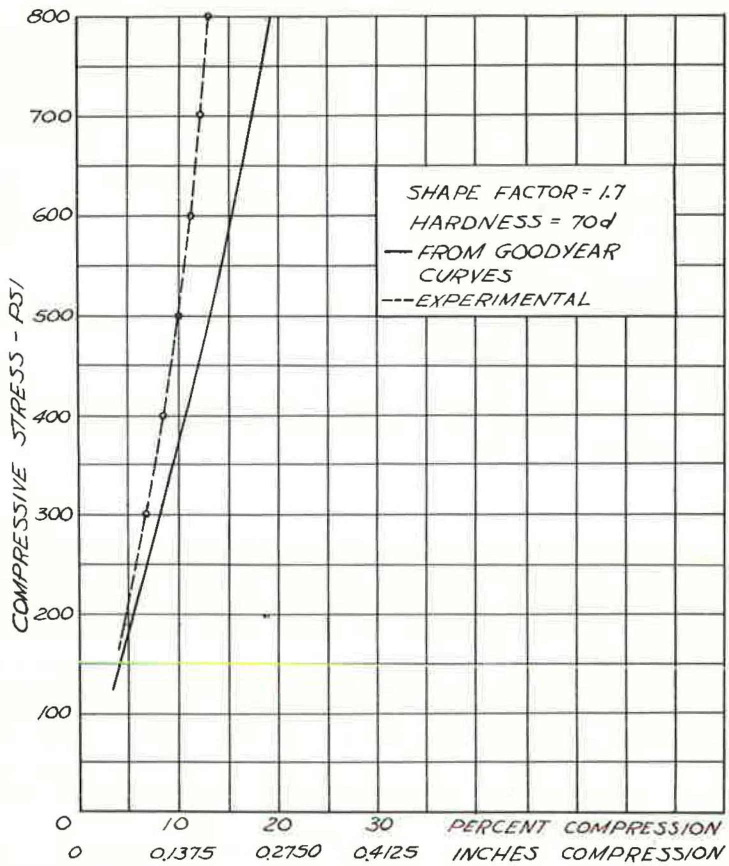


Figure 6. Experimental compression-deflection curve for original bearings and theoretical curve developed by interpolation from standard curves.

cantilever strip deflection gages, as shown in Figure 9, at the midpoint of all beams and over the bearings at both ends of the 2 interior beams on the variable span. The strain and deflection gages were connected to recording oscillographs that made a continuous trace of the gage outputs throughout the passage of the test vehicle.

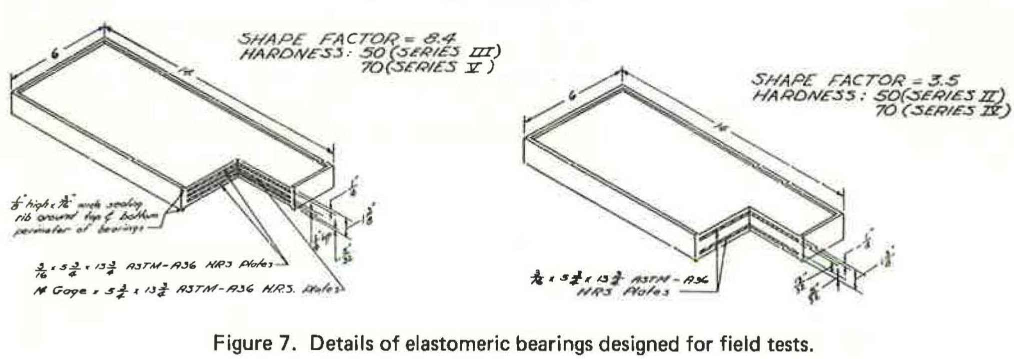


Figure 7. Details of elastomeric bearings designed for field tests.

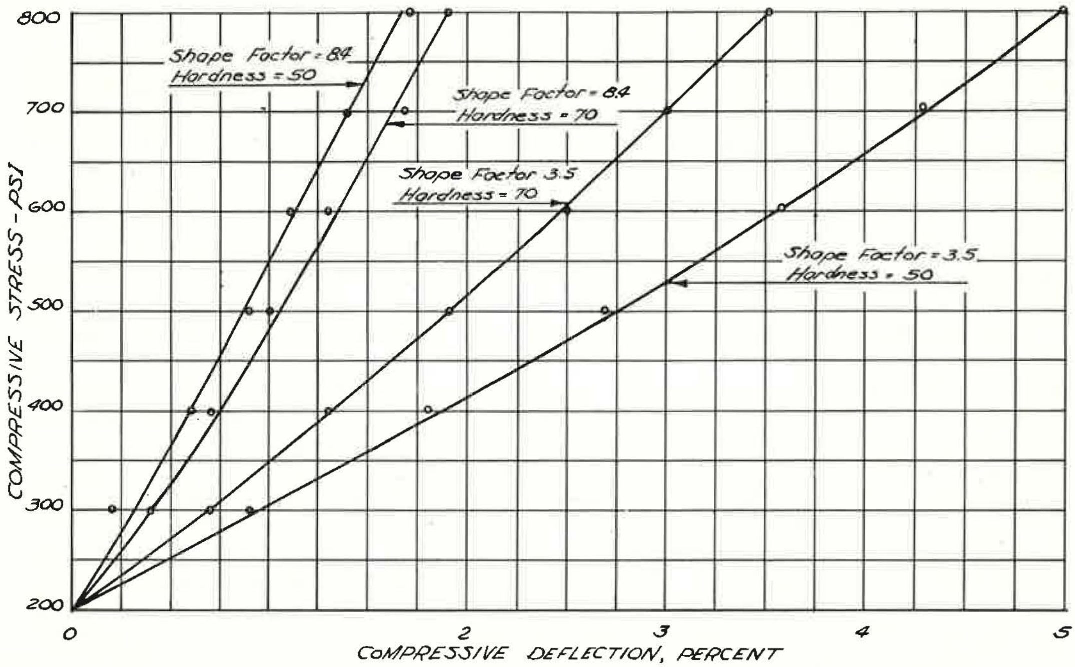


Figure 8. Experimental compression-deflection curves for bearings designed for field tests.

The test vehicle, a 3-axle diesel tractor semi-trailer loaded to closely simulate an AASHO HS20-44 standard truck, made runs in 3 lateral positions across the deck, in each of the 2 traffic lanes and directly on the centerline of the bridge roadway, at creep speed and at 10, 20, and 30 mph. Generally, time permitted only 2 repetitions of runs for each bearing type at each speed and position. The average measured speeds of the test vehicle were within 1 mph of the nominal speed in every case, and the average deviation of the test vehicle was less than 2 in. from the prescribed course in 75 percent of the runs.

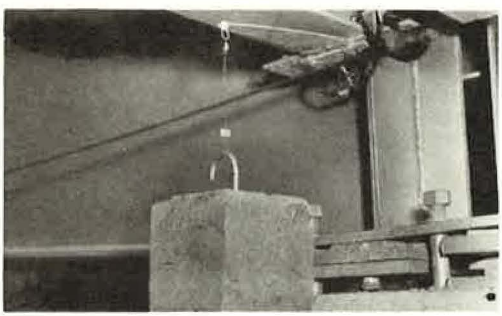


Figure 9. Typical deflection gage positioned on lower flange of diaphragm to measure bearing deflection.

DISCUSSION OF RESULTS

Nature of Results

A review of the results of this study must be made with a realization of the limitations inherent in the experimental procedure. Because of the rather extensive scope of the investigation, generally only 2 repetitions were made for each combination of vehicle speed and position and type of bearing; and the experimental results are sensitive to variations among individual runs. Accordingly, the analysis of the experimental results is generally qualitative in nature, and it is based on the identification of trends rather than on comparisons between individual values.

Deflections of Elastomeric Bearings

A cantilever strip deflection gage was mounted on the W16 by 40 end diaphragm of the bridge over each of the 2 interior bearings at both ends of the variable spans, as shown in Figure 9, with the arm extending toward the center of the structure. Thus, the gage measured deflections on only one side of the bearing from a position several inches above the bearing assembly, and some error due to distortion of the superstructure elements under load was inevitable. It is believed that an estimate of the error was provided by the data for the series VI tests at which time the variable span was supported on conventional bearings, and the average deflection recorded at the steel bearings during the series VI tests, 0.008 in., was subtracted from the recorded deflections of the elastomeric bearings.

The distribution of the live load reaction to the individual bearings was not determined experimentally. However, 2 distinct cases were studied analytically for the vehicle on the centerline of the bridge roadway: case A, which utilized a moment-distribution technique to determine the live load applied to the bearings; and case B, which was based on the portion of the live load carried by each stringer at midspan. The latter case is likely to be in error because of the increased transverse stiffness of the span at the bearings, but it presents a practical lower limit to the bearing reactions. Approximately 53 percent of the total reaction was distributed to each interior bearing in case A, with a corresponding uplift or negative reaction being indicated at the exterior bearings. The midspan lower flange stresses indicated that an average of 33.7 percent of the resisting moment was provided by beam 2 and 33.2 percent by beam 3, and the average of these values, 33.45 percent of the total reaction, was considered to be distributed to each interior beam in case B. The applied live load in either case is in addition to the computed dead load of 30.7 kips per bearing. The dead load and applied live load for both distributions and the corresponding compressive stresses are given for the test bearings in Table 2. The live load differs between the east and west bearings because site conditions allowed the heavy test vehicle to approach the bridge from only one direction.

Table 3 gives a comparison of the ranges and average values of the pad deflections recorded in the field test and the predicted values based on the experimental compression-deflection curves shown in Figures 6 and 8 and the standard curve shown in Figure 6. The data given in Table 3 indicate that, within the range of loading presented, the measured pad deflections are consistently smaller than predicted values based on the compression-deflection curves. The discrepancy between the field test deflections and those predicted by the standard curve is particularly great.

It appears reasonable that the discrepancy between the measured and predicted deflections might be due to the nature of the loading inasmuch as the dynamic modulus of rubber is invariably higher than the static modulus (3). Even at creep speed the load was applied fairly rapidly, and as each axle crossed the bearings and moved away an

TABLE 2

DEAD AND LIVE LOADS AND RESULTING COMPRESSIVE STRESSES IN ELASTOMERIC BEARINGS FOR VEHICLE ON CENTERLINE OF ROADWAY

Case	Nature of Loading	West Bearings (entry) Load (kips)	West Compressive Stress (psi) Series I	West Compressive Stress (psi) Series II Through V	East Bearings (exit) Load (kips)	East Compressive Stress (psi) Series I	East Compressive Stress (psi) Series II Through V
A	Dead load	30.7	190	365	30.7	190	365
	Live load	31.1	190	370	28.9	175	345
	Total	61.8	380	735	59.6	365	710
B	Dead load	30.7	190	365	30.7	190	365
	Live load	19.5	120	320	18.1	110	215
	Total	50.2	310	595	48.8	300	580

TABLE 3

COMPARISON OF ACTUAL AND PREDICTED DEFLECTIONS OF ELASTOMERIC BEARINGS

Test Series	Bearing	Experimental Deflections (in.)			Predicted Deflections (in.)			
					Case A Loading		Case B Loading	
		Measured Deflection Range	Corrected Deflection Range[a]	Corrected Average Deflection[a]	Experimental Curve	Standard Curve	Experimental Curve	Standard Curve
I	West	0.018 to 0.026	0.010 to 0.018	0.013	0.050	0.066	0.033	0.043
	East	0.018 to 0.019	0.010 to 0.011	0.011	0.045	0.060	0.030	0.038
II	West	0.014 to 0.024	0.006 to 0.016	0.013	0.030	0.065	0.020	0.041
	East	0.016 to 0.020	0.008 to 0.012	0.010	0.028	0.061	0.018	0.039
III	West	0.010 to 0.014	0.002 to 0.006	0.005	0.009	—[b]	0.006	—[b]
	East	0.012 to 0.014	0.004 to 0.006	0.005	0.009	—[b]	0.006	—[b]
IV	West	0.014 to 0.019	0.006 to 0.011	0.009	0.021	—[b]	0.013	—[b]
	East	0.015 to 0.018	0.007 to 0.010	0.009	0.019	—[b]	0.012	—[b]
V	West	0.010 to 0.012	0.002 to 0.004	0.003	0.010	—[b]	0.007	—[b]
	East	0.010 to 0.012	0.002 to 0.004	0.003	0.009	—[b]	0.006	—[b]

[a]Corrected deflection is measured value less estimated error of 0.008 in., the average deflection recorded during test series VI.
[b]Standard curves unavailable.

oscillating or cyclic loading resulted. In contrast, the compression-deflection curves were based on static tests in which the load was applied at an even rate. The error is compounded when the standard curves are used, because, as discussed previously, deflection showed by static tests of full-sized bearings at a given compressive stress are generally less than that predicted by the standard curves.

Figure 10 shows the average deflection recorded at the east and west bearings in the series II through V tests plotted against nominal vehicle speed for runs on the bridge centerline. The general relationship expressed by the standard curves, i.e., that compressive deflections decrease with increasing shape factor and hardness, is clearly verified.

Although the general relationship implicit in the standard curves has been verified, predicted live load deflections based on the curves have been consistently too high. However, because the design of elastomeric bearings is generally based on maximum allowable deflections, the error is conservative, and use of the readily available standard curves appears to be an acceptable practice.

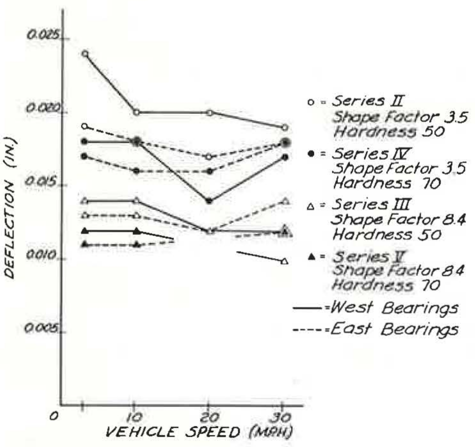


Figure 10. Average deflections for east and west bearings, test series II through V, position 2 runs, versus nominal speeds.

Vibration Characteristics of Supported Span

The fundamental natural frequencies of the 2 instrumented spans were determined experimentally from the gage traces after the test vehicle left the bridge. A comparison is given in Table 4 of the experimental frequencies and calculated values based on Zuk's work in the case of the span on elastomeric bearings and the following widely accepted equation for the span on steel bearings:

$$f = [\pi/(2L^2)]\ [(EI)/m]^{1/2}$$

where

L = length of the span;
EI = flexural rigidity of the span; and
m = mass of the span per unit length.

TABLE 4

SUMMARY OF AVERAGE EXPERIMENTAL AND THEORETICAL FREQUENCIES OF VIBRATION

Span	Test Series	Number of Values	Range of Values (cps)	Average Experimental Frequency (cps)	Theoretical Frequency (cps)
Variable	I	17	6.33 to 6.40	6.37	5.31
	II	48	6.17 to 6.29	6.23	5.36
	III	18	6.23 to 6.33	6.27	5.98
	IV	22	6.17 to 6.27	6.23	5.63
	V	20	6.17 to 6.30	6.21	5.96
	VI	3	6.25 to 6.29	6.28	6.35
Control	All	131	6.37 to 6.49	6.43	6.35

The agreement between the measured and computed frequencies of the variable and control spans supported on steel bearings can be considered good. However, the experimental values for the span on elastomeric bearings are not arranged in accordance with theory, and, except for the unexplainably high values in the series I tests, there is little difference in the frequency values associated with the various bearings. Emanuel and Ekberg, in their more closely controlled experiment, did verify the effect of flexible bearings in decreasing the natural frequency of the span, but their experimental values differed by considerably less than those predicted by theory (2). It, therefore, appears that the degree of the effect of flexible bearings on frequency predicted by the theoretical study might be in error, possibly because of the increased stiffness exhibited by the bearings under dynamic loading. The data given in Table 4 indicate at most a rather slight decrease in the natural frequency of the span due to the use of elastomeric bearings, and, in fact, the frequency could be computed with acceptable accuracy by means of the expression applied to the span on steel bearings.

Average logarithmic decrements of the oscillations of the instrumented spans, indicators of the rate of damping of the vibrations, were also obtained experimentally from gage traces showing a regular decay pattern. A comparison of the effect of the elastomeric bearings on the damping of vibrations was essentially precluded by a scarcity of data for the variable span supported on steel bearings; however, 2 conclusions were possible on the basis of the limited data. First, the difference in the logarithmic decrements obtained for the variable span on elastomeric bearings having a wide range of shape factors and hardnesses was insignificant in consideration of the wide range of experimental values obtained in each case. Second, the damping ratios for all series and both spans were quite low, less than 1 percent of critical damping in every instance, and the practical advantage in improved damping, if any exists, can probably be considered negligible.

A comparison of the maximum double amplitudes of stringer oscillations for the

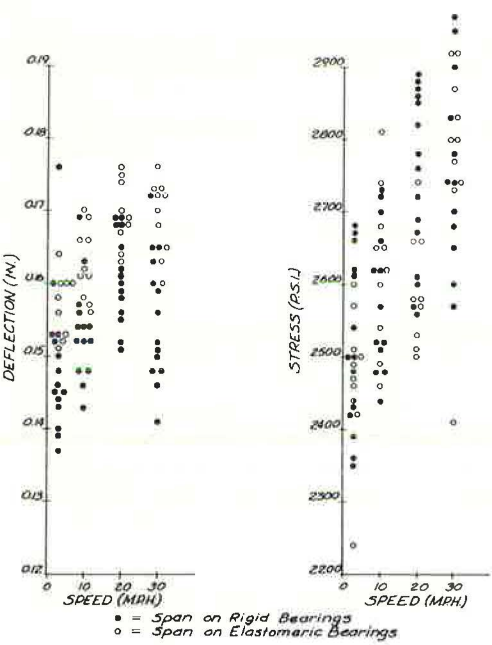


Figure 11. Peak midspan deflections and lower flange stresses in interior beams versus nominal speed for test vehicle on bridge centerline.

2 instrumented spans in each series and of the series VI results against those of the other series disclosed no consistent difference that could be attributed to the type of bearing. The experimental scatter typical of double amplitude data would have obscured minor effects of the bearings, but it is believed that variations of practical significance would have been apparent.

Dynamic Stress and Deflection Response of Supported Span

Figure 11 shows plots of midspan deflections and lower flange stresses in the 2 interior beams versus nominal speeds for the test vehicle crossing the instrumented spans on the centerline of the bridge roadway. The deflection data indicate a tendency toward greater deflections for the variable span on elastomeric bearings, but the effect of individual elastomeric bearings was obscured by experimental scatter. Because the moderate increase in deflections is not accompanied by greater stresses, it is believed to be caused by the action of the flexible bearings.

There was no consistent difference evident in the stresses in the beams of the variable and control spans that could be attributed to the type of bearing employed. Although the stress shows a general tendency to increase with increasing speed of the test vehicle, the difference in maximum flexural stress at resonance, indicated by the work of Zuk and verified by Emanuel and Ekberg, was not apparent under the realistic loading conditions employed in the field tests. The condition of resonance is difficult to define in the case of an initially oscillating mass on 3 axles, but it is believed that the amplification of response associated with resonance would not occur. It is, therefore, doubtful that an advantage in reduced stress would be gained through the use of elastomeric bearings under normal loading conditions.

Average live load impact factors based on the percentage increase in stress and deflection with respect to the values at creep speed exhibited no consistent variation that could be related to the nature of the bearings. Regardless of the nature of the bearings and throughout the range of speeds, the experimental impact percentages of the most heavily loaded beams were lower than the design impact factor of 27 percent (calculated in accordance with the AASHO Specifications for Highway Bridges) in all but one passage of the test vehicle. The experimental impact percentage consistently exceeded the AASHO value only in the case of the lightly loaded beams farthest from the test vehicle, for which the effect was insignificant. Most of the values obtained for the 2 beams directly under the test vehicle were less than 20 percent.

CONCLUSIONS

The experimental results of the subject field tests represent the response of a rather complex structure to loading by an elaborate dynamic system with numerous degrees of freedom. The conclusions are thus qualitative in nature, and they are applicable primarily to the structure and test vehicle utilized in the investigation and to the response at a limited range of speeds. It is believed, however, that the results are indicative of the effects of a realistic loading on an actual highway bridge span.

1. The general relationship indicated by the standard curves, that compressive deflections decrease with increasing shape factor and hardness, is apparent under both static and dynamic loading.
2. Static compression-deflection tests of elastomeric pads having a relatively wide range of shape factors and hardnesses indicated that the stiffness exhibited by full-sized bridge bearings is greater than that indicated by the standard design curves.
3. The dynamic compressive deflections of elastomeric bearings caused by a rapidly applied oscillating live load, not including the effects of dynamic creep, are consistently smaller than the values predicted by either experimental or standard curves based on static tests. The discrepancy in the case of the standard curves is particularly great. However, because the design of elastomeric bearings is based on maximum allowable deflections, the error inherent in the use of the standard curves is conservative.
4. Elastomeric bearings tend to reduce the natural frequency of vibration of the supported span, but the effect of the bearings is slight. The natural frequency can be

predicted with acceptable accuracy by expressions commonly applied to spans on rigid bearings.

5. The damping of vibrations in a span on elastomeric bearings is not affected to a significant degree by pad characteristics including a wide range of practical shape factors and hardnesses.

6. Although a complete comparison of the damping of vibrations in a span on elastomeric and rigid bearings was precluded by a scarcity of data, the damping ratios for both spans on all types of bearings were low, less than 1 percent of critical damping in every case. It appears likely that any increased damping due to the use of elastomeric bearings would be of little practical advantage.

7. The nature of the bearings has no significant effect on the magnitude of the maximum amplitude of oscillation.

8. Beam deflections may be moderately increased by the use of elastomeric bearings under normal loading conditions. Because the increased deflections are not accompanied by higher stresses, the trend is attributed to the effect of the bearings.

9. It is doubtful that an advantage in reduced stresses will be gained through the use of elastomeric bearings under normal loading conditions. It is perhaps also important to note that no disadvantages in increased stress are apparent in the use of elastomeric bearings.

10. The nature of the bearings, either rigid or elastomeric, has no apparent effect on the impact percentage with respect to either stress or deflection.

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REFERENCES

1. Zuk, W. Bridge Vibrations as Influenced by Elastomeric Bearings. HRB Bull. 315, 1962, pp. 27-34.
2. Emanuel, J. H., and Ekberg, C. E., Jr. Problems of Bridge Supporting and Expansion Devices and an Experimental Comparison of the Dynamic Behavior of Rigid and Elastomeric Bearings. Iowa Eng. Exp. Station, special rept., 1965.
3. Handbook of Molded and Extruded Rubber. Goodyear Tire and Rubber Co., 1949.
4. Design of Neoprene Bridge Bearing Pads. E. I. duPont de Nemours & Co., 1959.
5. Pare, R. L., and Keiner, E. P. Elastomeric Bridge Bearings. HRB Bull. 242, 1960, pp. 1-19.
6. Clark, E. F., and Moultrop, K. Load-Deformation Characteristics of Elastomeric Bearing Pads. Highway Research Record 34, 1963, pp. 40-116.
7. Aldridge, W. W., and Sestak, J. J., Jr. Tests on Five Elastomeric Bridge Bearing Materials. Highway Research Record 253, 1968, pp. 72-83.