COMPARISON OF BRIDGE STRESS HISTORY RESULTS WITH DESIGN-RELATED ANALYSES

David W. Goodpasture and Edwin G. Burdette, University of Tennessee

Six bridges at three bridge sites located near a weigh station were investigated with respect to the stress ranges caused by normal traffic. The summation of these stress ranges for each bridge is presented, and comparisons are made with calculated stresses. The main objective of the stress comparisons is to introduce a workable method for the design engineer to use in predicting probable maximum and "typical" girder stresses due to normal traffic. Two AASHO design vehicles are considered in the analysis, and the stress resulting from this load, considering equal distribution of the moment to each girder, was shown to exceed almost all stress ranges measured in the field. One-half of this stress compares favorably with a significant number of stress ranges encountered on the most highly stressed girder. This type of analysis is intended to furnish a method for enabling the design engineer to utilize the results of the many stress history research efforts currently in progress or recently completed. The results presented are for particular bridges and should not be used generally until additional verification is obtained by using the stress history results of other researchers.

•DURING the past few years, the behavior of actual highway bridges subjected to truck traffic has been under investigation. In particular, the loading or stress history of bridges has been of interest with the ultimate goal of providing the bridge design engineer with a workable method to use in designing bridges relative to their fatigue strength or life. During the past 3 years, a stress and loading history study has been in progress at the University of Tennessee under a contract with the Tennessee Department of Transportation, Bureau of Highways, in cooperation with the Federal Highway Administration. This paper is based primarily on a portion of the results of that research project. The main objective of the research project was the collection and correlation of large amounts of strain and vehicle weight data so that the stress history and loading history of the bridges considered could be determined. Only the stress history portion of the data will be used here. A brief description of the bridges and testing procedure follows.

Six bridges at three locations were included in the investigation, and a brief description of these bridges is given in Table 1. A more complete description of the bridges may be found elsewhere (1). These bridges were chosen because they are representative of a large number of bridges in use today and because of their proximity to a weigh station on the Interstate System. The steel bridge serves as a control for comparison to other stress and loading history studies, whereas the reinforced concrete bridges were chosen to expand our knowledge in an area relatively untouched by other stress history researchers.

The data collection system consisted of a minicomputer with a magnetic tape unit, teletype, multiplexer interface, and strain gauge conditioning and amplification units, all housed in an office trailer. The trailer was moved to each bridge site for the col-

Sponsored by Committee on Dynamics and Field Testing of Bridges.

lection of data. The strain caused by the passage of a truck was digitized at a rate of 300 samples/sec/gauge, and the data were stored on magnetic tape. These strains were reduced to stress ranges of a later time, which enabled two types of stress range history to be considered. First, only the maximum stress range per truck was considered, and, second, all stress ranges above 1,000 psi were considered. Tables 2, 3, and 4 give the results obtained.

Inspection of the A and B columns in each of the three tables reveals very little difference above a stress level of 2,000 psi. In fact, only in three cases do the two columns differ at all for stresses greater than 3,000 psi. This result is in agreement with the comparison reported by Galambos and Heins (2). Galambos and Heins reported that at the 95 percent confidence level there was no significant difference in the means of the two sets of data above 3,000 psi. Their two sets of data correspond to columns A and B in the tables. The t-test was also used in the present study for each girder for stresses greater than 2,000 psi. As a result of these statistical tests, it may be concluded that at the 95 percent confidence level there was no significant difference between columns A and B. A word of caution is in order, however, because both statistical analyses were performed on small sets of data.

Consider girder W-3 in Table 4 where a large number of vehicles caused numerous stress ranges even at the higher stress levels. The discrepancy between columns A and B at the lower stress ranges is much larger than for the other girders. Therefore, as more data are accumulated over longer periods of time, the difference in the methods of stress range measurement may be significant at the medium stress ranges. Whether this is an academic question will have to await the results of laboratory fatigue tests where low stress ranges are being used to learn whether there is a measurable fatigue limit for steel. If the fatigue limit, if one exists, is established near 3,000 psi, then stress ranges below that level need not be considered, and any difference in the methods of determining stress ranges below that level is not important.

ESTIMATION OF EXPECTED STRESS RANGE

Because the program of stress measurement in highway bridges necessarily includes only a minute percentage of the total number of bridges in use, a method to predict analytically the maximum stresses to which a given bridge may be subjected would be most useful. Such a method would, ideally, be characterized by two attributes: It would predict, with "reasonable accuracy," both the maximum stress range and a more "typical" stress range that the bridge could be expected to experience; and it would be easy to apply.

It should be emphasized here that this paper makes no claim of having developed a method that precisely meets these criteria. The development of an analytical method was not included in the scope of the research project from which this paper has evolved. However, an attempt was made to predict, approximately, the stresses that the study bridges might be expected to experience. The method used and the results obtained are described in the following paragraphs.

Loading

The AASHO HS20 loading with one truck in each traffic lane was used to calculate the maximum moment at midspan for each bridge.

Moment Calculation

The bending moment at midspan was calculated from statics for the simple span steel bridge (bridge 1). The STRUDL II subset of the ICES program was used to calculate midspan bending moments for the three-span continuous, reinforced concrete beam bridges (bridges 2 and 3). The spans were divided into several segments with different moments of inertia to account for the nonprismatic cross section due to the beam haunches. The moment of inertia for each section was computed on the basis of an uncracked section, and the entire bridge cross section, including curbs, was considered.

Stress Calculation

Stresses at midspan were calculated for all three bridges on the basis of a uniform lateral distribution of the applied loads. This assumption is not considered unreasonable for the prediction of maximum stress, which occurs under the condition of one truck in each lane. For the case of only one truck on a bridge, however, the only justification that can be made for this assumption is its simplicity.

As suggested in the previous paragraph, two stresses were calculated for each bridge: first, the maximum expected stress due to one truck in each traffic lane and, second, a "typical" stress due to one truck on the bridge taken to be one-half of the maximum expected stress. The moment of inertia used in each stress calculation was that obtained on the basis of the entire bridge cross section at midspan, including curbs. A cracked section was assumed in the calculation of stress in the reinforced concrete bridges.

Results

The expected stress levels, calculated as described, are as follows:

Bridge Site	Maximum Expected Stress (psi)	"Typical" Stress (psi)
1	3,980	1,990
2 (eastbound)	4,560	2,280
3	3,700	1,850

The calculated stress levels are shown on the stress range histograms (Figs. 1, 2, and 3). These histograms were obtained from the data given in Tables 2, 3, and 4, considering only the maximum stress range for each truck.

Discussion

The results shown in Figures 1, 2, and 3 suggest the following observation: Using the relatively simple analytical approach described previously makes it possible to predict with "reasonable" accuracy (a) the approximate maximum stress range that a bridge may be expected to experience a significant number of times during its life and (b) the stress range that may be thought of as an approximate "average" for the stresses produced by loaded trucks crossing the bridge.

The preceding observation is particularly well supported by data shown in Figure 3 for bridge 3. There were a few stress ranges higher than the predicted maximum; however, the percentage of occurrences of these higher stress ranges was insignificant. The results shown in Figures 1 and 2 for bridges 1 and 2 indicate that the calculated maximum stress range was somewhat higher than the highest stress range recorded in the field. However, the calculated maximum stress is "in the ballpark"; that is, it does provide a reasonable, conservative prediction of the maximum expected stress range.

The reason for the somewhat higher observed stresses in bridge 3 is not entirely clear. One factor that might provide a partial explanation is that each bridge at site 3 is located at the bottom of a sag vertical curve. This could lead to higher stresses in the bridge girders because the dynamic impact factor would tend to be higher and there would be a greater likelihood that two heavily loaded trucks might be on the bridge at the same time. The fact that bridge 3 was 40 ft curb to curb, as opposed to 30 ft for the other bridges, could also be a factor, inasmuch as the lateral distribution of load would be affected by the roadway width and girder spacing.

The "typical" stress calculated for all three bridges fitted, reasonably well, the stress history data shown in Figures 1, 2, and 3. In each case, the calculated stress range gave a reasonable indication of the stress range, high enough to be of interest from the viewpoint of fatigue damage, that could be expected to occur under the action of a relatively high percentage of trucks.

Figure 1. Percentage of occurrences versus stress range at bridge site 1 (both bridges).

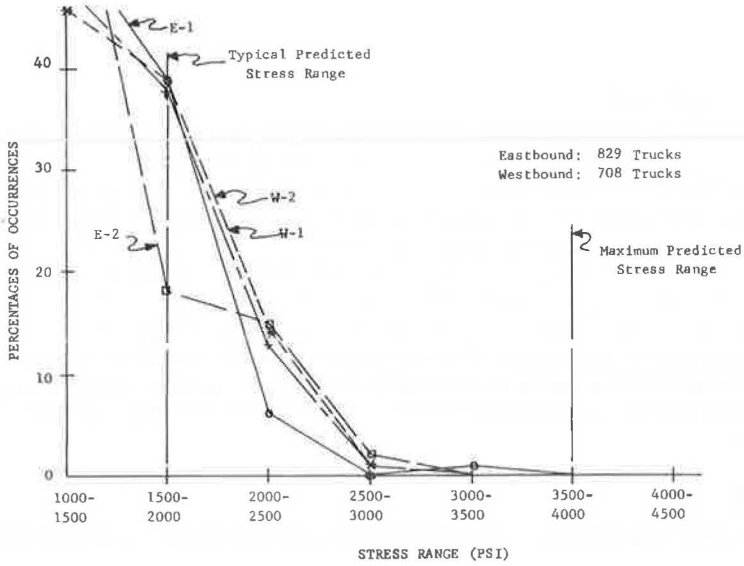

Figure 2. Percentage of occurrences versus stress range at bridge site 2 (eastbound).

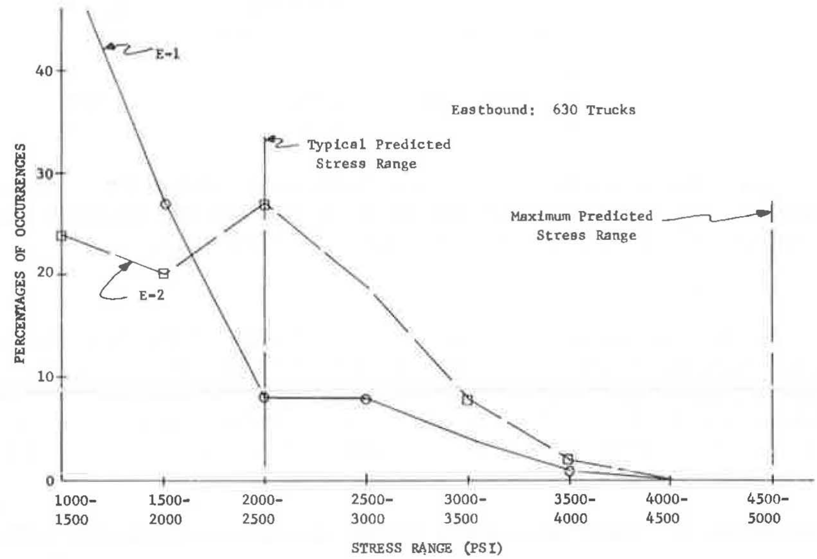

Figure 3. Percentage of occurrences versus stress range at bridge site 3 (both bridges).

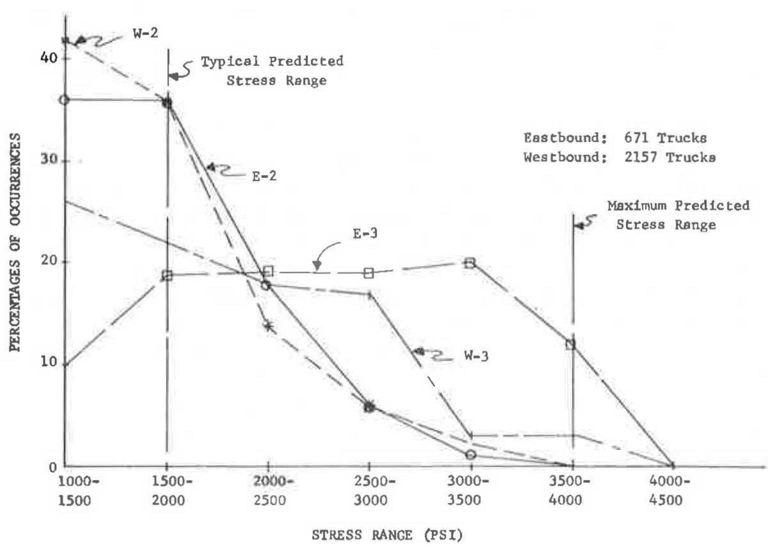

Table 1. Description of bridges.

Bridge No.	Direction	General Description	Span (ft)	Girder Spacing (ft, in.)	Skew (deg)	Location
1	E and W	Simple span steel girders with composite concrete deck, five W 36 × 170 girders with partial length cover plates	70	7 0	70	I-40 over Tenn-95
2	E	Three-span continuous, reinforced concrete deck girder, four girders	47, 66, 47	8 10	75	I-40 and I-75 over Everett Road
	W	Three-span continuous, reinforced concrete deck girder, five girders	58, 72, 58	6 8	75	
3	E and W	Three-span continuous, reinforced concrete deck girder, five girders	41, 60, 41	9 2	60	I-40 and I-75 over Campbell Station Road

Table 2. Stress ranges for bridge site 1.

Stress Range Level (psi)	Girder E-1		Girder E-2		Girder W-1		Girder W-2	
	A	B	A	B	A	B	A	B
1,000 to 1,500	270	367	280	307	196	355	206	265
1,500 to 2,000	196	206	78	82	157	184	176	186
2,000 to 2,500	29	30	64	64	52	54	62	63
2,500 to 3,000	1	1	7	7	5	5	3	3
3,000 to 3,500	3	3	1	1	1	1	0	0
3,500 to 4,000	1	1	—	—	—	—	1	1
Total	500	608	430	461	411	599	448	518

Note: A = one stress range per truck; B = all stress ranges > 1,000 psi. Number of trucks eastbound was 829; westbound, 708.

Table 3. Stress ranges for bridge site 2.

Stress Range Level (psi)	Girder E-1		Girder E-2		Girder W-2		Girder W-3	
	A	B	A	B	A	B	A	B
1,000 to 1,500	196	295	96	261	153	594	180	451
1,500 to 2,000	103	114	82	121	143	220	147	182
2,000 to 2,500	31	35	110	120	95	107	77	80
2,500 to 3,000	31	32	79	80	48	50	14	14
3,000 to 3,500	17	19	31	34	15	15	3	3
3,500 to 4,000	2	2	10	10	0	0	—	—
4,000 to 4,500	—	—	—	—	1	1	—	—
Total	380	497	408	626	455	987	421	730

Note: Number of trucks eastbound was 630; westbound, 623.

Table 4. Stress ranges for bridge site 3.

Stress Range Level (psi)	Girder E-2		Girder E-3		Girder W-2		Girder W-3	
	A	B	A	B	A	B	A	B
1,000 to 1,500	171	204	58	340	527	653	475	819
1,500 to 2,000	160	164	101	151	454	471	400	471
2,000 to 2,500	81	81	101	111	176	185	315	337
2,500 to 3,000	24	24	106	108	71	73	313	326
3,000 to 3,500	4	4	109	109	19	19	232	244
3,500 to 4,000	—	—	64	64	6	6	51	52
4,000 to 4,500	—	—	6	6	2	2	15	15
4,500 to 5,000	—	—	1	1	—	—	5	5
5,000 to 5,500	—	—	—	—	—	—	3	3
5,500 to 6,000	—	—	—	—	—	—	4	4
Total	440	477	546	890	1,255	1,409	1,813	2,276

Note: Number of trucks eastbound was 671; westbound, 2,157.

CONCLUSIONS

The stress history study that formed the basis of this paper was a part of a continuing national effort to extend the state of existing knowledge relative to the fatigue life of bridges designed under existing specifications. Some of the results of this study are given in Tables 2, 3, and 4. These results agree very well with similar published results from other studies. As noted earlier, this study supports the observation (2) that, for stress ranges above approximately 3,000 psi, it makes little difference in the data whether one stress range per truck is considered or all stress ranges caused by each truck are considered.

As more stress history data are accumulated, effort must be directed toward relating these data to bridge design. For example, it would be most helpful if a bridge designer could calculate, with at least approximate accuracy, the maximum stress range that a bridge might be expected to experience a "significant" number of times during its life. It would be of further help if the designer could decide, on the basis of available information, whether the predicted stress range would be "acceptable" from the viewpoint of expected fatigue life.

The stress calculations described in this paper represent at least a tentative step toward the prediction of the maximum stress range referred to earlier. The method presented needs considerable refinement, a task that requires not only additional computational effort but also additional field test data for comparison purposes. If one then moves beyond the problem of stress range prediction to the question of "acceptability" of the predicted stress range, a gap in existing knowledge becomes evident. Needed to fill this gap are more laboratory data on high-cycle, variable stress range fatigue. Thus, it would appear to be desirable in the future to broaden the scope of research on stress history to include specific efforts to relate research results to bridge design.

ACKNOWLEDGMENTS

Appreciation is expressed to the Tennessee Department of Transportation, Bureau of Highways, for assistance in the performance of the research studies described. The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data. The contents do not necessarily reflect the official views or policies of the state of Tennessee or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

REFERENCES

1. Goodpasture, D. W. Final Report on Stress History of Highway Bridges. Dept. of Civil Engineering, Univ. of Tennessee, 1972.
2. Galambos, C. F., and Heins, C. P., Jr. Loading History of Highway Bridges: Comparison of Stress Range Histograms. Highway Research Record 354, 1971, pp. 1-12.