PREDICTION OF BRIDGE GIRDER STRESS HISTOGRAMS FROM TRUCK TYPE DISTRIBUTION

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Stress history studies are conducted so that bridge girder stresses due to various types of truck loadings can be predicted. Being able to predict these stresses obviates having to measure them for every bridge. This paper presents a seven-step procedure for using stress history data to predict stress in bridge girders. Stress data for 3,120 trucks identified by type and lane location and weight data from 3,865 trucks identified by type were obtained. A comparison between the stresses and weights showed that there were notable similarities in the shapes of the two distributions. The ability to simulate or predict stresses based on truck type, lane location, and weight distribution will eliminate the need for complicated and costly field measurement of stresses.

•DURING the last several years the Federal Highway Administration has actively encouraged and supported a program of data collection and analysis related to the determination of the stress history of highway bridges. Results of a number of investigations conducted as a part of this program have been reported (1 through 5).

The objective of the stress history program may be stated as follows: Given a distribution of major truck types (obtained by visual count or projection) and a distribution of truck weights for each major truck type (obtained from state weight data), predict, on the basis of calculated girder stresses under the action of each major truck type, the stress histogram for each girder in a bridge. From this stress histogram and a knowledge of the fatigue characteristics of the girder (which is currently incomplete), the fatigue life of a member or bridge may be predicted.

This paper presents a logical and practical approach to achieving the objectives of the stress history program, applies this approach to predict girder stress histograms for a particular bridge, and compares these results to field strain data.

Once the stress histograms obtained from strain data can be approximately duplicated by prediction based on truck weight distribution data, a significant step has been taken toward the accomplishment of the ultimate objective of the stress history program.

APPLICATION OF STRESS HISTORY DATA

Girder strain data and truck weight data are used to predict the stress histograms for the girders in a bridge. The bridge for which strain data are presented is the westbound roadway of Interstates 40 and 75 over Twenty-Second Street in Knoxville, Tennessee. Truck traffic over this bridge averages 250 to 300 trucks per hour. The bridge is a simple span, composite steel girder bridge with a 62-ft (19-m) span, and it has seven longitudinal girders.

The proposed method, as it is applied later to the bridge described above, is outlined in the following paragraphs in step-by-step fashion. It is assumed, as a starting point, that a multigirder bridge exists for which facilities are available to obtain strain data, truck traffic data, and truck weight data as needed.

1. Obtain a stress histogram for each girder in the bridge for each major truck type traveling in each traffic lane. To ensure that the histograms are statistically meaningful requires that strain measurements for a relatively large number of trucks of

each type in each lane be obtained.

2. Obtain weight histograms for each major truck type. Again, weights for a relatively large number of each truck type should be obtained.

3. Correlate the stress and weight histograms obtained in steps 1 and 2. This is obviously a key step that requires judgment not only in the choice of statistical methodology but also in the interpretation of the results for the particular bridge. For example, the stress histogram for the extreme left girder for a particular truck type in the extreme right lane may bear little resemblance to the weight histogram for that truck type because a lightly loaded truck may not cause stresses high enough to be included in the stress histogram. After the completion of step 3, the stress histogram for a particular girder can be predicted for a known distribution of major truck types in the different traffic lanes.

4. Determine the percentage of each major truck type traveling in each traffic lane.

5. For a known distribution of truck types on the bridge, predict the stress histogram for each girder. Compare results with field data.

6. Relate measured stress in a girder due to a truck of known type and weight in a particular traffic lane to computed stress in the girder under similar conditions. This step also is a key one. The analytical method chosen should be both easy to use and reasonably accurate. This paper offers no guidelines with regard to step 6.

7. Finally, for a known distribution of truck types, predict the stress histogram for each girder on the basis of the calculated stress in the girder.

The remainder of this paper describes the application of steps 1 through 5 to the bridge described earlier.

DATA COLLECTION

To achieve the objectives of this study requires much information about the stresses caused by different types of trucks in different lanes and the distribution of weights of different types of trucks. The collection of the data used in this report is described in the same sequence as the steps outlined above.

Stress Histogram According to Truck Type and Lane Location (Step 1)

For 2 weeks, a total of 11 tests were conducted on a single bridge. All strain gauges were located on the bottom surface of the bottom flange at the center of the span. Truck type and lane location were noted for each truck, and the strains in the seven girders of the bridge were recorded after they were digitized at a rate of 240 samples per second per gauge. Approximately 3½ sec of data were recorded for each truck passage. Particular care was taken to ensure that the truck type and lane location could be related to the corresponding strain record. A total of 3,120 trucks were observed during the tests. After the data were recorded on the digital magnetic tape, a computer program was used to scan the strain range caused by the passage of that vehicle. The strain range was converted to a stress range and printed on the teletype for each truck. The type of truck and lane location were then written on the computer output sheet, and any inconsistencies were resolved. No multiple crossings were included in these data. A description of the equipment and computer program used has been published by Goodpasture (1).

Weights of Trucks (Step 2)

A weight station for trucks on Interstates 40 and 75 is located approximately 10 miles (16 km) from the bridge site used for this study. The weight station is operated by the Tennessee Department of Revenue. Because there were numerous interchanges between

the bridge site and the weigh station, the trucks that had actually caused the recorded strains could not be weighed. Therefore, 3,865 trucks were weighed during three time periods: May 1972, December 1972, and June 1973. The weights were obtained by the use of three scales connected to a printer at the weigh station. The front steering axle of the truck was weighed on the first scale, the drive axle weight was obtained on the second scale, and the trailer axles were weighed on the third scale. The printer recorded each scale weight and summed the three scales for the gross vehicle weight. Only gross vehicle weights were used.

Truck Type, Lane Location, and Stress Data (Steps 4 and 5)

A second computer program was written to collect data and reduce them in terms of strain ranges in real time. This program is very similar to the program used by the FHWA during the early stress history studies. The main difference between the FHWA program and the University of Tennessee program is that no data are lost during the testing period with the UT program. Intermediate results are written on magnetic tape each 15 min during the test. The time required for recording the data is less than 1 sec, which, therefore, does not interfere with the test in progress. After the test is completed, the results are read from the tape and printed by the computer at any convenient time. These results form the field data mentioned in step 5.

The type and lane location of all trucks crossing the bridge are noted in 15-min intervals corresponding to the strain data. Multiple crossings are also noted on the data sheet. This information forms the basis of the information required in step 4.

ANALYSIS OF RESULTS

Traffic Characteristics

The traffic mix varies throughout the day, but distinctions can be made between day and night. The day data contain a high percentage of local delivery trucks; large tractor trailers are the dominant truck traffic at night.

Table 1 gives the distribution of truck type by lane. Note that during the day approximately 50 percent of the trucks are single-unit types 2D, 3, and 4. However, at night approximately 20 percent of the trucks are single-unit types. Total truck traffic volume is essentially the same for 1973 and 1974 during the day. The number of type 3S2 trucks each hour changes slightly during the 24-hour period. Earlier tests (1) indicated, however, that a significant number of 3S2 trucks pass over the bridge every hour of the day.

Table 2 gives the types and lane locations of the trucks used in step 1. The objective was to record data on approximately 300 trucks per lane. This was achieved for truck types 2D and 3S2, but only one-half that number was recorded for types 3 and 2S2. It appears highly unlikely that the required number of truck types 4 and 2S1 can be recorded within a reasonable test length. Several test periods were chosen during July 1974 in which strains from only truck types 3, 4, 2S1, and 2S2 were recorded. These tests lasted from 6 to 8 hours during the day, and fewer than 300 of all these types combined were noted.

Stress Distribution

The maximum stress ranges for types 2D and 3S2 trucks are given in Table 3. Table 3 was constructed by noting the maximum stress range in each of the seven girders and recording that range by the lane location of the truck. The maximum observable stresses occur in the girders centered underneath the lane in which the vehicle is operated. The distributions are skewed to the right and then are skewed to the left as the vehicle moves from the left lane to the right lane. The type of data shown in Table 3

Table 1. Truck type and lane distribution.

Date	Time	Truck Type	Lane Left	Lane Middle	Lane Right	Total Number	Total Percent
August 1973	9:15 a.m. to noon	2D	58	128	110	296	38.6
		3	15	62	37	114	14.9
		4	0	3	3	6	0.8
		2S1	8	3	3	14	1.8
		2S2	16	33	22	71	9.3
		3S2	113	65	83	261	34.1
		Others	1	3	0	4	0.5
		Total				766	
July 1974	9:00 a.m. to noon	2D	59	116	139	314	39.3
		3	18	21	33	72	9.0
		4	0	0	3	3	0.4
		2S1	8	4	4	16	2.0
		2S2	24	21	23	68	8.5
		3S2	147	77	97	321	40.2
		Others	2	1	2	5	0.6
		Total				799	
	8:00 p.m. to midnight	2D	26	34	27	87	16.7
		3	5	8	10	23	4.4
		4	0	0	0	0	0
		2S1	4	7	0	11	2.1
		2S2	20	25	12	57	10.9
		3S2	126	121	96	343	65.7
		Others	0	0	1	1	0.2
		Total				522	

Table 2. Trucks included in study.

Truck Type	Lane Left	Lane Middle	Lane Right	Truck Type	Lane Left	Lane Middle	Lane Right
2D	271	360	318	2S2	161	189	119
3	139	178	160	3S2	381	361	300
4	11	13	17	Others	8	9	8
2S1	30	41	46				

is required for all truck types for step 1.

Weight Distribution (Step 2)

The distribution of the gross weight for six truck types is given in Table 4. These weights were obtained during the three sampling periods. Again, the large number of truck types 2D and 3S2 is evident. The weight interval is the same for all types of trucks in order to simplify the presentation of the data. However, different weight intervals were used for each truck type in order to correlate these data with those from step 1. The weight distribution for type 3S2 trucks is definitely bimodal, and a large number of trucks were at the maximum legal loading. The weight distribution for type 3S2 trucks is shown as a histogram in Figure 1. Single-unit trucks such as type 2D do not exhibit the bimodal distribution so clearly.

Correlation Between Stresses and Truck Weights (Step 3)

Although extensive data were collected regarding vehicle weight distribution and stress range for all commercial vehicles on the road, only type 3S2 vehicles are discussed here. One method of exhibiting the stress range data is to pool all values for all seven girders and ignore lane position. The result of these pooled data is shown in Figure 2.

Table 3. Stress ranges for 2D and 3S2 trucks by lane.

Trucks			Stress Range	Lane						
Type	No.	Lane	(ksi)		Left		Middle		Right	
2D	271	Left	0.50 to 0.75	53	85	91	17	1	3	0
			0.75 to 1.00	24	65	55	3	2	1	
			1.00 to 1.25	8	30	17				
			1.25 to 1.50		19	16				
			1.50 to 1.75		13	6				
			1.75 to 2.00		8					
			2.00 to 2.25		3					
			2.25 to 2.50		1					
	360	Middle	0.50 to 0.75	2	36	104	118	73	10	1
			0.75 to 1.00		1	49	48	55		
			1.00 to 1.25		1	34	34	37		
			1.25 to 1.50			10	28	27		
			1.50 to 1.75			2	26	8		
			1.75 to 2.00			0	27	3		
			2.00 to 2.25			1	16	1		
			2.25 to 2.50				5			
			2.50 to 3.00				1			
	318	Right	0.50 to 0.75	0	3	1	12	90	138	43
			0.75 to 1.00					29	48	10
			1.00 to 1.25					13	23	2
			1.25 to 1.50					3	10	
			1.50 to 1.75					1	4	
			1.75 to 2.00						1	
			2.00 to 2.25						1	
3S2	381	Left	0.50 to 0.75	103	0	23	137	27	16	7
			0.75 to 1.00	104	44	100	79	3	1	
			1.00 to 1.25	102	94	73	11			
			1.25 to 1.50	32	56	52	1			
			1.50 to 1.75	16	42	44				
			1.75 to 2.00	6	42	47				
			2.00 to 2.25	1	36	29				
			2.25 to 2.50	2	31	4				
			2.50 to 2.75		18	0				
			2.75 to 3.00		5	1				
			3.00 to 3.25		0					
			3.25 to 3.50		0					
			3.50 to 3.75		0					
			3.75 to 4.00		1					
	361	Middle	0.50 to 0.75	36	132	82	4	57	118	24
			0.75 to 1.00	2	25	90	44	69	23	
			1.00 to 1.25			94	48	54	0	
			1.25 to 1.50			50	38	36	0	
			1.50 to 1.75			16	32	72	1	
			1.75 to 2.00			4	40	34		
			2.00 to 2.25				65	14		
			2.25 to 2.50				38	5		
			2.50 to 2.75				17	2		
			2.75 to 3.00				3	0		
			3.00 to 3.25				3	0		
			3.25 to 3.50				2	1		
	300	Right	0.50 to 0.75	0	6	20	95	22	4	75
			0.75 to 1.00				20	61	30	60
			1.00 to 1.25				7	32	53	47
			1.25 to 1.50				2	35	30	31
			1.50 to 1.75					37	20	7
			1.75 to 2.00					23	29	4
			2.00 to 2.25					12	38	1
			2.25 to 2.50					4	21	
			2.50 to 2.75					0	6	
			2.75 to 3.00					2	2	
			3.00 to 3.25					0	1	
			3.25 to 3.50					1	0	
			3.50 to 3.75						2	

Note: 1 ksi = 6.9 MPa.

Table 4. Weight distribution of each truck type.

Weight (kips)	Truck Type 2D	3	4	2S1	2S2	3S2	Other
0 to 3	3	0	0	0	0	0	0
3 to 6	13	0	0	0	0	0	0
6 to 9	79	0	0	0	0	2	0
9 to 12	134	2	0	1	4	0	0
12 to 15	133	23	0	3	3	0	1
15 to 18	96	16	0	3	1	2	0
18 to 21	61	12	0	10	13	0	0
21 to 24	74	12	0	9	36	16	0
24 to 27	36	6	0	43	71	104	2
27 to 30	6	13	0	15	69	336	3
30 to 33	4	11	0	29	62	174	0
33 to 36	2	5	0	18	44	95	1
36 to 39	6	9	1	11	35	70	0
39 to 42	1	12	0	7	60	60	0
42 to 45	0	9	0	5	38	64	2
45 to 48	0	0	3	1	55	79	1
48 to 51	0	4	2	0	24	96	1
51 to 54	0	0	2	0	20	101	2
54 to 57	0	0	0	0	9	91	0
57 to 60	0	2	3	0	9	104	0
60 to 63	0	8	3	0	5	150	0
63 to 66	0	2	0	0	0	139	2
66 to 69	0	0	0	0	0	177	1
69 to 72	0	0	0	0	0	285	2
72 to 75	1	0	0	0	0	160	0
75 to 78	0	0	2	0	0	6	0
78 to 81	0	0	0	0	0	6	1
>81	0	0	0	0	0	4	1
Total	649	146	16	155	558	2,321	20

Note: 1 kip = 450 kg.

Figure 1. Weight distribution of 3S2 trucks.

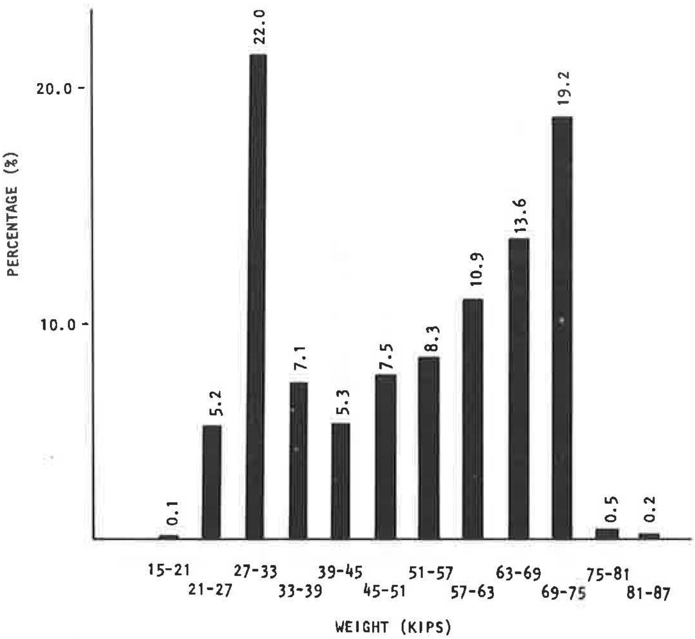


Figure 2. Pooled stress distribution from all girders for 3S2 trucks.

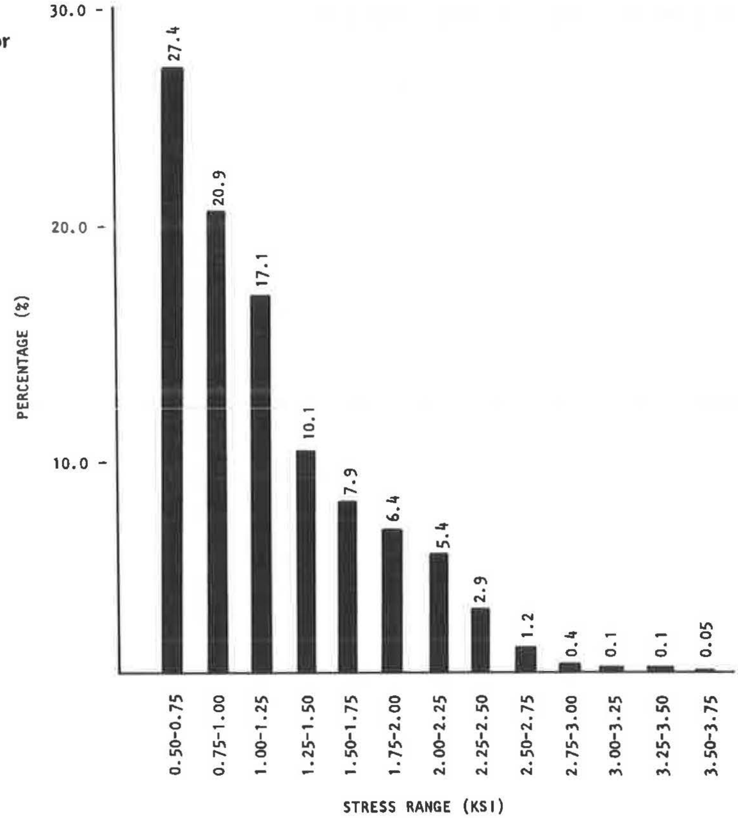
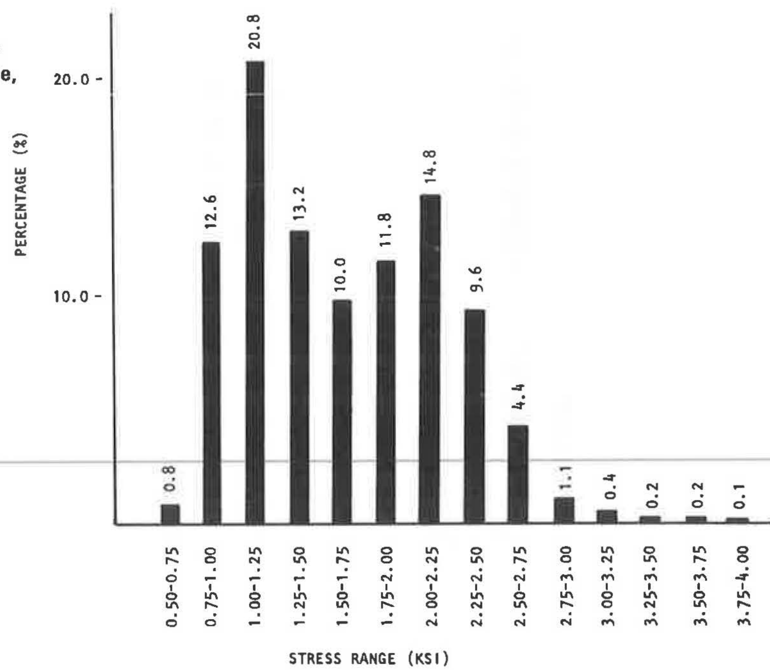


Figure 3. Pooled stress distribution for principal load-carrying girders in right, middle, and left lanes.



It is obvious that this distribution is of the general form of a decaying exponential, and there appears to be little specific relationship between this pool distribution and the distribution of vehicle weights shown in Figure 1.

To further define the stress ranges observed on the bridge as a function of 3S2 vehicles, we generated the histogram shown in Figure 3. This figure presents the distribution of maximum stress ranges observed in the girder centered under the lane used by the vehicle. Thus, for each vehicle there is one specific stress range value that contributed to the makeup of this figure.

Note that the distribution in Figure 3, although by no means identical to the weight distribution for 3S2 vehicles (Figure 1), has a somewhat similar shape. It would appear that this distribution is bimodal in nature, as was the weight distribution. However, the development of the stress range intervals for these data greatly influences the apparent shape of the distribution. Furthermore, it is possible that some of the unusually high stress ranges observed in this distribution are the consequence of either noise in the instrumentation or interaction between the natural frequency of the vehicle suspension and that of the bridge.

To understand the nature of these data, we summed the stress ranges in the two girders adjacent to the girder directly under the path of the vehicle. The resulting distribution is shown in Figure 4.

A comparison of the distributions shown in Figures 3 and 4 indicates that the stress ranges in the girders adjacent to the principal load-carrying girders are indeed less than the stress ranges in the principal load-carrying girders themselves. The shape of the distribution in Figure 4 is similar to the shape shown in Figure 2, i.e., the negative exponential form. To determine the precise nature of the distribution in Figure 4 would require larger sample sizes than were used.

So far, a direct correlation between the stress ranges and the weights has not been developed. The data obtained thus far do indicate that a positive correlation between truck weight and stress range is possible, but it is very sensitive to the stress range and weight intervals chosen.

Another possible method of correlation is a direct correlation between the sum of all girder stresses and the weight of the vehicle operating on the bridge at that time, independent of the position of the vehicle on the read. This, of course, assumes that the bridge cross section is essentially uniform relative to girder size and deck thickness. When this correlation is studied, the stress ranges for all seven girders will be added for each vehicle. These sums will then be compared to the gross weight data for the particular type of truck. Preliminary results indicate that this relationship is a straightforward one.

Field Data for Steps 4 and 5

During the July 1974 tests, stress histograms for the bridge under study were obtained as described earlier. One of these tests contains data taken during a 4-hour period. The types of trucks observed and their lane location are the night data given in Table 1.

Although, as indicated earlier, the correlation between weights and stress ranges has not been fully developed, a prediction of the stress histogram based on the measured stress ranges is possible. In fact, if the stress histogram cannot be approximated by superposition of measured stresses, then there is little hope that the truck weights can be used even after correlation with the stress ranges.

A comparison of measured stress ranges and predicted stress ranges was made for the principal load-carrying girder for each lane. Table 5 gives the values used for the comparison. Stress ranges of less than 1,000 psi (6900 kPa) were neglected because only one stress range per truck is considered in predicting the histogram, whereas all stress ranges are considered in the continuous sampling program described earlier. In addition, it is doubtful that stress ranges of less than 1,000 psi (6900 kPa) have any effect on the fatigue lives of the girders. An additional source of difference is the fact that 41 multiple crossings were recorded during the 4-hour period. In other words, there were two trucks on the bridge at one time a total of 41 times during the test.

Figure 4. Pooled stress distribution for girder adjacent to principal load-carrying girders.

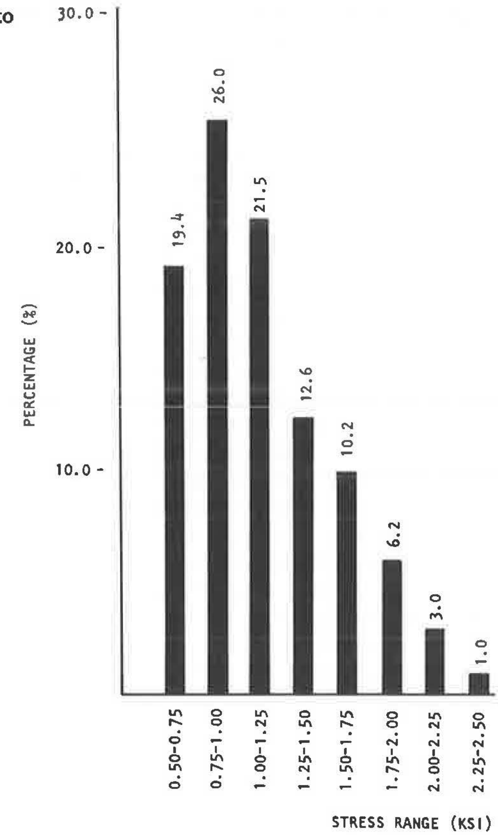


Table 5. Comparison of measured and predicted stress ranges.

	Lane							
	Left		Middle		Right		Total	
Item	Measured	Predicted[a]	Measured	Predicted[a]	Measured	Predicted[a]	Measured	Predicted[a]
Stress range, ksi								
1.00 to 1.25	42	39.7	40	24.8	27	20.9	109	85.4
1.26 to 1.50	26	25.2	16	20.8	13	11.2	55	57.1
1.51 to 1.75	17	17.4	20	16.6	13	7.1	50	41.2
1.76 to 2.00	13	15.3	12	17.5	21	9.7	46	42.4
2.01 to 2.25	15	12.3	19	24.3	15	12.4	49	48.9
2.26 to 2.50	16	10.6	27	13.8	11	6.7	54	31.1
2.51 to 2.75	9	6.0	14	6.1	2	1.9	25	14.0
2.76 to 3.00	8	1.7	3	1.2	1	0.6	12	3.5
3.01 to 3.25	4	0	2	1.0	0	0.3	6	1.4
3.26 to 3.50	1	0	1	0.7	0	0.0	2	0.7
>3.51	0	0.3	1	0	0	0.6	1	0.9
Truck type								
2D	26		34		27		87	
2S2	20		25		12		57	
3S2	126		121		96		343	
Others	9		15		11		35	
Total							522	

Note: 1 ksi = 6.9 MPa.

[a]Neglecting trucks classified as others, i.e., 7 percent of the total.

The agreement between the measured and predicted stress ranges is remarkably good in view of the approximations used. First, only 2D, 2S2, and 3S2 trucks were considered for the predicted values; other types (7 percent) were neglected. For the left, middle, and right lanes, 161, 189, and 119 2S2 trucks were used. As mentioned earlier, 300 trucks per lane was considered the minimum number for meaningful results. This example indicates clearly that the methods described herein have been justified and that work in this direction should continue.

CONCLUSIONS

The seven steps outlined for using truck type and weight data to predict the stress histogram for a given bridge and subsequently the fatigue life of the bridge girders are merely a first step. After these steps have been completed for a number of bridges in the nationwide stress history study, it is expected that a somewhat more direct approach will evolve that will be useful to the bridge designer. There is much potential in the method outline, but more data are required before a satisfactory solution can be achieved. Therefore, one of the main objectives of this paper was to present a methodology and invite comments, suggestions, and criticism as applicable.

Many data related to truck type, lane position, and resulting stress range were presented. Analyses of the shapes of the stress range and weight distributions were made for type 3S2 trucks. There is a relationship between stress range and weight as expected, but the exact form of the correlation has not yet been identified.

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