To the Graduate Council:

I am submitting herewith a thesis written by Peyabutr Sagooleim entitled "Statistical Aspects of a Stress History of Highway Bridges." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Civil Engineering.

David W. Goodpasture
Major Professor

We have read this thesis
and recommend its acceptance:

Charles R. Walker

Edwin G. Burdette

Accepted for the Council:

Hilton A. Smith
Vice Chancellor
Graduate Studies and Research

STATISTICAL ASPECTS OF A STRESS HISTORY OF HIGHWAY BRIDGES

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Peyabutr Sagooleim

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ABSTRACT

The purpose of this study was to establish a mathematical expression for stress ranges and corresponding frequencies on a highway bridge caused by present day truck traffic.

Two highway bridges, part of the interstate system, were selected and properly instrumented for the collection of data. A Raytheon 703 computer with magnetic tape unit, housed in a trailer, was used for the collection of field data which were stored on magnetic tapes. Data concerning the classification of trucks were taken at the bridge site and at a nearby weigh station. Weights of trucks were also obtained at the weigh station. Four methods of data collection were used in collecting stress range data. The most severely stressed girder from each bridge was selected for the study. The stress range data for the girders were plotted on Weibull Probability Paper. Mathematical expressions for stress range distributions were then derived for each bridge.

It was found that the distributions were bimodal. Comparisons were made between observed and theoretical distributions. Interpretations of theoretical stress range distributions caused by all trucks were made. Further research was suggested to investigate a mathematical expression for truck gross weight distribution and to find the relationship of variables in the mathematical expressions between stress range and weight distributions.

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CHAPTER I

INTRODUCTION AND SCOPE

1. INTRODUCTION

In late 1970 fatigue cracking was observed in Connecticut on a steel girder bridge where complete fracture of a tension flange was generated from fatigue crack growth at the toe of a transversely welded cover plate.[1]* This particular bridge was only 14 years old. Subsequently, inspection of the other 15 cover plate ends of this bridge revealed that the two beams adjacent to the cracked member were also cracked through one-half the flange thickness. Smaller fatigue cracks were detected at several other cover plate ends. Also, investigations of the reasons for the catastrophic collapse during December 1967 of the Silver Bridge in Ohio and West Virginia have shown that fatigue induced by the repeated loading due to heavy vehicles may have been the most significant factor.[2]

Occasionally failures of bridges have occured, but they were attributed to inexperienced or faulty work during construction. Today,

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*Superscript numbers in parentheses refer to similarly numbered entries in the List of References.

however, more care is exercised for minor factors affecting the response, the economy, and safety of structures; therefore, fatigue problems must be given more and more consideration.

In an attempt to develop basic knowledge relative to prediction of probable lives of highway bridges, the Federal Highway Administration (FHWA) has funded, both directly and indirectly, several studies of the stress and loading histories of highway bridges throughout the United States. Due to complexity of the structure, dynamic effects and other variations, only field tests on properly instrumented structures subjected to actual loading conditions give an accurate description of the stresses caused by truck loads. Large numbers of stress ranges need to be recorded together with the types and weights of trucks, and this laborious work could not be efficiently performed without the development of suitable instrumentation and equipment. In several studies a computer system has been utilized to record changes of strain on different girders while a truck was crossing a bridge. In order to be able to describe stress ranges occurring on a bridge due to a type of truck loading, a mathematical formulation of stress ranges and corresponding frequencies appears desirable.

2. OBJECTIVE

For a stress history study of a bridge, it is required that a "typical" relationship between stress ranges and corresponding frequencies

on a girder be determined in order to give a good estimate of fatigue cycles of the girder due to normal traffic. According to a statistical analysis, the "typical" relationship usually refers to a distribution of mean stress ranges caused by "population" of trucks. The term "population" usually refers to an infinite number of samples. Normally, once a "typical" relationship is established, a mathematical expression for the relationship can be derived. Thus, the objective of this study was to establish a mathematical expression of stress ranges and corresponding frequencies on a bridge caused by present day truck traffic.

3. SCOPE

In an attempt to establish the "typical" relationship, two steel girder bridges in Knoxville, Tennessee, were instrumented with strain gages in order to measure the stress responses at various points when traffic was crossing the decks. The bridges carried eastbound and westbound traffic of Interstates 40 and 75. Each bridge was sampled separately except in two cases when both bridges were sampled at the same time. Two methods of data collection were used. One was called individual sampling, and the other was called continuous sampling. In each method two types of tests were performed. One was the sampling of a particular type of truck of interest; the other was a sampling of all trucks crossing the bridges. Sample periods were selected from different hours

of the day and night so that a combination of these different periods would result in a situation which could be considered as representative of a longer period of time. Traffic characteristics were recorded such as truck types and lane usage at the bridge site and truck types and weights at the weigh stations located nearby.

According to the data obtained at the bridge site and at the weigh station, 3S2 truck traffic, trucks with a 3-axle tractor pulling a 2-axle semi-trailer, was assumed to represent all truck traffic. The first part of the study was focused on combining all stress ranges on a highway bridge. The second part was focused on selecting the most severely stressed location on each of the bridges for the study. Stress range distributions of the selected locations were reduced into percentage and cumulative percentage values. A distribution from each bridge was chosen for estimating a "typical" distribution for each bridge. A bimodal Weibull distribution was assumed for stress range distributions of both bridges. Finally, mathematical expressions of stress range distributions for each bridge were derived from the plotting of cumulative frequencies versus corresponding stress ranges on Weibull Probability Papers (WPP). An attempt was made to establish mean stress ranges of 3S2 trucks for each bridge.

The study was limited to interpretation of the field test results and to correlation of the knowledge obtained from similarly conducted field

tests elsewhere. The comparison between results and existing data of stress range distributions caused by 3S2 trucks or all truck traffic show good agreement.

CHAPTER II

BACKGROUND

1. REVIEW

The Federal Highway Administration has been promoting the stress history program during the past several years. The program is guided by committees of the American Society of Civil Engineers and the Highway Research Board. For purposes of correlating research data, a standard truck classification was used in the program. Trucks were classified by the number of axles as shown in Figure 1.

Minnesota

The study was done by the University of Minnesota, Civil Engineering and Mineral Department.[2] The bridge had three continuous spans with steel girders and a concrete deck. The tested span length was 61 feet. The bridge was divided into two lanes carrying traffic of 18,099 vehicles per day of which 15.38 percent were truck traffic. Only 25.7 percent of the truck traffic were type 3S2 at the bridge site. However, 3S2 truck gross weights were found to dominate truck gross weight distrubution at 50 kips and higher. The distribution of 3S2 truck gross weights was bimodal as shown in Figure 2. Data of the relationship between stress range events caused by all truck traffic and 3S2 traffic were not available.

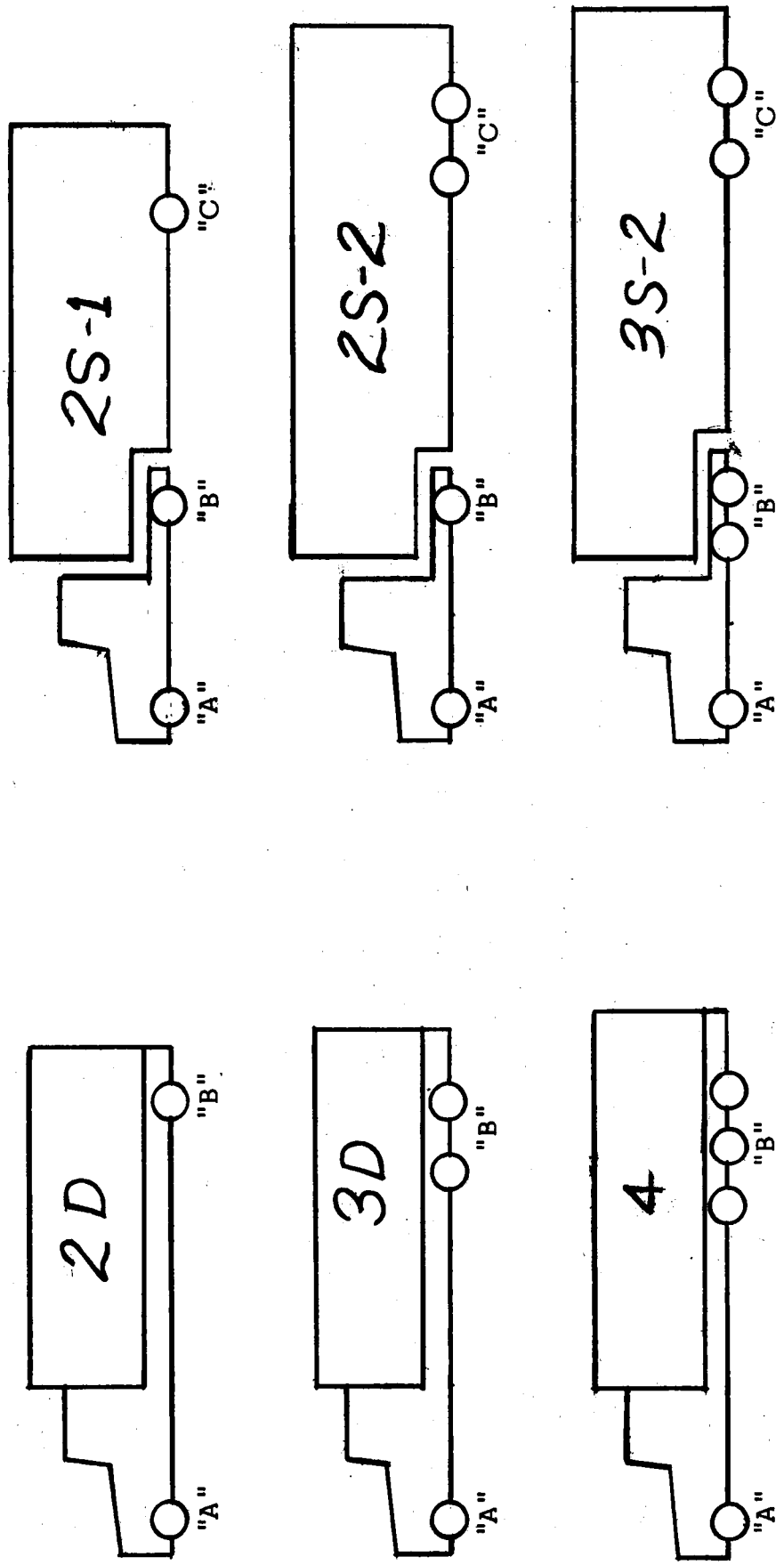


Figure 1. Axle type designations.

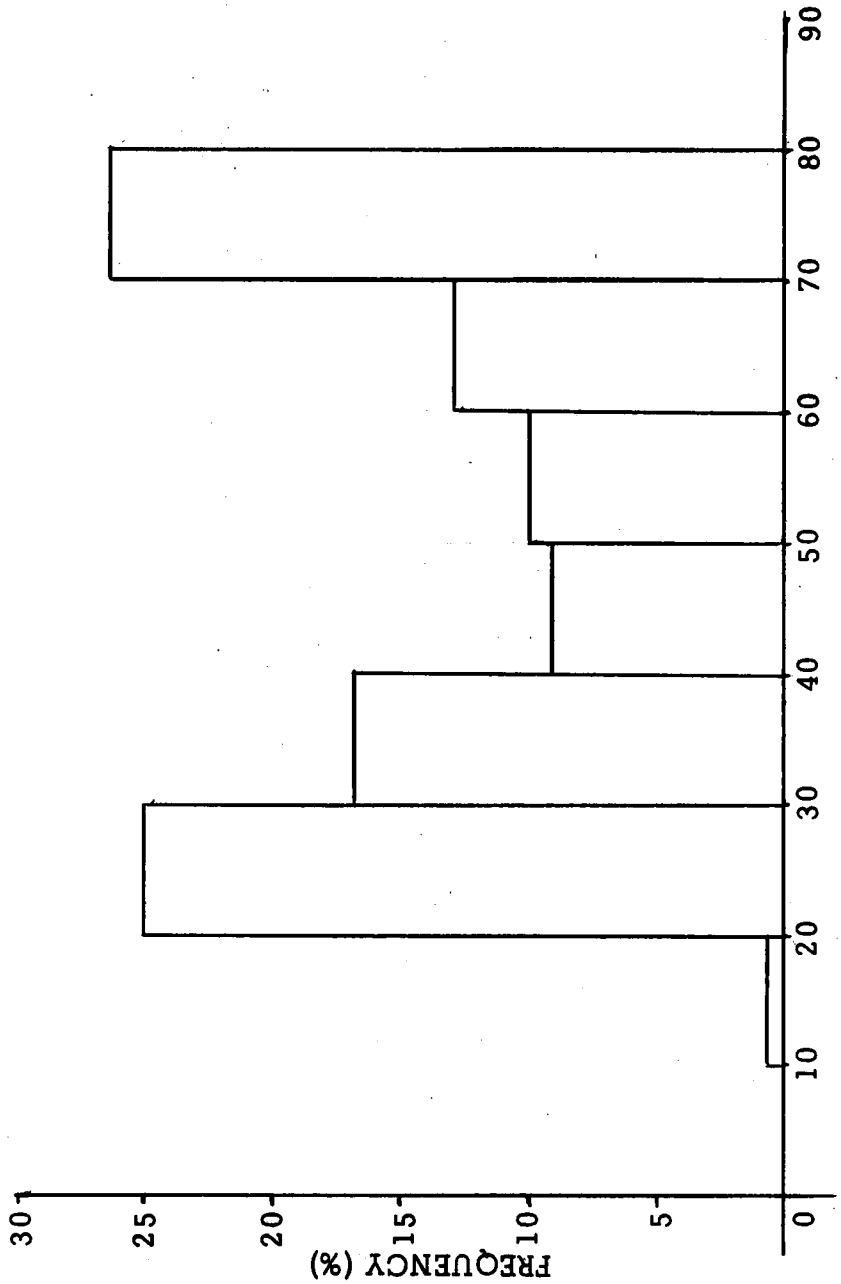


Figure 2. Weight distribution at Minnesota stress history research.

One of the conclusions stated was that the number of stress range events at the end of the cover plate at the most severely stressed member was approximately one-fourth that produced at the middle span of the same member.

Alabama

The University of Alabama, Civil Engineering Department conducted research on three steel bridges with concrete decks.[3] One of the bridges used for the study was a continuous span bridge with a span length of 80.5 feet. The remaining two bridges were simple spans having span lengths of 80 feet and 50 feet. All of the bridges were 4 lane, divided highways carrying 5,000 to 7,500 vehicles per day including 750 to 1,000 trucks other than panels and pickups in each direction. Approximately 40 percent of truck traffic on the bridges were 3S2 trucks. It was unfortunate that the truck gross weight distributions were not available.

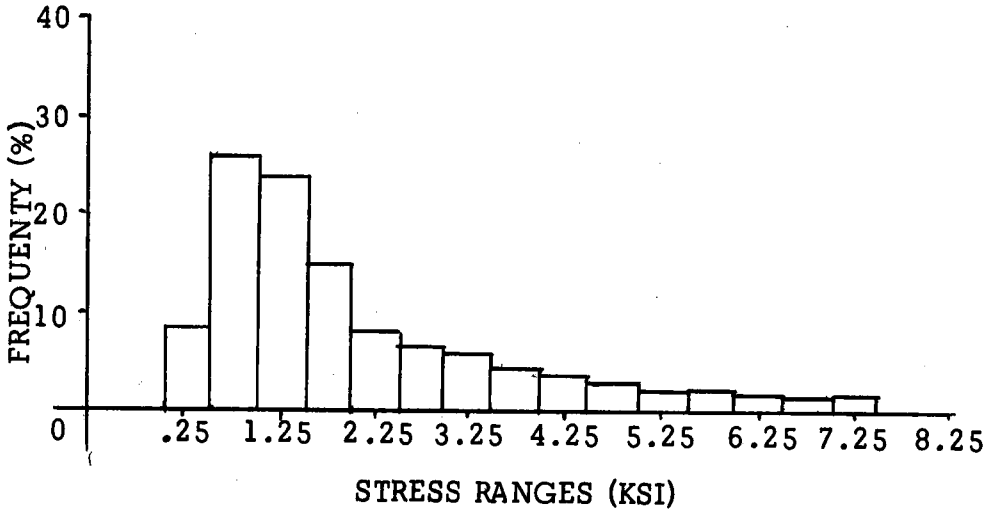
Two points were made in the report. First, approximately 10 percent of the trucks were heavier than those recommended by the American Association of State Highway Officials (AASHO). Second, the 80 feet simple span bridge was carrying mining traffic. Approximately 19 percent of truck type 3 which was used in coal mine operations were found to be overloaded, and 6 percent of the overloaded trucks were overloaded by 50 percent or more. The stress range distribution of truck traffic with a mining operation within the vicinity showed higher stress events than the

distribution without mining operations within the vicinity as may be seen in Figure 3.

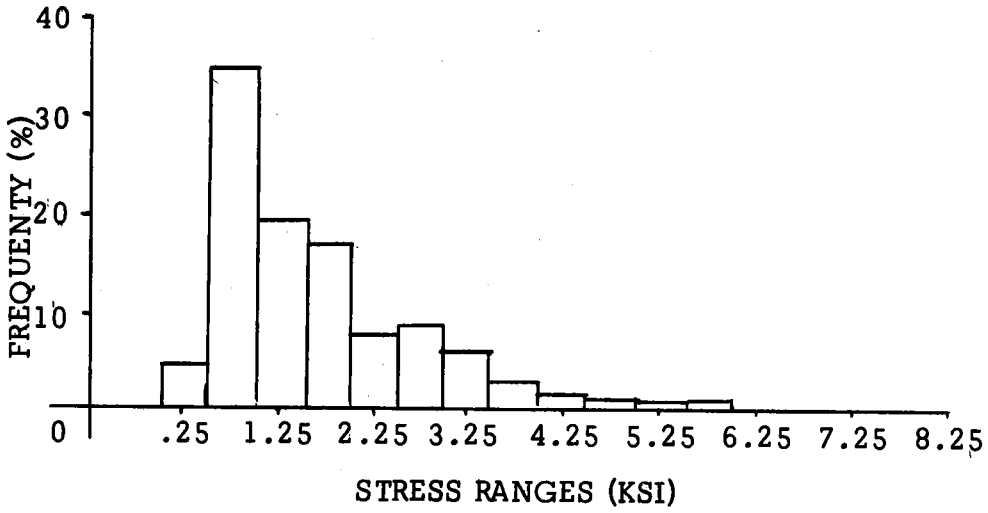
Maryland

The research was conducted by the Department of Civil Engineering at the University of Maryland.[4, 5, 6] Four simple supported steel bridges were tested. One of the bridges carried Interstate 83 southbound traffic while the other three bridges were part of the United States primary highway system. The span lengths of the bridges were from 27 feet to 76 feet. Average daily traffic (ADT) volumes at the bridges were not reported. Average truck volume at the bridges was 969 vehicles per day of which 43 percent were 3S2 trucks. Truck gross weight distributions were not reported. One study focused on establishing a relationship between truck gross weights and stress ranges.[4] Strain gages were used to measure strain ranges at cover plate ends, on cover plates and midspans of all bridges. Five types of trucks were considered. They were 2D, 3, 2S1, 2S2 and 3S2 types. After the relationships for those trucks were established and traffic data was known, predictions of the fatigue life of the bridges were attempted. The results supported the conclusion that those bridges were safe from fatigue failure.

The study showed that the relationships between gross weights and stress ranges for any types of trucks were straight lines. The simple formula of regression line was used and can be described as follows:



(a) Truck traffic with mining operation within vicinity.



(b) Truck traffic without mining operation within vicinity.

Figure 3. Stress range distribution at two bridges in Alabama.

$$\sigma_r(S/L) = A + B(G)$$

where

σ_r = induced dynamic stress ranges on girder, kips per square inch (ksi).

G = gross weight of a vehicle that induces stress range, kips.

S = elastic section modulus of bottom flange of girder, $inch^3$.

L = girder span length, inch.

A, B = coefficients obtained from a regression analysis of data.

Two interesting aspects were pointed out. One, the trucks with short axle spacing shared a common relationship of gross weights and stress ranges, and the trucks with longer axle spacing shared another common relationship as shown in Figure 4. For example, those trucks with short axle spacing (types 2D and 3) shared one equation and long axle spacing (types 2S1, 2S2, and 3S2) shared another equation. Two, the slope of the latter equation was less than the first equation. This meant that with the given gross weight, as high as 50 kips, the short axle spacing trucks would cause higher stress ranges than the longer axle spacing ones. It was shown from several traffic data that next to 3S2 trucks 2D and 3 trucks constituted most of the truck traffic. Also, in several places there were indications of trucks being overloaded when a mining operation was in the vicinity of a bridge.

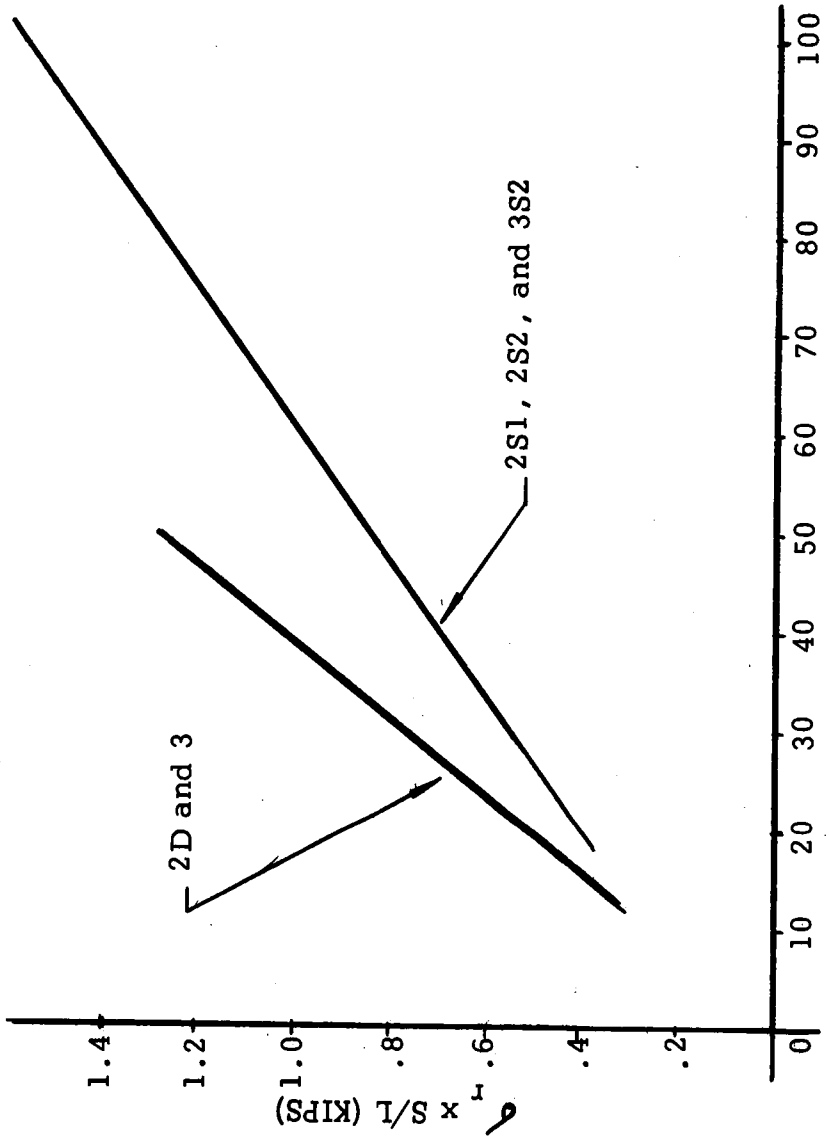


Figure 4. Relationship between stress ranges and truck gross weights in Maryland.

Virginia

The field study was conducted by the Virginia Highway Research Council and Federal Highway Administration.[7] Two different bridges were tested. One was a 76 feet simply supported steel bridge. It carried northbound traffic of Interstate 95. The concrete deck was divided into three lanes carrying an ADT volume of 18,185 vehicles. Truck traffic constituted 18.3 percent of all vehicles, and almost 65 percent of the truck traffic were 2S1, 2S2, and 3S2 trucks. The second bridge was a prestressed concrete bridge. It carried northbound traffic of Interstate 81. The span length was 60 feet. There were two lanes on the bridge. The ADT volume was 3,692 vehicles of which 33 percent were trucks. Approximately 61 percent of the truck traffic were 2S1, 2S2, and 3S2 trucks. Type 3S2 truck distributions at bridge sites were reported in combination with 2S1 and 2S2 trucks. An average of 86 percent of trucks which were weighed at weigh stations near bridge sited crossed the bridges.

A normal curve was assumed for truck gross weight distribution. However, the mean of the gross weights indicated that the distribution might, in fact, be slightly skewed. The number of high stress ranges at the midspan of the most severely stressed members was found to be higher than at the cover plate end of the same member. One interesting fact from the data was that the transverse (main) reinforcing bar in the lower level of the deck steel near the point of the maximum positive moment in the

slab was subjected to higher stress ranges (as high as 6 ksi), and those were more frequent than what occurred at midspan of any member. Similar occurrences happened at the bottom flange of the midspan diaphragm midway between beams supporting the lane which trucks were using the most. However, the occurrence was less frequent and had range magnitudes less than those at the reinforcing bar.

Tennessee

The Civil Engineering Department at the University of Tennessee at Knoxville has been conducting stress history research since 1970.[8,9] During the year of 1972, six bridges were tested at three sites.

At site one, two steel bridges were tested. They were three span simply supported bridges. Only the center spans were used for the test. The bridges carried westbound and eastbound Interstate 40 traffic. The ADT during 1971 showed 12,490 and 11,070 vehicles to the west and east of the bridges, respectively. Approximately 9 percent of ADT were truck traffic in each direction. About 62 percent of the truck traffic were 3S2 trucks. Almost all trucks which were weighed at the weigh station near the bridge sites crossed the bridges.

At site two, two bridges with three continuous reinforced concrete spans were tested. They carried Interstates 40 and 75 traffic. Approximately 21,090 vehicles per day crossed the bridges in 1971. It was noted that the bridges were located near the top of a long grade, and heavily

loaded eastbound trucks sometimes slowed to 20 miles per hour while crossing the bridges.[8] Approximately 7 percent of total traffic were truck traffic. Of the truck traffic 58.2 percent were 3S2 trucks. It was also noted that all trucks passing the weigh stations near the site crossed the bridges.

At site three, two reinforced concrete bridges with continuous spans were tested. In 1971 approximately 21,090 and 23,350 vehicles were encountered west and east of this bridge site, respectively. Approximately 7 percent of the ADT were truck traffic. About 63 percent of the truck traffic were 3S2 trucks. Almost all trucks which crossed the bridge were weighed at the stations near the site. It was noted that the bridges were located in a slight sag in vertical alignment allowing high truck speeds in both directions.

From data obtained at the three sites, three aspects were shown.

1. All of the 3S2 truck weight distributions were bimodal.
2. A comparison of truck type distributions between the years of 1968, 1970, and 1972 at bridge site three was made. The 3S2 trucks were shown to have a rate of increase approximately 10 percent which, coincidently, was equal to the combination of the decreasing rates of 2D and 2S2 trucks. The distributions of 2S1 trucks or any other types of trucks were about the same during those three years which may be seen in Figure 5.

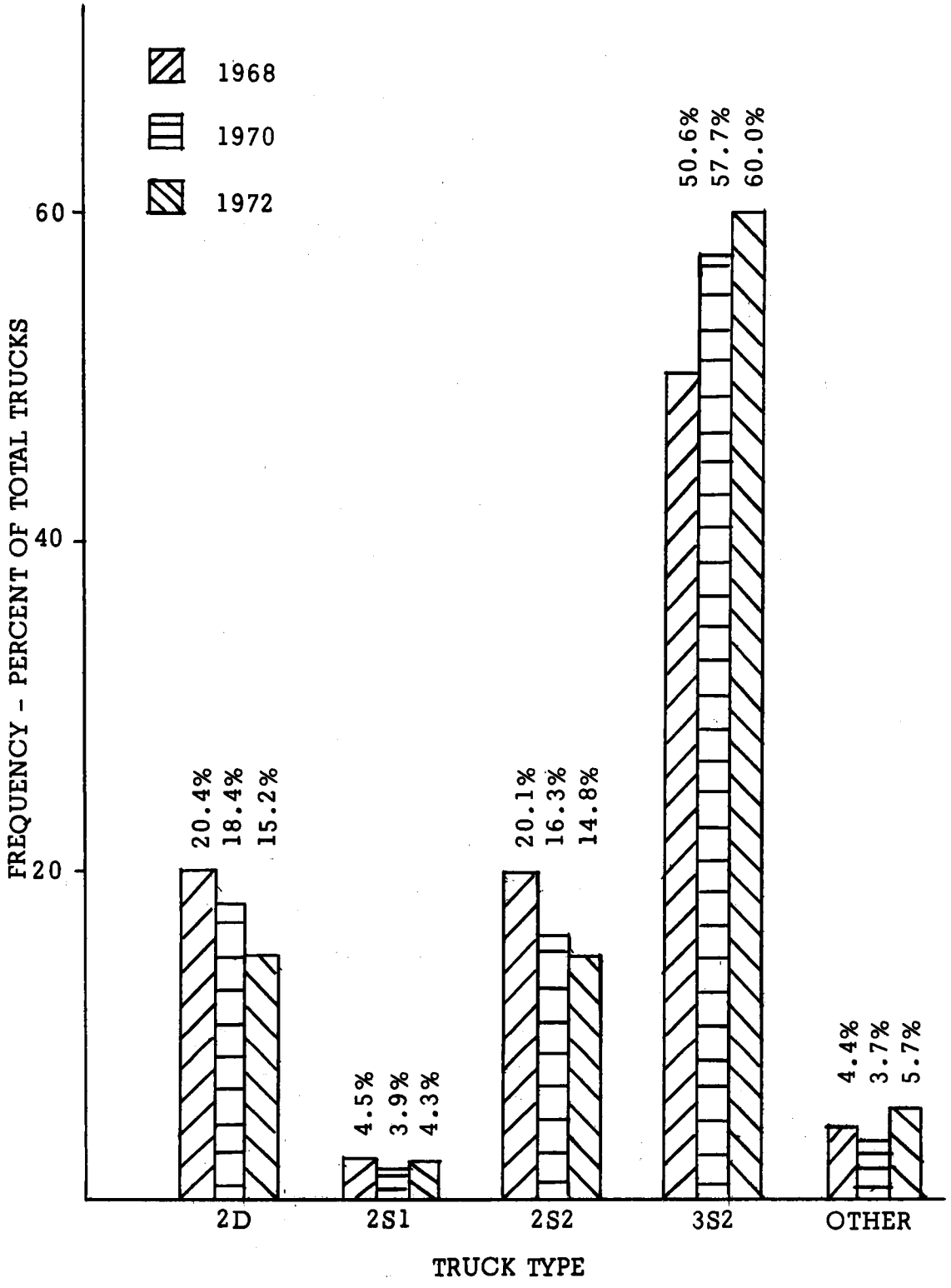


Figure 5. Truck type distribution in Tennessee.

3. The frequencies of high stress ranges on the bridges at site three were higher than the ones at sites one and two. Also at site three, the maximum stress range was found to be as high as 6 ksi, where as at sites one and two the maximum was 4.5 ksi. The tested span lengths were 60 feet at site three, 72 and 66 feet at site two, and 70 feet at site one. The skew of those bridges was comparatively small. The results from the tests showed a possibility that the speed of a truck might increase the magnitude of stress ranges on a bridge.

An attempt was made to establish a relationship between truck gross weights and corresponding stress ranges at bridge sites two and three based on the data of highly stressed girders. Both sites showed straight line relationships. Both relationships had slopes within 95 percent confidence of each other. This incident meant that at 95 percent confidence a truck gross weight would cause stress ranges within a given stress range interval on either bridge. In other words, an interpretation could be made that both bridges had similar characteristics under repeated loadings.

CHAPTER III

THE STRESS HISTORY RESEARCH

1. GENERAL

In past research truck type distributions have shown that 3S2 trucks displayed two major characteristics related to all trucks. First, 3S2 trucks constituted 55 percent or more of the truck traffic. Second, 3S2 truck gross weights dominated truck gross weight distributions at 50 kips and higher. Because of these characteristics, it was assumed that a good approximation of the true distribution of stress ranges on a bridge due to all truck traffic could be obtained if the stress distribution caused by 3S2 truck traffic only was used.

Bridge Selection

Two bridges located in Knoxville were selected for this study. The bridges were part of the interstate system. They were designed with rolled steel beams and a concrete deck over three simple spans with an average span length of 63.5 feet. The westbound bridge carried an estimated ADT volume of 46,128 vehicles of which approximately 11 percent were truck traffic. Approximately 43 percent of truck traffic were 3S2 trucks. The eastbound bridge carried an estimated ADT volume of 43,032 vehicles of which approximately 10 percent were truck traffic.

Type 3S2 trucks constituted approximately 43 percent of the truck traffic. The bridges were located far from the weigh station, and not all trucks which crossed the bridges went to or came from the weigh station due to many exits along the route. However, in order to obtain a general idea of the truck weight distribution, truck weight data were obtained at the weigh station prior to the study. Gross weight distributions of 3S2 trucks and all trucks were compared. The result, which can be seen in Table I, showed that 3S2 trucks dominated the distribution at weights of 50 kips and above. A 24-hour truck gross weight distribution made during 1972 was assumed to be the "typical" distribution. By using a Chi-square test, no significant differences were found between the distribution obtained and the assumed "typical" distribution within 95 percent confidence.

Truck type data were taken at the bridge site prior to the study. The distribution of truck types was compared with that obtained at the weigh station. The percentage distribution of 3S2 trucks at the weigh station was found to be twice the distribution at the bridge site. One interesting fact was that 3S2 trucks were found to have a steady rate of flow during a day which can be seen in Table II. This was also true for the 3S2 truck traffic throughout 24 hours during 1968.[10] Unfortunately, all data which were taken at the weigh station prior to the study were for westbound only. This was due to the fact that the eastbound weigh station was closed for repairs.

TABLE I

A COMPARISON BETWEEN 3S2 TRUCK AND ALL TRUCK GROSS WEIGHT DISTRIBUTION - WESTBOUND

Gross Weight Intervals (Kips)	Number of Trucks	
	3S2	All
5 - 10	-	21
10 - 15	-	43
15 - 20	-	31
20 - 25	8	40
25 - 30	70	113
30 - 35	41	59
35 - 40	19	33
40 - 45	23	40
45 - 50	17	31
50 - 55	20	25
55 - 60	23	26
60 - 65	39	40
65 - 70	39	40
70 - 75	60	60
75 - 80	3	4
> 80	-	1

TABLE II

TRUCK TYPE DISTRIBUTION AT WEIGH STATION AND BRIDGE SITE - WESTBOUND

Hours (AM)	Bridge Site, May 1973 Frequencies			Bridge Site, June 1973 Frequencies			Weigh Station, July 1973 Frequencies		
	All	3S2	% To All Trucks	All	3S2	% To All Trucks	All	3S2	% To All Trucks
10:00 - 11:00	319	100	31.35	251	80	31.87	85	46	54.12
11:00 - 12:00	293	93	31.74	275	73	26.54	75	47	62.67
12:00 - 1:00	255	97	38.04	248	81	32.66	75	47	62.67
1:00 - 2:00	287	88	30.66	250	77	30.80	90	44	48.89
2:00 - 3:00	292	95	32.53	240	65	27.08	80	45	56.25
3:00 - 4:00	-	-	-	307	102	33.22	110	70	63.64

Sampling Methods

During the test, each bridge was sampled separately except two cases which were designated KEWC 11 and KEWC 12. In these two cases, both bridges were sampled at the same time.

Two methods of data collection were used for each direction. One method was to record stress ranges due to individual trucks on a magnetic tape. The other, neglecting stress ranges of individual trucks, categorized any stress range that occurred on the bridge into a histogram. The histogram was then recorded on a magnetic tape periodically. In other words, the second method recorded frequencies of the ranges from zero stress range up to the highest range programmed regardless of the number of trucks on the bridge. However, with a data reduction program a histogram could also be obtained from the first method.

Two types of sampling were done. One was the sampling of a particular type of truck crossing the bridge. The other was the sampling of all types of trucks crossing the bridge. Both sampling types were applied to both methods of data collection.

Instrumentation

Every girder except the outer most girders on the eastbound bridge were instrumented with strain gages. Each girder was instrumented with strain gages at the middle of the span and at the cover plate end in the direction of opposing the traffic flow when looking from the middle span

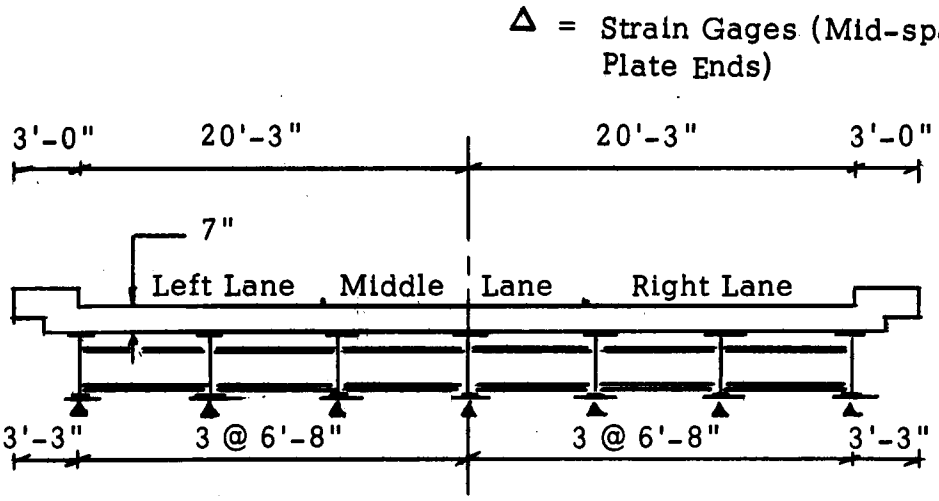
of the girder. The locations of the gages can be seen in Figure 6. A computer system, Raytheon 703, which was housed in a temperature controlled trailer was used for the data collection. The electric power was obtained from a utility company line near the bridges. The schematic of instrumentation can be seen in Figure 7. For most of the tests, ten gages were used in testing.

2. DATA COLLECTION

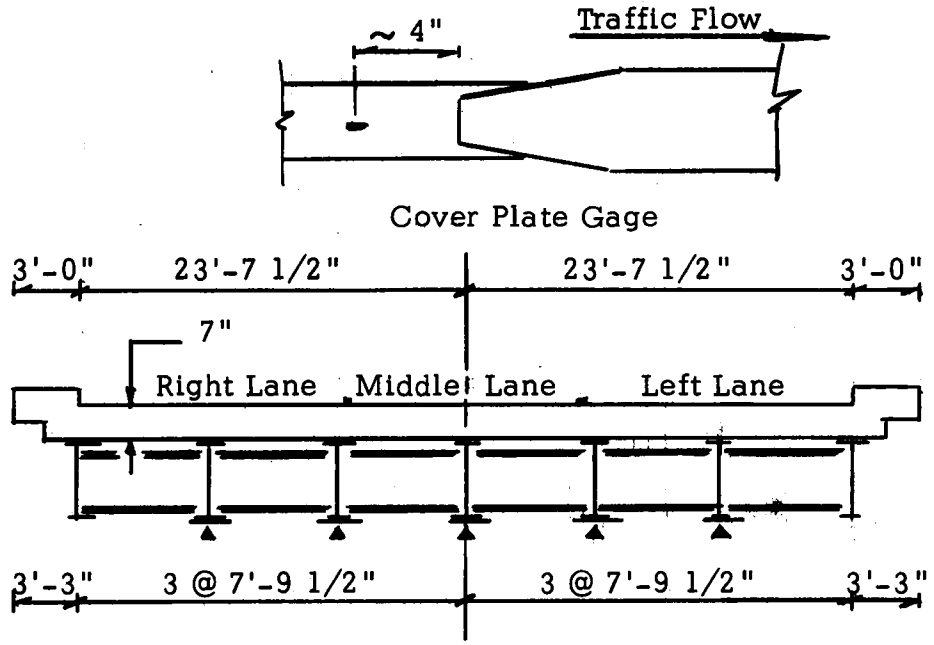
As mentioned earlier, two methods of sampling were used. However, both methods had one similar procedure. The person who was conducting the test classified trucks and recorded the lane used on a data sheet. The classification data were recorded hourly. The testing periods were conducted almost continuously throughout the day except for short breaks which were required to set up a new tape, change the method of sampling, or during the period between midnight and 9 o'clock A.M.

Individual Sampling

The collection program was written in the Fortran language. It was programmed to have the computer record on tape initial gage reading, calibration numbers and test identification on the front portion of the magnetic tape used for the data collection. The initial reading was usually the reading of gages when the bridge was clear of all vehicles. Test identification consisted of a test number, date, month and starting time



(a) Westbound: Beams - 33 WF 130, Cover Plates - 14" x 3/4".



(b) Eastbound: Beams - 36 WF 150 except 36 WF 182 at ends, Cover Plates - 14" x 3/4" except outer girders.

Figure 6. Cross sections of bridges - (a) westbound bridge and (b) eastbound bridge.

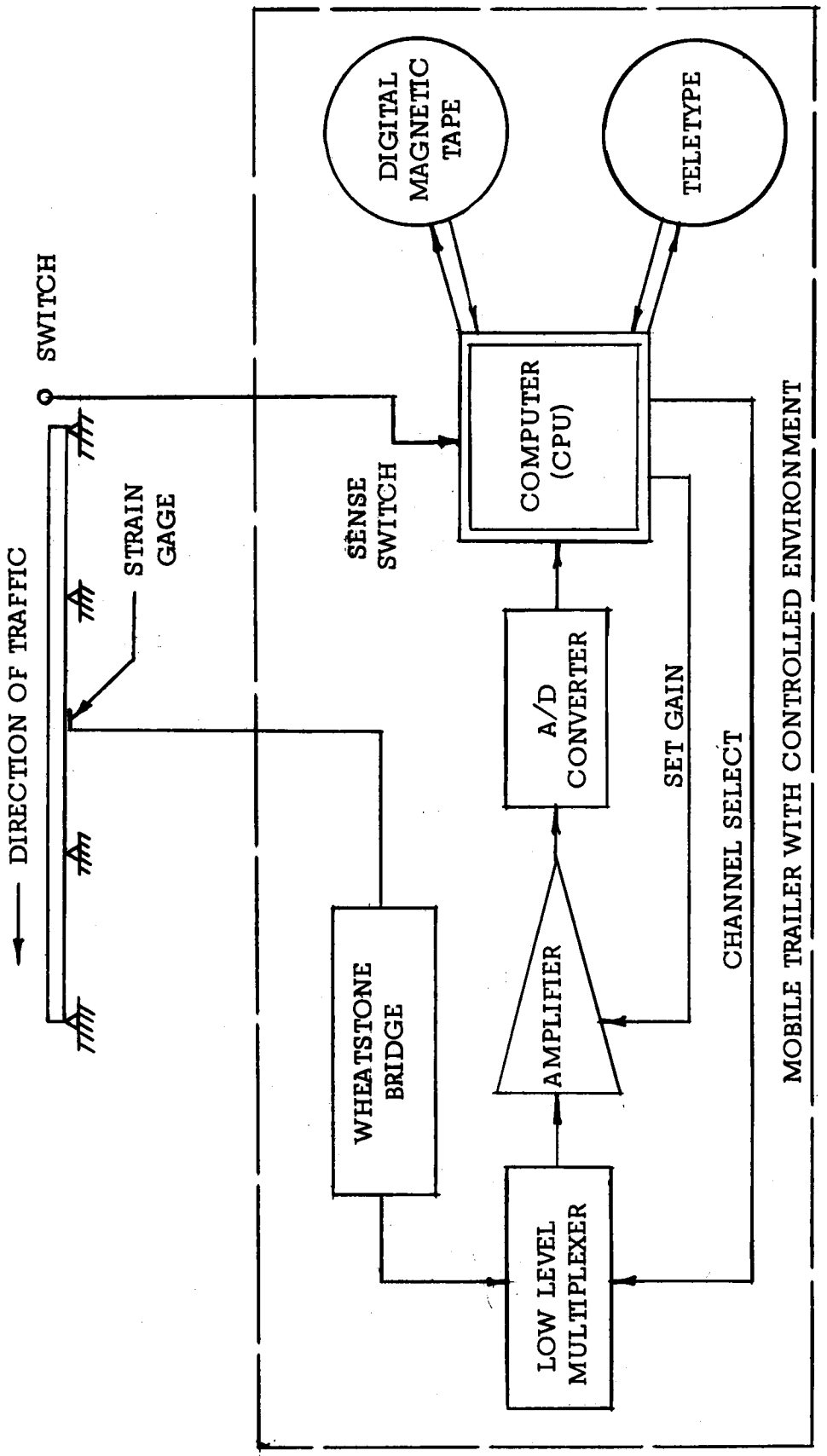


Figure 7. Schematic of instrumentation.

of the test. Calibration numbers were the reading of gages when the amplifiers were set at calibration position and the test bridge was clear of traffic.

Each time the investigator desired, the computer sampled the gages and recorded data on a magnetic tape simultaneously. The program was written in order that the computer would continue sampling until the investigator instructed it to stop sampling. This enabled data to be taken for a longer period of time, such as when trucks were following each other closely while crossing the bridge. One disadvantage of this data collection method was that the amount of magnetic tape used was large. One roll of a magnetic tape was enough to record approximately 300 trucks only. In most cases, this was considered sufficient to statistically represent the "population."

Continuous Sampling

This program was written in a symbolic language. The program allowed the recording of initial gage reading, calibration numbers, and data histogram on a magnetic tape.

The program set up standard range levels for each amplifier in the computer memory. The ranges were from zero to 255. After the computer sampled the strain ranges from gages, it would convert them into standard range levels. The computer would register tally counts of the levels which were reached. In other words, the computer would sample and

record histogram of strain ranges in standard range levels. All processing was done in the computer memory during testing. The program allowed the histogram to be recorded cumulatively unless the investigator rezeroed the histogram during the test. In most of the tests, the histogram was recorded cumulatively every 15 minutes of the hour and rezeroed at the end of each hour. One disadvantage of this data collection method was that secondary strain ranges (shown in Figure 8) would be recorded along with primary strain ranges. Noise within the system also gave problems with this method. High ranges of noise were found in the histogram at low strain range records. However, two advantages of this method were that the data was partially reduced and the magnetic tape requirement was small.

3. DATA REDUCTION

Each type of sampling data was reduced by different methods. One common approach used in reducing the data was that the computer used calibration values to scale electric signal from a gage sampling into equivalent strain and measured strain offset by using initial gage reading as a zero level. Then, strains were converted to stresses, and ranges were measured. All conversion of strain was based on modulus of elasticity of 29×10^6 pounds per square inch (psi) since the gages were mounted on steel girders.

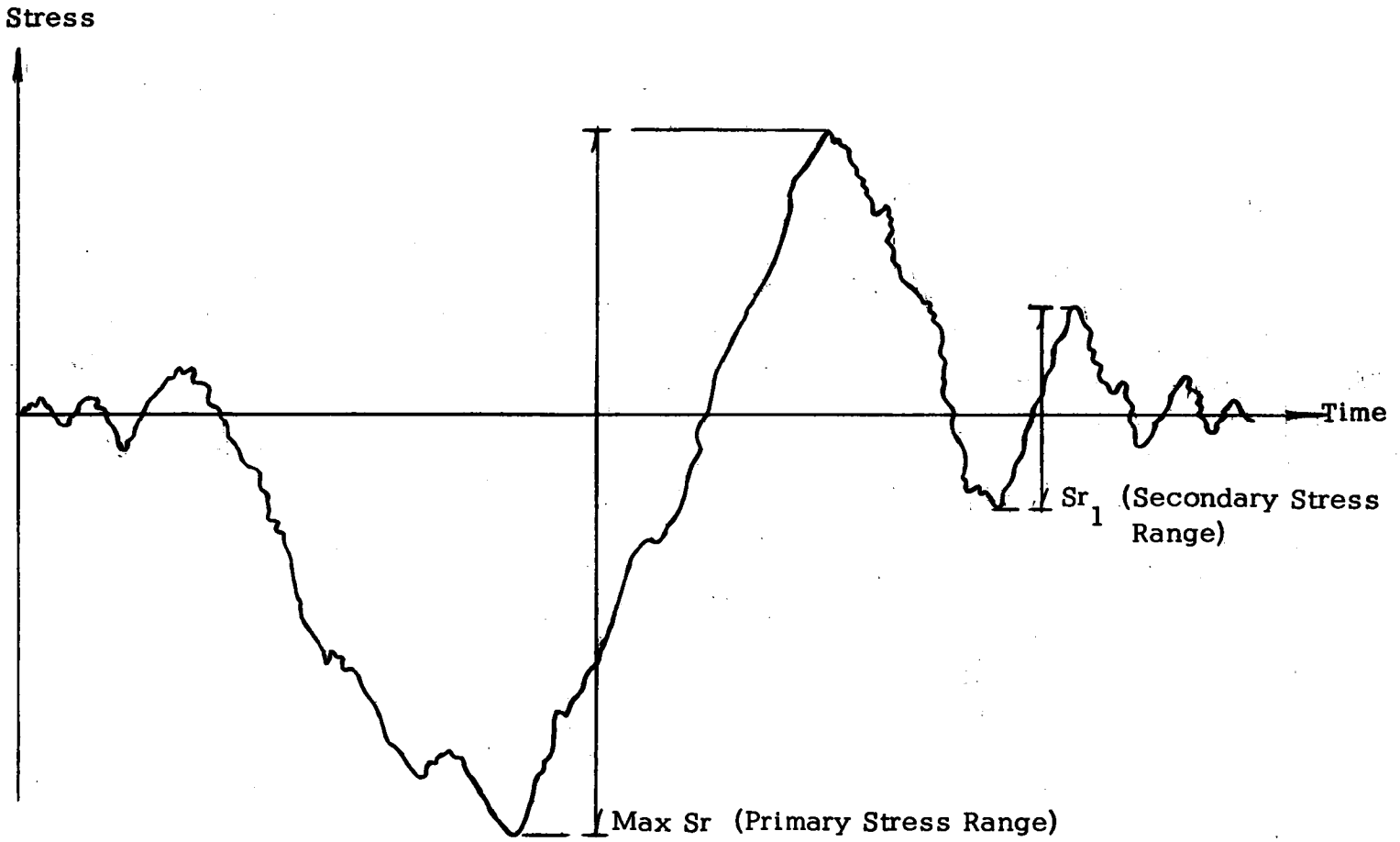


Figure 8. Stress trace indicating maximum and secondary stress ranges per truck passage as defined by the Federal Highway Administration.

Individual Sampling

The computer program chose one gage at a time in the reduction process. Three pieces of information were printed for each gage. Namely, the primary stress range for each record, the histogram of primary and secondary stress ranges, and the histogram of primary stress ranges only. The last two items were printed at the end of the last record for each gage. Fortran language was used in programming.

One disadvantage of this method was the requirement of time. To reduce the data for 300 trucks with 10 gages, it required approximately 26 hours. However, one advantage was that the investigator was able to use a program using the California computer plotter (CALCOMP PLOTTER) to plot the pattern of changes in stress in certain records for a detailed investigation.

Continuous Sampling

The standard ranges were converted into stress ranges by using strain offset factor, modulus of elasticity and calibration numbers. The process was done manually for each gage after the computer has printed out the histogram. The program which allowed the computer to print out the histogram was written in a symbolic language.

The standard ranges were used in the data collection process because there was no provision to input the strain offset factor, modulus of elasticity in either collection or reduction process. Both factors would be different and important for different types of bridges.

Final Reduction

After all data were reduced, the most severely stressed girder from each bridge was chosen for this study. The centerline girder at the middle span of each bridge was chosen. Then the data from those two locations were reduced further. Frequency of each stress range in percentage was calculated. The summary of all tests can be seen in Tables III and IV. A computer was used to calculate the frequencies. The base used for 100 percent was the total number of trucks for each test. The reason for that base was based on the assumption that the reduced data were tally counts of primary stress ranges. For continuous sampling method, the assumption would not be true for low stress ranges but more likely to be true for high stress ranges. To confirm the assumption, a program using CALCOMP PLOTTER was used to approximate a rough curve of the stress ranges and corresponding frequencies for each test method as shown in Figure 9. The figure shows a similar pattern for high stress ranges when continuous and individual sampling methods were compared. The assumption was also supported by the fact that in earlier research[6, 8, 11] a conclusion was made that at stress ranges 2.0 ksi and above primary stress ranges were found to dominate a stress range distribution on a bridge.

TABLE III

STRESS RANGE FREQUENCY DISTRIBUTION OF 3S2 TRUCKS AT MIDDLE SPAN OF MIDDLE GIRDER

Ranges (Ksi)	Frequency (%) Westbound (KW 2)	Eastbound KE 8	Eastbound KEC 6
.5	26.00	25.9	53.74
.75	19.00	24.6	15.65
1.00	11.00	11.8	7.48
1.25	9.00	9.2	4.76
1.50	6.00	2.2	3.40
1.75	8.00	3.5	4.76
2.00	4.00	1.8	3.40
2.25	6.00	3.9	2.70
2.50	7.00	7.9	3.40
2.75	3.00	4.4	.70
3.00	1.00	3.1	.01
3.25	-	.9	-
3.50	-	.8	-
3.75	-	-	-

TABLE IV

STRESS RANGE FREQUENCY DISTRIBUTION OF ALL TRUCKS AT MIDDLE SPAN OF MIDDLE GIRDER

Ranges (Ksi)	Frequency (%)										
	Westbound							Eastbound			
	KW 3	KWC 3	KWC 7	KWC 8	KWC 9	KEWC 11	KEWC 12	KEC 4	KEC 10	KEWC 11	KEWC 12
.50	43.77	-	45.2	8.6	16.62	37.3	41.4	64.1	27.1	25.4	20.0
.75	17.73	36.4	13.2	52.4	56.18	18.4	21.8	12.9	32.3	27.3	38.2
1.00	14.96	13.6	10.5	9.5	6.47	13.2	13.2	6.0	16.4	12.5	15.2
1.25	5.82	4.5	9.6	6.8	5.90	7.2	6.2	3.8	8.1	8.2	6.8
1.50	4.43	9.1	11.9	6.8	2.70	4.1	3.9	2.8	3.7	4.5	5.5
1.75	3.05	4.5	3.7	4.4	4.00	4.1	2.6	1.9	3.5	3.1	3.9
2.00	1.11	9.1	3.7	5.6	2.80	3.3	1.6	1.3	1.2	4.2	1.4
2.25	2.22	-	.9	3.2	2.10	5.2	1.8	3.5	2.2	5.9	2.9
2.50	1.38	13.6	.5	2.1	1.60	3.1	.4	2.5	2.3	3.8	2.6
2.75	1.11	4.7	-	.6	.70	2.3	.9	1.2	1.5	2.6	1.9
3.00	.55	-	.5	-	.20	1.2	1.2	-	1.5	2.1	.9
3.25	.55	-	.3	-	.73	.6	1.4	-	.2	.4	.7
3.50	.83	-	-	-	-	-	1.6	-	-	-	-
3.75	.83	4.5	-	-	-	-	.9	-	-	-	-
4.00	.83	-	-	-	-	-	.5	-	-	-	-
4.25	.28	-	-	-	-	-	.6	-	-	-	-
4.50	.55										

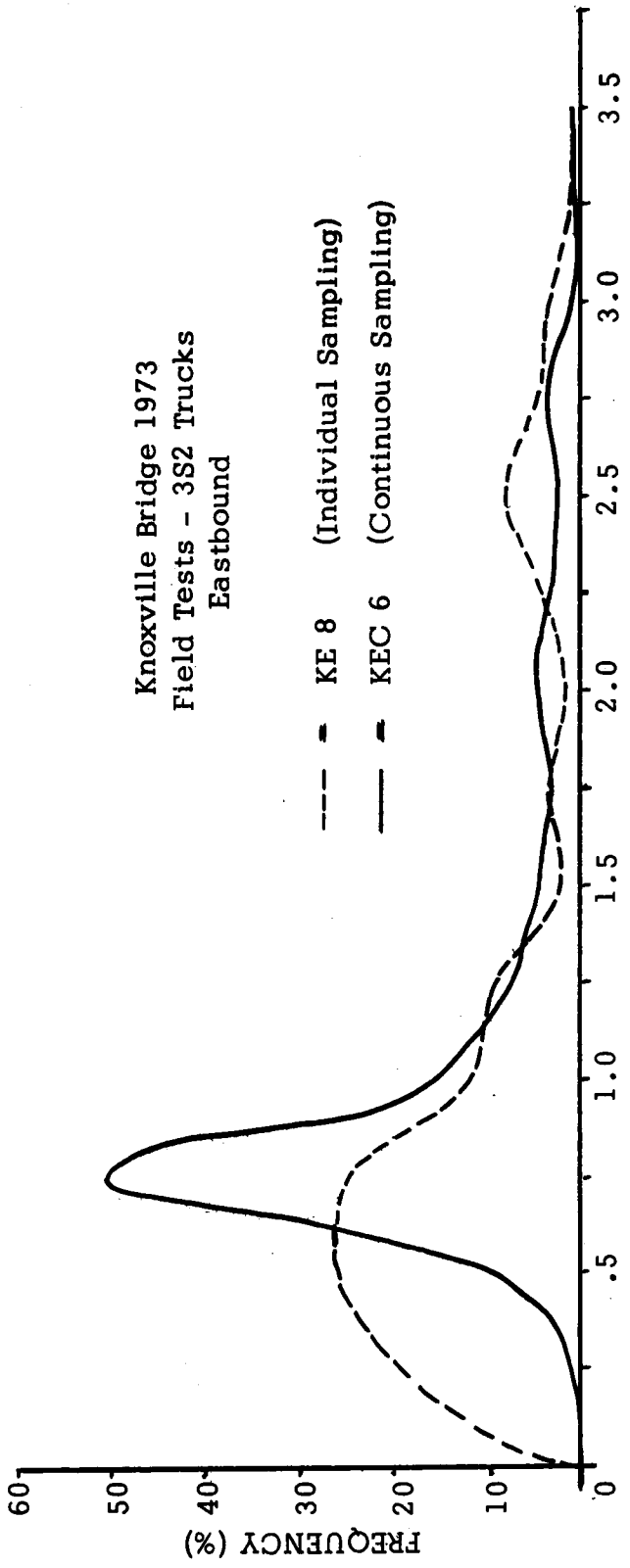


Figure 9. A comparison of results between continuous sampling and individual sampling.

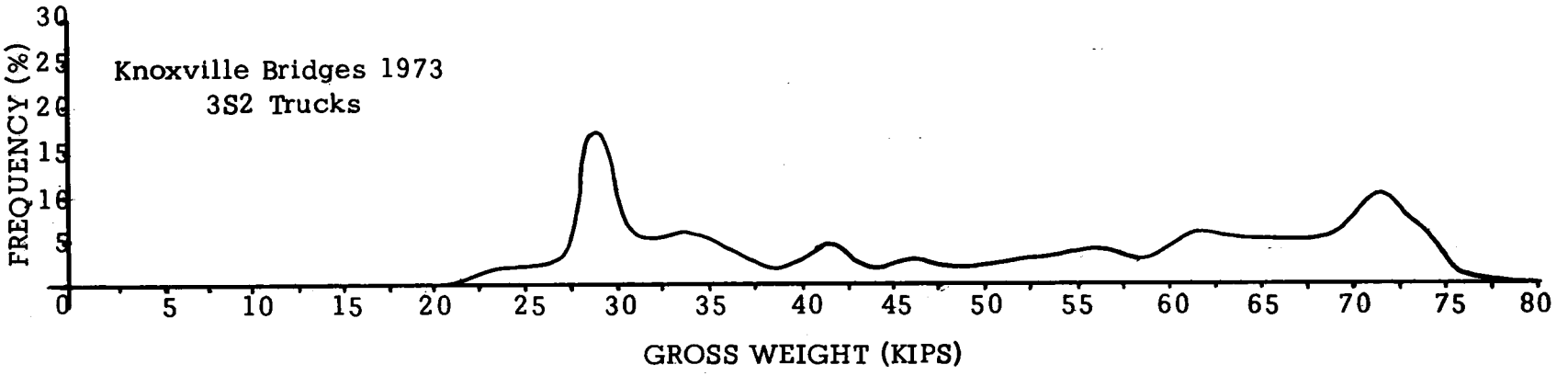
CHAPTER IV

DEVELOPMENT OF DISTRIBUTION TYPE

1. ANALYSIS OF DATA

Before any analysis of stress ranges was done, gross weight distributions of trucks were investigated. A distribution which was obtained from a nearby weigh station prior to the field investigation of stress ranges was tested against a "typical" weight distribution by using a Chi-square test. Twenty-four hours of truck gross weight data which was taken at the station during 1972[8] was assumed to be the "typical" distribution for this study. The differences were found to be acceptable within 95 percent confidence interval. The purpose of this test was to see if there was any abnormality of the truck gross weight distribution for the study.

Inspection of the weight distribution led to the observation that a bimodal curve might possibly fit the distribution. The same observation was also found when the distributions made in Virginia[7] and Minnesota[2] were inspected. A CALCOMP PLOTTER curve smoothing program was used to plot the weight data taken prior to the field investigation of stress ranges. The curves are shown in Figure 10.



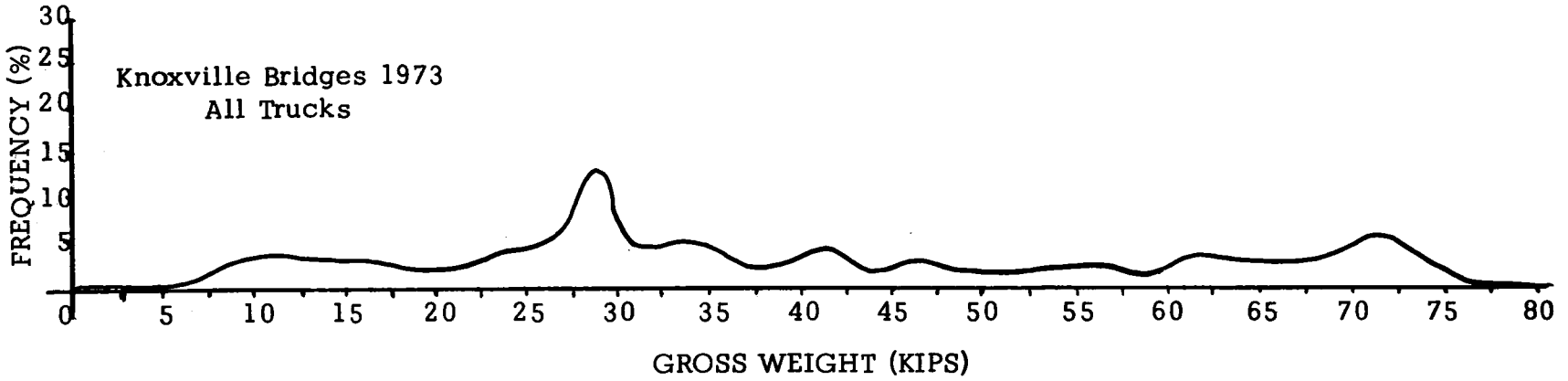


Figure 10. Truck gross weight distributions.

With the bimodal gross weight distribution in mind, the stress range distribution was thought to be bimodal also. One peak of the stress range distribution was possibly for light trucks or empty trucks, and the other was possibly for heavy trucks.

In many cases of analyzing data, one is confronted with finding the appropriate distribution to describe the pattern of variation of the empirical data. The usual approach to this problem is to plot data on normal probability paper, and if the data is in a straight line the normal distribution is accepted as a representation of the underlying distribution of the empirical data.

Another approach to this problem is to plot the data on Weibull Probability Paper (WPP). If the data plots as a straight line, then the Weibull distribution can be accepted as a representation of the empirical data. This approach is more general because other distributions, such as the exponential and the normal, are related to or approximated by the Weibull distribution. Also, the Weibull plot is very sensitive in showing heterogeneous and/or mixed distributions.[12]

Mathematical Formulation

The equation of the cumulative frequency function of the Weibull distribution is

$$F(x) = 1 - e^{\frac{-(x-\gamma)\beta}{\alpha}} \qquad (4\text{-}1)$$

where

α = scale parameter, positive real number.

β = shape parameter, positive real number.

γ = location parameter, any real number.

$x \geq \gamma$

It is generally reasonable to assume that an item is subject to failure from the instant it is put into use. For this study, it can be interpreted that a bridge is subjected to stresses from the instant it is put into use. In this case, $\gamma = 0$ and equation 4-1 reduces to form

$$F(x) = 1 - e^{\frac{-x^{\beta}}{\alpha}} \qquad (4\text{-}2)$$

One characteristic should be noted that when $\beta = 1$, equation 4-2 becomes the one-parameter exponential with $\alpha =$ mean life which refered to a mean stress range on a bridge for this study. It should be stressed that $\alpha =$ mean life only when $\beta = 1$.[12] When α and β are known, the mean life μ, can be obtained from the equation

$$\mu = \alpha^{1/\beta}\,\Gamma\left(\left(\frac{1}{\beta}\right) + 1\right) \qquad (4\text{-}3)$$

where $\Gamma((1/\beta) + 1)$ is interpreted as the gamma function of $(1/\beta) + 1$. From equation 4-3, it is easily verified that mean life is equal to α when $\beta = 1$. Values of gamma function are tabulated and can be found in a mathematical or statistical handbook or references 13 and 14.

General Method for Obtaining α and β

Estimations of α and β usually are done on a special graph paper called a Weibull Probability Paper. To understand how the estimates of parameters α and β can be determined on this type of graph, note that in Figure 11 depicting the Weibull Probability Paper there are four scales, one at each of the four sides of the graph. The upper and right scales are refered to as the principal scales and are linear; the lower and left scales are auxiliary and nonlinear. During the estimation process, the raw failure data, which for this study refers to a stress range distribution, are plotted with reference to the auxiliary scales. Estimates of α and β are then obtained with reference to the principal scales. The principal scales are related to the principal ordinate and the principal abscissa, which are represented on the graph in Figure 11 by the two dark lines that intersect at the point (0, 0).

To obtain estimates of α and β on the Weibull probability graph, the accumulated percentage of failure (the cumulative percentage of stress ranges in this study) is plotted versus failure age (stress ranges). The cumulative percent failure is plotted with reference to the left scale (auxiliary ordinate) and failure age with reference to the bottom scale (auxiliary abscissa). A straight line is then fitted to the plotted points.

β estimation. Since β is the slope of the straight line (a Weibull line), a line was drawn from coordinates (1, 0) on the principal

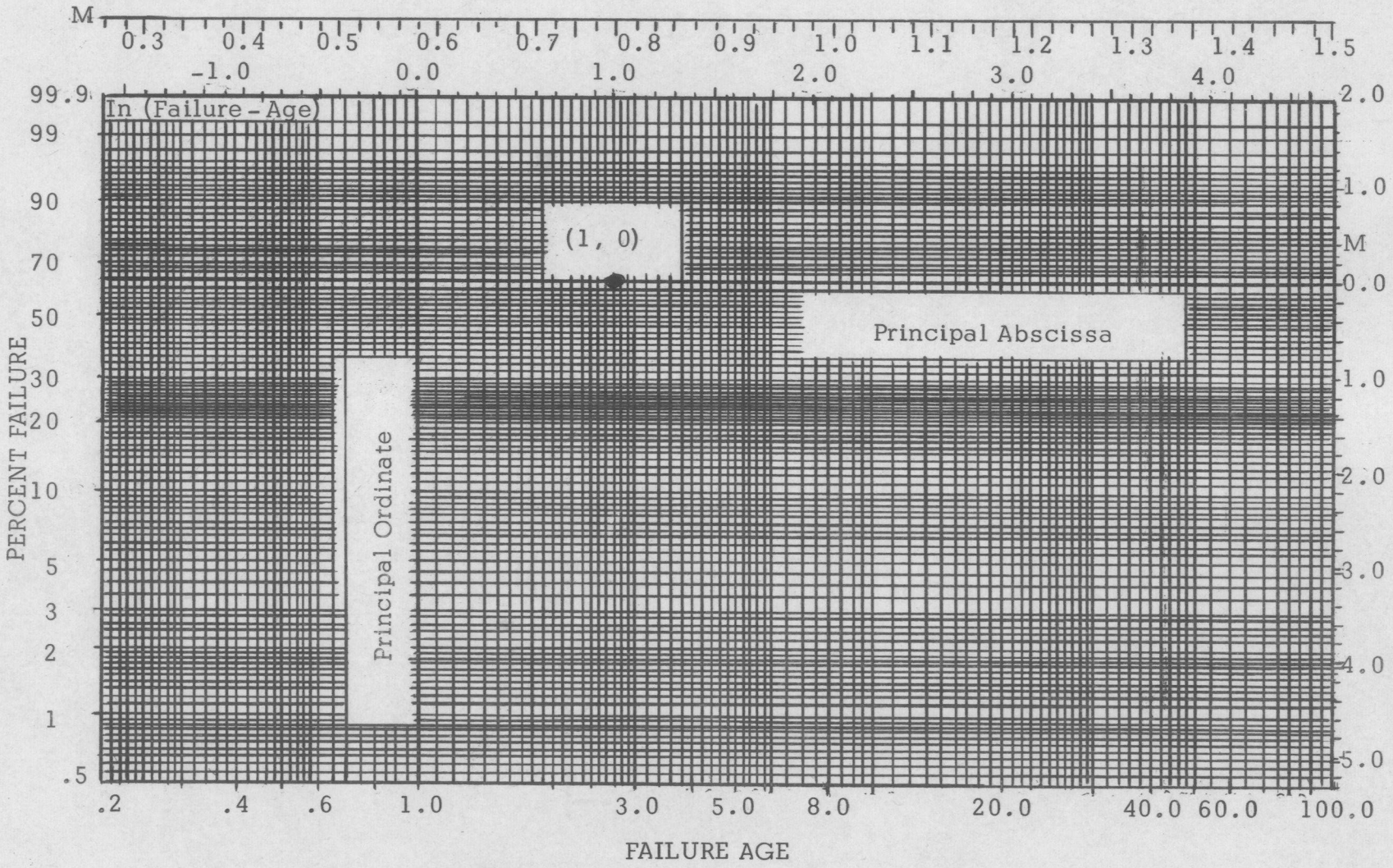


Figure 11. Weibull Probability Paper.

abscissa. The point of intersection of the line drawn with the principal ordinate is then read from the right scale m and the value is the estimate of β.

α estimation. Ln α (natural logarithm of α) which is read from the right scale m is the value that corresponds to the intersection of the Weibull line with the principal ordinate. Then the value of α equals to the antilogarithm of ln α.

In certain instances, it is necessary to obtain the estimate of ln α from the upper m scale; this occurs, for example, when the straight line fitted to the plotted data intersects the principal ordinate outside the graph. To obtain an alternate estimate of ln α, read from the upper m scale that value which corresponds to the intersection of the Weibull line with the principal abscissa. This value is the estimate of β^{-1} lnα; and knowing the estimated value of β, lnα can be readily obtained and subsequently α. The Weibull Probability Paper is not sold in a commercial market; however, it can be ordered from Cornell University for a small fee.

2. APPLICATION TO THIS STUDY

Two assumptions were made. First, the bridges were subjected to stresses from the instant they were put into use. Second, both empty

trucks and heavy trucks contributed to the stress ranges on the bridges at the instant they were on the bridges.

Westbound

The cumulative percentage frequencies of stress ranges of test KW 2, shown in Table V, were plotted on WPP. In Figure 12 two straight lines were drawn and were designated as Weibull lines. Both lines were extended until they intersected. Each line represents an equation of a Weibull distribution. The intersection of the two lines denotes the location where one distribution will change to another. For this study, the first Weibull line refers to the Weibull line on the left side of the intersection, and it was used to derive the first Weibull equation. Similarly, the second Weibull line is the line on the right side of the intersection, and it was used to determine the second Weibull equation. α and β were determined in the following manner.

α determination. For the first Weibull equation, $\ln \alpha_1$** (natural logarithm of α_1) was read directly from the m scale which is located on the right hand side of the paper at the value corresponding to the intersection of the first Weibull line with the principal ordinate.

** Superscript refers to an equation in which the variable will be used.

TABLE V

CUMULATIVE PERCENTAGE OF STRESS RANGE FREQUENCIES OF FIELD INVESTIGATIONS

Ranges (Ksi)	Cumulative Percentage Frequency			
	Westbound	Eastbound		
	KW 2	KE 8	KEC 6	Average
.75	45	50.5	53.74	52.12
1.00	56	62.3	69.39	65.85
1.25	65	71.5	76.87	74.19
1.50	71	73.7	81.63	77.67
1.75	79	77.2	85.03	81.12
2.00	83	79.0	89.79	84.40
2.25	89	82.9	93.19	88.05
2.50	96	90.8	95.89	93.35
2.75	99	95.2	99.29	97.25
3.00	100	98.3	99.99	99.10

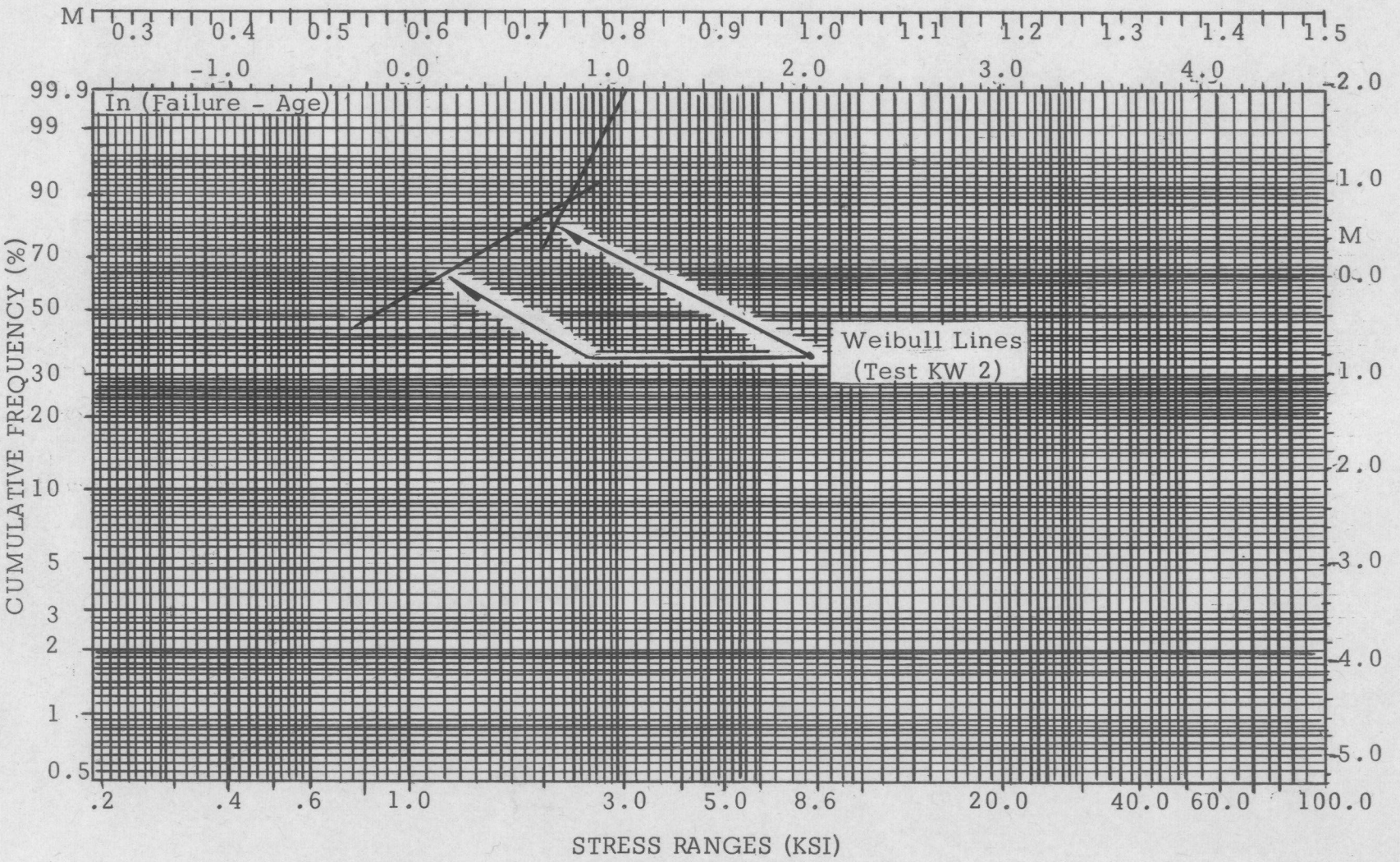


Figure 12. Weibull Probability Paper plotting of westbound stress range distribution.

$$\ln \alpha_1 = .2$$

$$\text{then } \alpha_1 = 1.21$$

Likewise for the second equation, $\ln \alpha_1$ was read directly on the m scale by extending the second Weibull line to intersect the principal ordinate.

$$\ln \alpha_2 = 2.4$$

$$\text{then } \alpha_2 = 11.02$$

Since β is the slope of a Weibull line on WPP, lines were drawn from coordinates (1, 0) on the principal abscissa parallel to the Weibull lines. β's were determined by the intersection of the parallel lines and the principal ordinate. The values of β's were read from the m scale corresponding to the point of intersections.

$$\beta_1 = 1.2$$

$$\beta_2 = 3.9$$

Finally, the values of the variables were substituted into Weibull distribution equations.

$$F(x)_1 = 1 - e^{\frac{-x^{1.2}}{1.21}} \text{ when } 0 \leq \Delta\sigma < 2.5 \qquad (4\text{-}4)$$

$$F(x)_2 = 1 - e^{\frac{-x^{11.02}}{3.9}} \text{ when } 2.25 \leq \Delta\sigma \leq \infty \qquad (4\text{-}5)$$

Eastbound

Similar analysis procedures for the eastbound bridge were used. Eastbound stress range data, shown in Table V, page 43, were used for plotting. Average values of the variables were used in the following formulas.

$$F(x)_1 = 1 - e^{\frac{-x^{1.0}}{1.0}} \text{ when } 0 \leq \Delta\sigma \leq 2.5 \qquad (4\text{-}6)$$

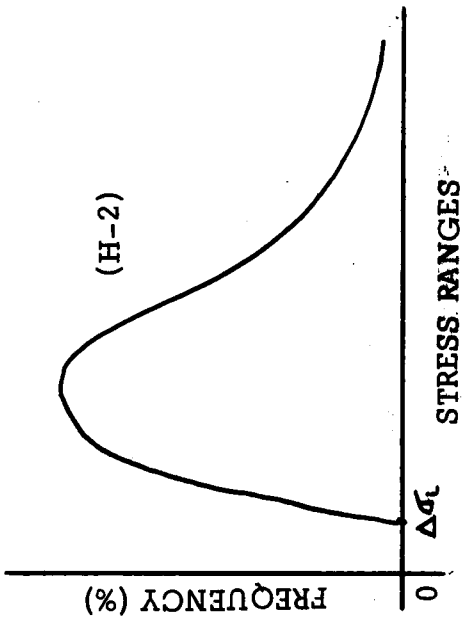
$$F(x)_2 = 1 - e^{\frac{-x^{2.9}}{5.37}} \text{ when } 2.5 < \Delta\sigma \leq \infty \qquad (4\text{-}7)$$

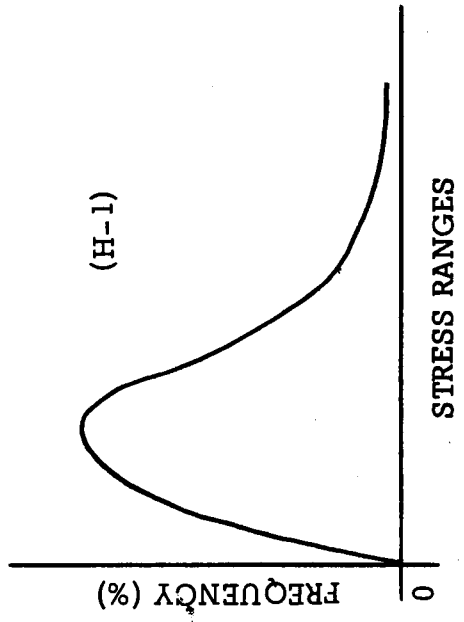
3. OTHER APPROACHES

Since the stress ranges lower than 1.0 ksi could not be assured for this study, sone other approaches were made. The following hypothesis can be seen in Figure 13.

Hypothesis 1 (H-1)

The distribution was one mode initially starting at zero. The assumption was made that there was only one stress range distribution. All trucks contributed to the stress ranges on the bridges in such a manner that there was no break point between heavy and light trucks. However, all trucks contributed to stress ranges on the bridges at the instant they were on the bridges.





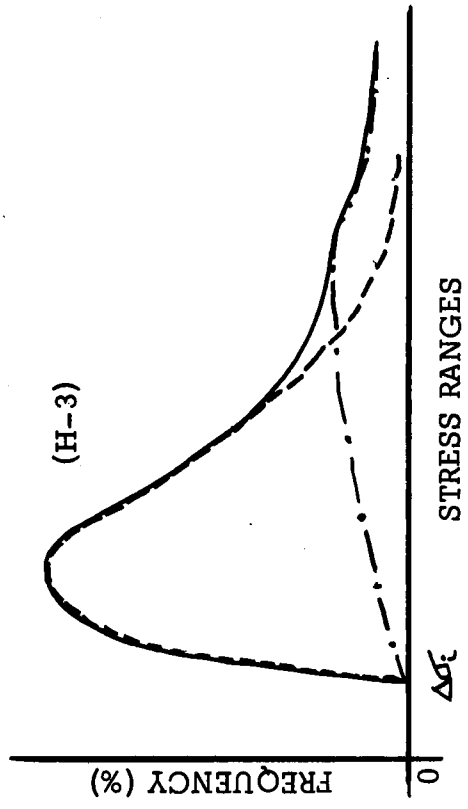


Figure 13. Three hypotheses used for the approach.

Hypothesis 2 (H-2)

The distribution was one mode initially starting at $\Delta\sigma_1$ (i.e. $\gamma = \Delta\sigma_1$). The same assumption as in H-2 was made except that stress ranges on the bridges were no lower than an assumed limit $\Delta\sigma_1$. For this study the assumed limit was .25 ksi.

Hypothesis 3 (H-3)

The distribution was bimodal initially starting at $\Delta\sigma_1$ (i.e. $\gamma_1 = \gamma_2 = \Delta\sigma_1$). The same assumption as H-1 was made except that stress ranges on the bridges were assumed not to be lower than an assumed limit $\Delta\sigma_1$. Again, for this study the assumed limit was .25 ksi.

Stress range distributions using the hypotheses were computed. They were then compared with observed data in Chapter V.

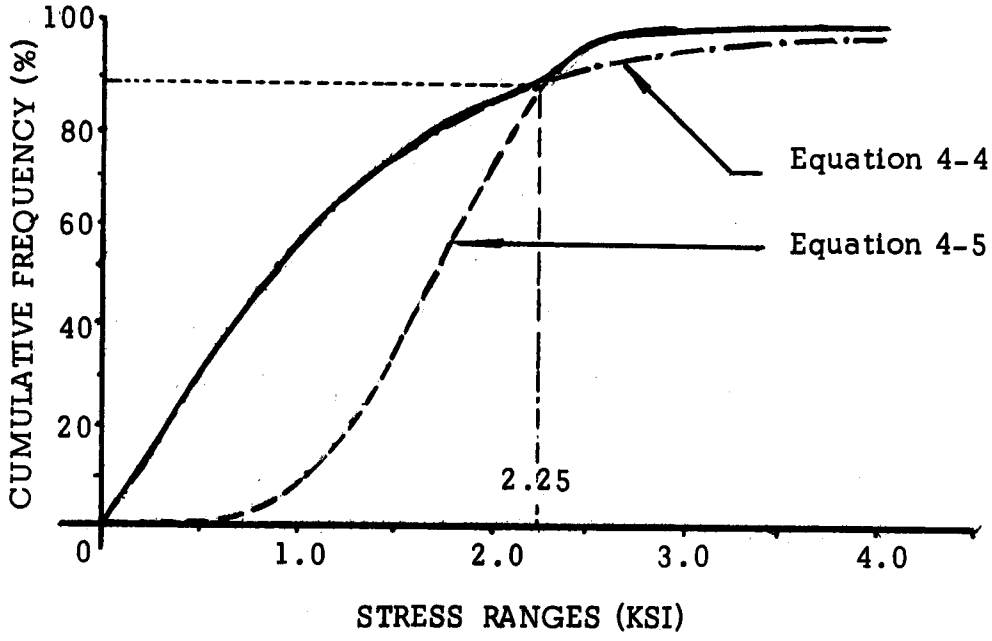
CHAPTER V

COMPARISON OF WEIBULL DISTRIBUTION TO OBSERVED DATA

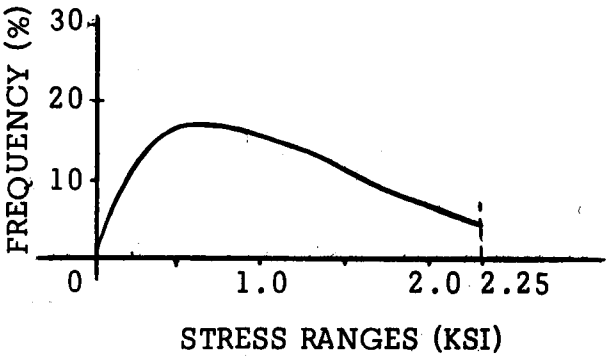
1. THEORETICAL DISTRIBUTION

The theoretical stress range distribution for each bridge followed the higher values of Weibull equation 4-4, page 45, or equation 4-5, page 45, when they were compared. The location of the change of one distribution to another should be at the location where two Weibull lines on a WPP plotting intersected.

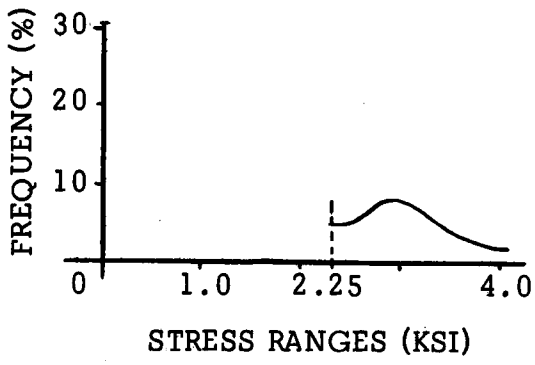
For illustration purposes, a development of the theoretical stress range distribution for the westbound bridge is shown in Figure 14. The cumulative frequencies from equations 4-1 and 4-2 are plotted. Then, the theoretical cumulative frequency distribution of stress ranges on the bridge followed the top line which was drawn as a solid line in Figure 14 (a). The theoretical stress range distribution on the bridge was then described in parts. First, at stress ranges lower than 2.25 ksi, the distribution was obtained from the cumulative distribution using equation 4-1. Similarly, at stress ranges higher than 2.25 ksi, the distribution was obtained from the cumulative distribution using equation 4-2. The two parts are shown in Figure 14 (b) and Figure 14 (c).



(a)



(b)



(c)

Figure 14. Development of theoretical stress range distribution - westbound.

2. COMPARISON OF THEORETICAL AND OBSERVED DATA

The theoretical stress range distributions for westbound and eastbound bridges were plotted and compared with observed data as shown in Figures 15 and 16. Also, the results were tabulated for both bridges and are shown in Tables VI and VII. The results indicated good agreement in cumulative frequency distribution of stress ranges. However, at stress ranges .5 ksi and lower the discrepancy between the theoretical values and observed values was due to the fact that the actual stress data could not be obtained.

3. COMPARISON OF DIFFERENT HYPOTHESIS RESULTS AND OBSERVED DATA

The results were tabulated as shown in Tables VIII and IX. Variation in variables had been tried but no better fit could be achieved. The measure of fit was based on the least difference of observed and predicted stress range distribution.

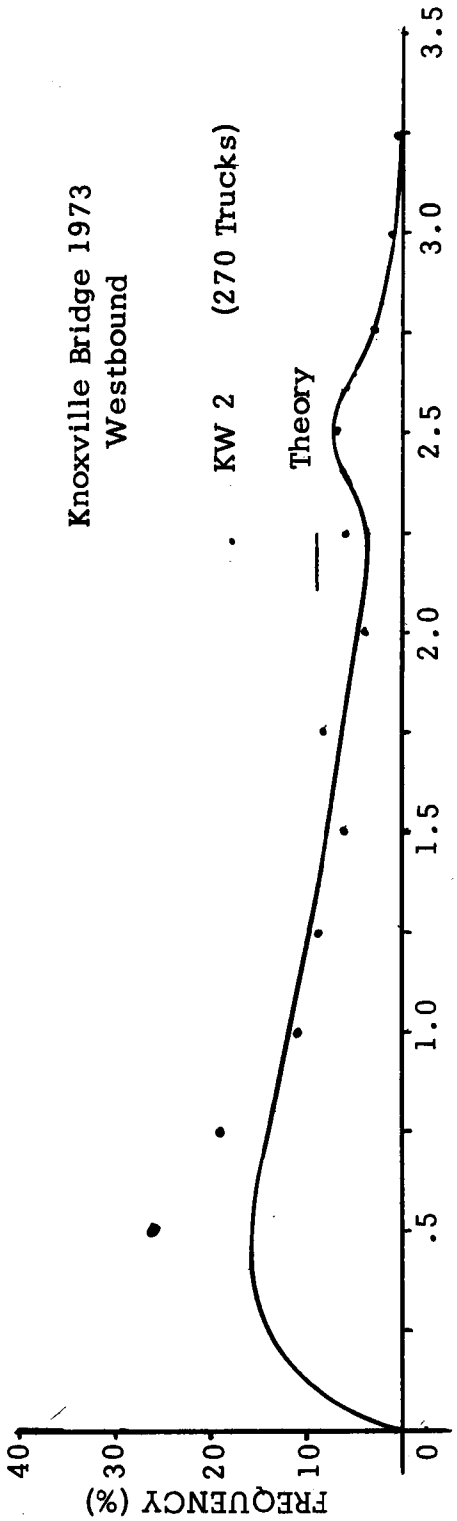


Figure 15. A comparison between observed and theoretical stress range distribution of 3S2 trucks - westbound.

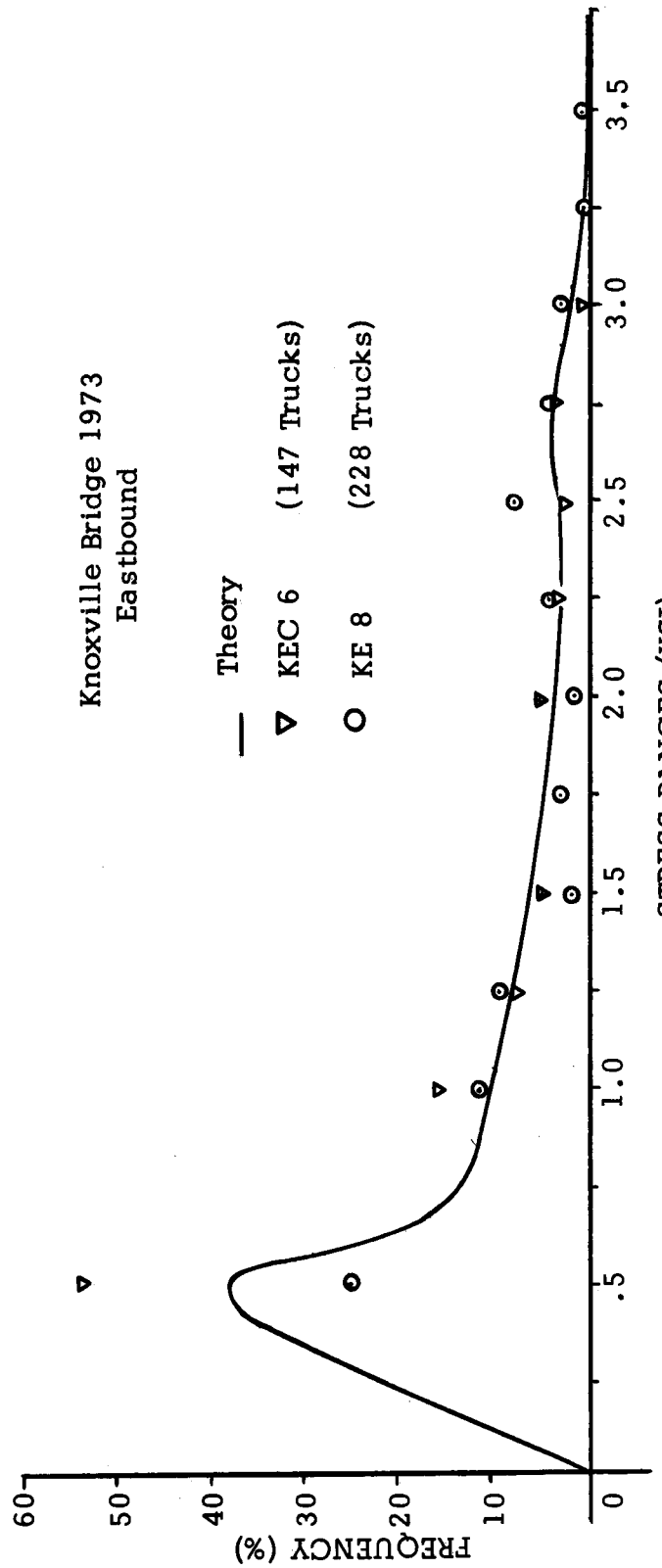


Figure 16. A comparison between observed and theoretical stress range distribution of 3S2 trucks - eastbound.

TABLE VI

COMPARISON BETWEEN OBSERVED AND THEORETICAL STRESS RANGE DISTRIBUTIONS - WESTBOUND

Ranges (Ksi)	Cumulative Frequency (%)		Frequency (%)		
	Observed	Predicted	Observed	Predicted	Difference
.75	45	44.30	19	14.09	4.91
1.00	56	56.24	11	11.94	.94
1.25	65	66.05	9	9.81	.81
1.50	71	73.93	6	7.88	1.88
1.75	79	80.16	8	6.23	1.77
2.00	83	85.02	4	4.86	.86
2.25	89	88.77	6	3.75	2.25
2.50	96	96.06	7	7.29	.29
2.75	99	99.08	3	3.02	.02
3.00	100	99.86	1	.78	.22
					Σ 13.95

TABLE VII

A COMPARISON BETWEEN OBSERVED AND THEORETICAL
STRESS RANGE DISTRIBUTIONS - EASTBOUND

Ranges (Ksi)	Cumulative Frequencies (%)		Frequencies (%)		Difference
	Observed	Predicted	Observed	Predicted	
.75	52.12	52.76	NA[a]	13.41	-
1.00	65.85	63.21	13.73	10.45	3.28
1.25	74.19	71.35	8.34	8.14	.20
1.50	77.67	77.69	3.48	6.34	2.86
1.75	81.12	82.62	3.45	4.93	1.48
2.00	84.40	86.47	3.28	3.85	.57
2.25	88.05	89.46	3.65	2.99	.66
2.50	93.35	92.97	5.30	3.51	1.79

TABLE VII (continued)

Ranges (Ksi)	Cumulative Frequencies (%)		Frequencies (%)		
	Observed	Predicted	Observed	Predicted	Difference
2.75	97.25	96.98	3.90	4.01	.11
3.00	99.10	98.89	1.85	1.91	.06
					$\sum$ 11.01

[a]NA stands for not available.

TABLE VIII

COMPARISONS OF HYPOTHESIS RESULTS AND OBSERVED DATA - WESTBOUND

Ranges (Ksi)	Observed Frequency (%)	Frequency Predicted (%)					
		H-1	Difference	H-2	Difference	H-3	Difference
.75	19.0	14.09	4.91	15.7	3.3	15.7	3.3
1.00	11.0	11.94	.94	14.1	3.1	14.1	3.1
1.25	9.0	9.81	.81	11.9	2.9	11.9	2.9
1.50	6.0	7.88	1.88	9.8	3.8	9.8	3.8
1.75	8.0	6.23	1.77	7.9	.1	7.9	.1
2.00	4.0	4.86	.86	6.2	2.2	6.2	2.2
2.25	6.0	3.75	2.25	4.9	1.1	4.9	1.1
2.50	7.0	2.90	4.10	3.8	3.2	3.8	3.2
2.75	3.0	2.20	.80	2.9	.1	7.3	4.3
3.00	1.0	1.60	.60	2.2	1.2	3.0	2.0
			$\sum$ 18.92		$\sum$ 21.0		$\sum$ 26.0

TABLE IX

COMPARISONS OF HYPOTHESIS RESULTS AND OBSERVED DATA - EASTBOUND

Ranges (Ksi)	Observed Frequency (%)	Frequency Predicted (%)					
		H-1	Difference	H-2	Difference	H-3	Difference
.75	NA[a]	13.41	-	39.35	-	39.35	-
1.00	13.73	10.45	3.28	13.41	.32	13.41	.32
1.25	8.34	8.14	.20	10.45	2.11	10.45	2.11
1.50	3.48	6.34	2.86	8.14	4.66	8.14	4.66
1.75	3.45	4.93	1.48	6.34	2.89	6.34	2.89
2.00	3.28	3.85	.57	4.93	1.65	4.93	1.65
2.25	3.65	2.99	.66	3.85	.20	3.85	.20
2.50	5.30	2.33	2.97	2.99	2.31	2.99	2.31

TABLE IX (continued)

Ranges (Ksi)	Observed Frequency (%)	Frequency Predicted (%)					
		H-1	Difference	H-2	Difference	H-3	Difference
2.75	3.90	1.82	2.08	2.33	1.57	3.51	.39
3.00	1.85	1.41	.44	1.82	.03	4.01	2.16
			$\sum$ 14.54		$\sum$ 15.74		$\sum$ 16.66

[a]NA stands for not available.

CHAPTER VI

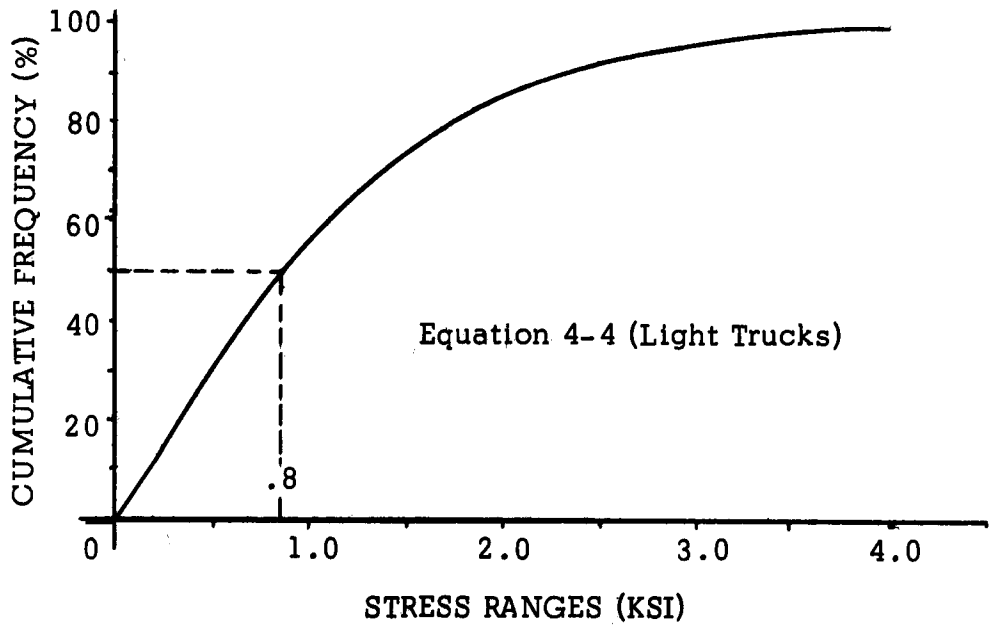
MEANS OF DISTRIBUTIONS

Since the stress range distribution was found to be a heterogeneous one, the mean of the distribution will not represent an average stress range of the distribution. A heterogeneous "population" is formed by combining two given "populations" in a given "population." A better way to express the significance of the distribution is to analyze each "population" separately.

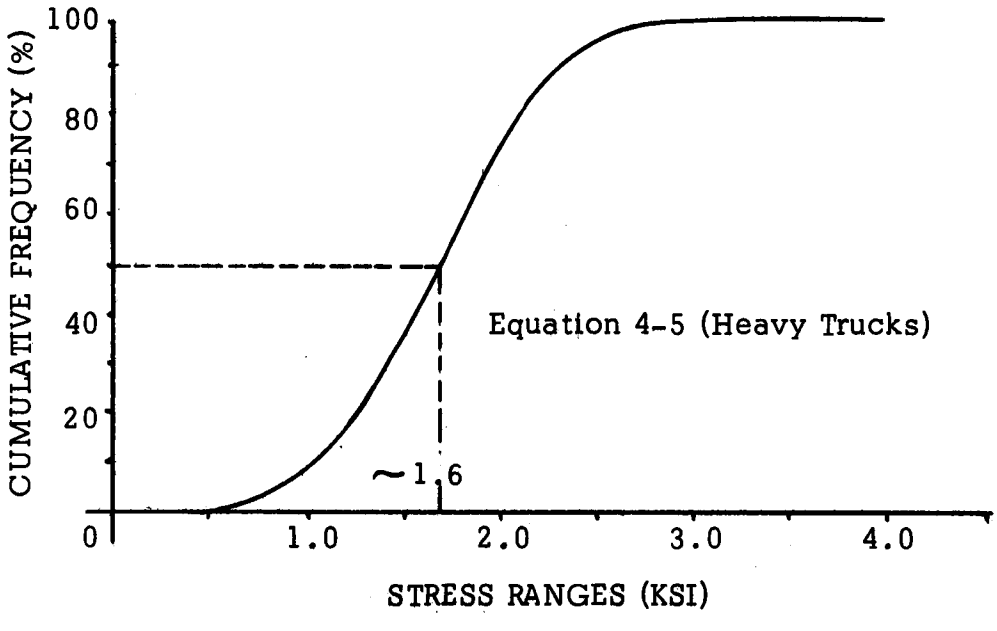
1. WESTBOUND

The theoretical cumulative frequencies of stress range distributions were plotted separately as shown in Figures 17 and 18. Figure 17 (a) was assumed to be the cumulative stress range distribution for light trucks, and, likewise, Figure 17 (b) was for heavy trucks. Figure 18, the combination of Figure 17 (a) and 17 (b), represented the theoretical cumulative distribution of stress ranges for all 3S2 trucks.

According to assumptions above, the mean stress range caused by light trucks was found to be approximately 0.8 ksi as may be seen on Figure 17 (a). For heavy trucks, the mean stress range was found to be approximately 1.7 ksi as shown on Figure 17 (b). However, 90 percent



(a)



(b)

Figure 17. Cumulative distribution of stress ranges due to light and heavy trucks - westbound.

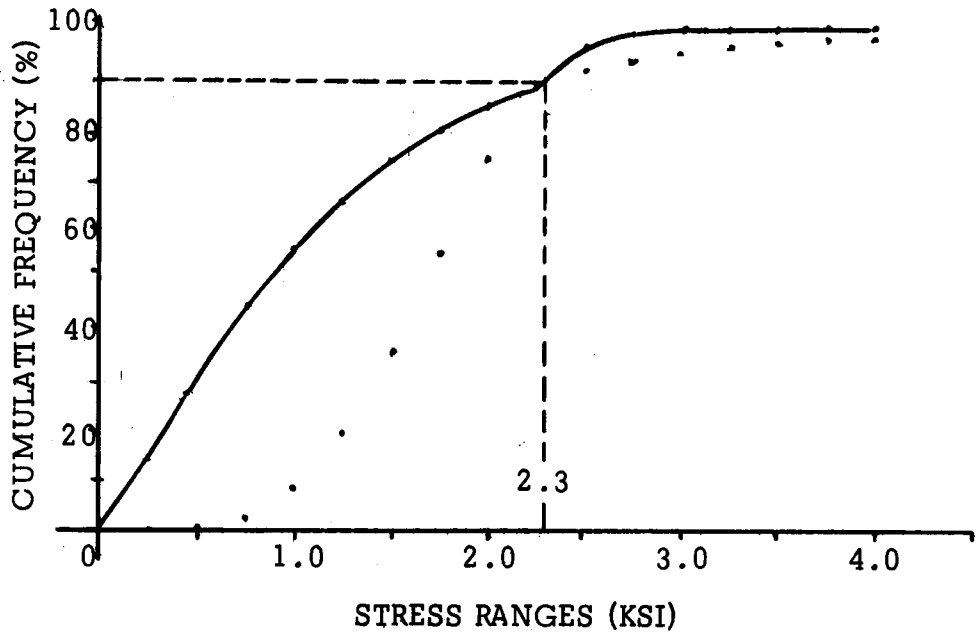


Figure 18. Theoretical cumulative frequency distribution of stress ranges - westbound.

of stress range occurrences on the bridge were found to be below 2.25 ksi as shown on Figure 18, page 62.

2. EASTBOUND

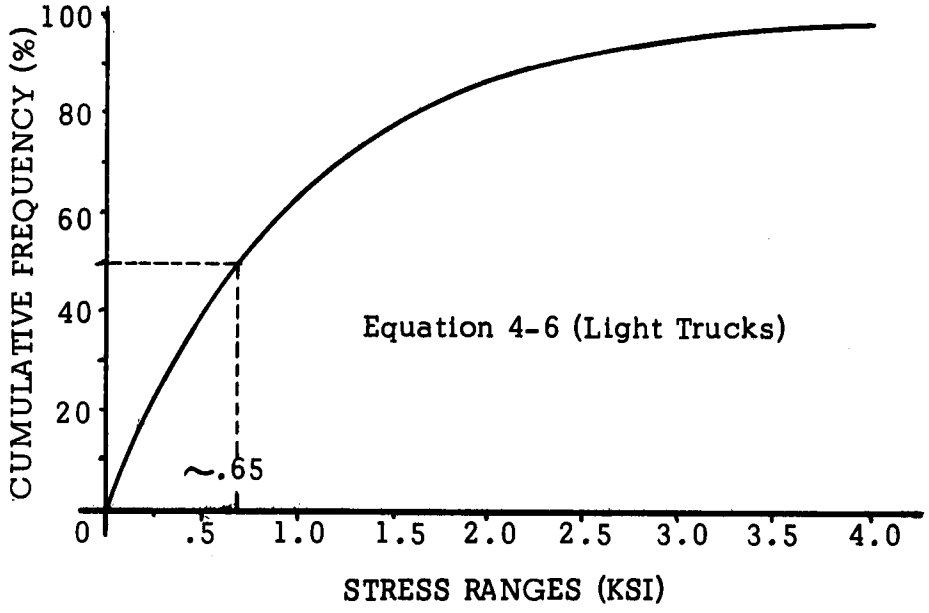
The same assumptions were made for Figure 19 (a), (b) and Figure 20 as in the westbound analysis.

Based on these assumptions, the mean stress range for light trucks was found to be approximately .8 ksi as may be seen in Figure 19 (a). For heavy trucks, the mean stress range on the bridge was found to be approximately 1.6 ksi as shown on Figure 19 (b). However, 90 percent of stress range occurrences on the bridge were found to be below 2.3 ksi as shown on Figure 20.

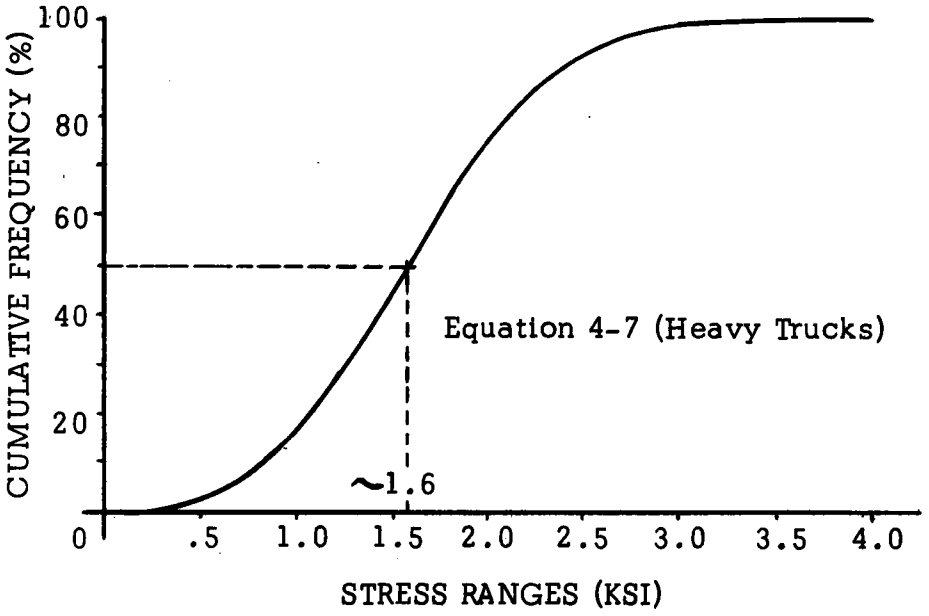
3. WESTBOUND AND EASTBOUND

In Figure 21 a comparison of theoretical stress range distributions due to 3S2 trucks and observed distributions due to all trucks was made. At stress ranges 1.0 ksi and above, the theoretical distribution showed good agreement with observed distributions. Discrepancies at low stress ranges were due to the fact that low stress ranges could not be identified.

Assuming that the theoretical stress range distribution is for all trucks, the following possible interpretations of Figures 18, page 62, and 20 can be made.



(a)



(b)

Figure 19. Cumulative distribution of stress range due to light and heavy trucks - eastbound.

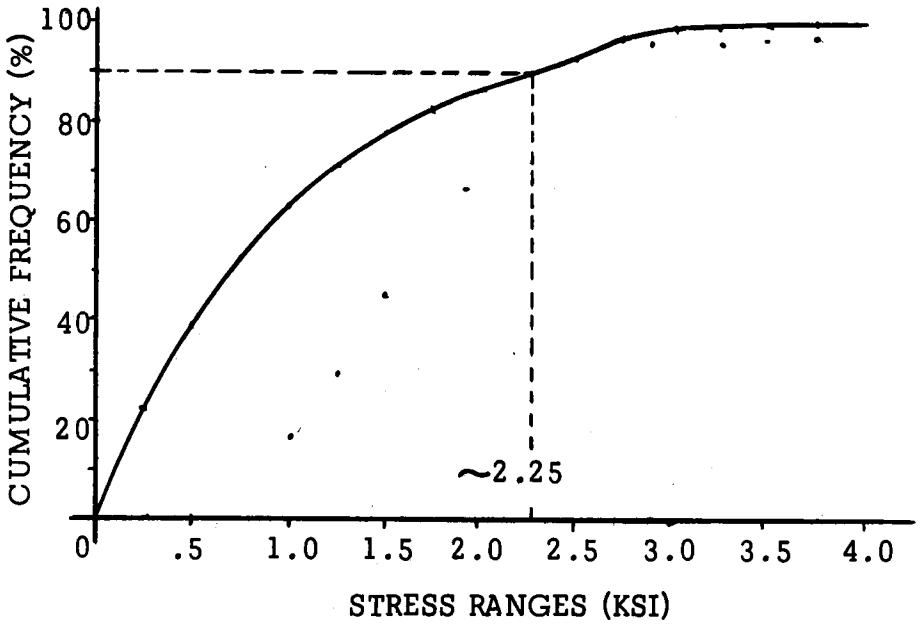


Figure 20. Theoretical cumulative distribution of stress ranges - eastbound.

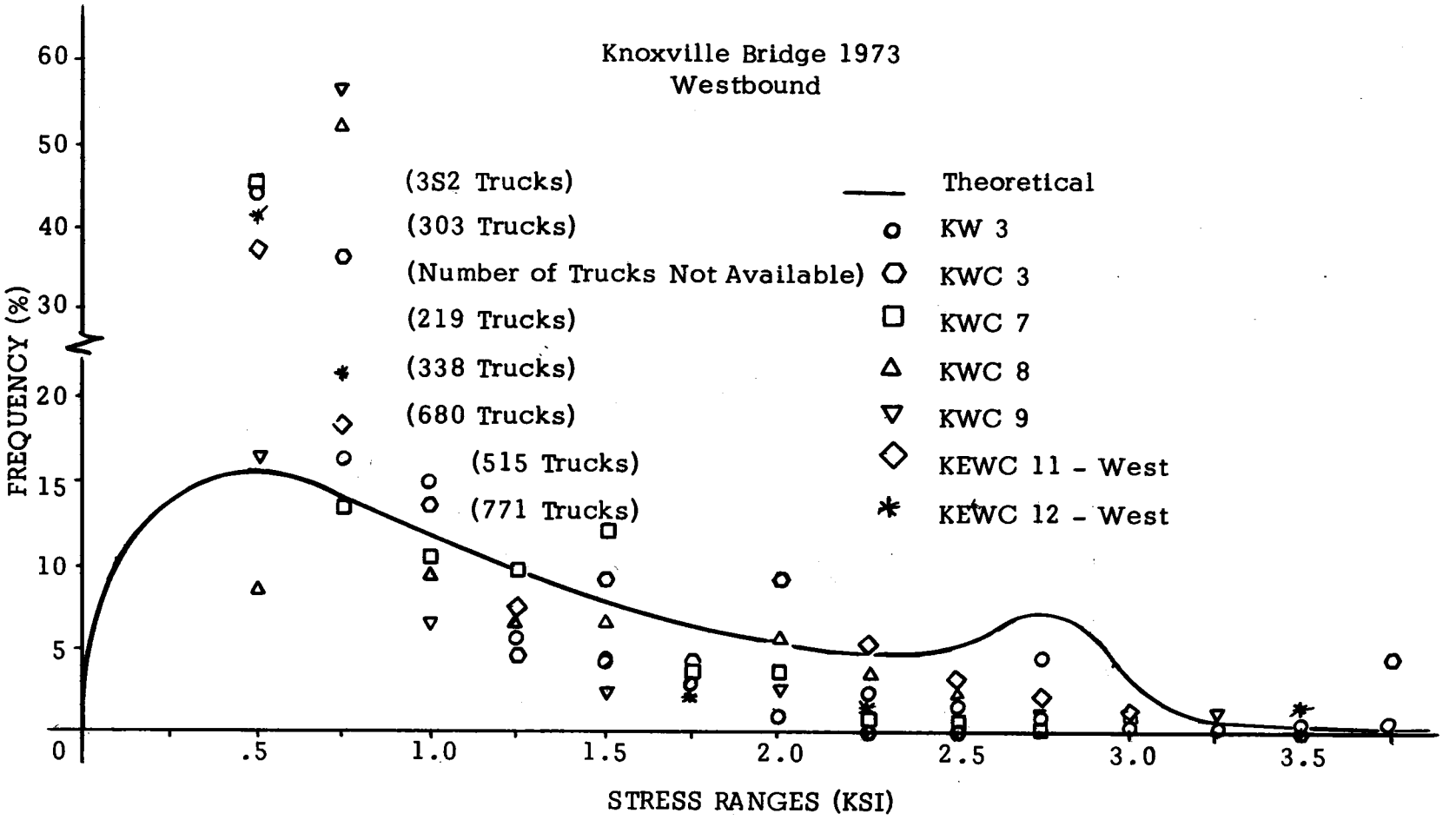


Figure 21. Comparison of theoretical stress range distributions of 3S2 trucks and all trucks - westbound.

1. Stress range distributions on both bridges composed of two distributions which were caused by two different populations. One of those populations was a population of light or empty trucks. The other population was a population of heavy trucks.
2. Approximately 90 percent of stress ranges on both bridges were below 2.25 ksi.
3. Fifty percent of stress ranges on both bridges which possibly were caused by light or empty trucks were approximately below .8 ksi.
4. Fifty percent of stress ranges on both bridges which were possibly caused by heavy trucks were approximately above 1.6 ksi.

CHAPTER VII

SUMMARY AND CONCLUSION

1. SUMMARY

Two Knoxville bridges which carried westbound and eastbound traffic of Interstates 40 and 75 were instrumented with strain gages. A computer system was used in recording the changes of strains on a girder due to a truck passage on the bridge. The strain at two locations on each girder was measured; the first location was at the end of the cover plate; and the second location was at the middle of the span. Every girder was instrumented except the outermost girders on the eastbound bridge.

Two methods of sampling were used. One method was individual sampling, and a second method was a continuous sampling program. Each method was also divided into two parts. The first part was to sample only a particular type of truck. The second part was to sample all types of trucks. During sampling periods, lane usage by trucks and types of trucks were recorded manually.

Gross weight data for the trucks were recorded at a nearby weigh station prior to the test. The weight distribution was compared with data taken for 24 hours in 1972. No significant difference was found within 95

percent confidence interval. The stress range data were reduced, and the most severely stressed girders were chosen to be studied. The results indicated that the location at the middle span of a girder was subjected to more severe stresses than at the end of the cover plate of the same girder. The middle span of the middle girder of each bridge was chosen for the study.

By investigating truck gross weight distribution, it was believed that either the distribution was bimodal or that the "population" distribution was the combination of two distributions. The first distribution was the weight distribution for light or empty trucks, and the second distribution was for loaded trucks. From this reasoning, the stress ranges occurring on the bridge also were believed to have a bimodal distribution. By investigating truck traffic distribution, 3S2 trucks were found to constitute 55 percent and above of all truck traffic. The 3S2 truck gross weight distribution was found also to be bimodal and at gross weights of 50 kips and above; 3S2 trucks were found to dominate the distribution of truck gross weights. Thus, 3S2 trucks were chosen to be studied.

An assumption was made that the distribution of stress ranges on a bridge was a Weibull distribution. Four approaches were made in the attempt to establish a best fitted curve for stress range distribution on each bridge. The final solution was that the curve was bimodal consisting of two combined distributions having zero as initial point. Four

mathematical expressions for the Weibull distribution were derived to represent the stress history data. These equations are given in Chapter IV.

Stress range distributions on both bridges were found to be skewed heterogeneous ones. Due to skewness characteristics, means of the distributions lost their significance in representing the average values of the distributions. The stress range distribution for each "population" was then analyzed separately.

Comparisons between the theoretical distribution, which were derived by using observed 3S2 stress range distributions, and the observed stress range distribution caused by all trucks were made. Good agreement was indicated. Interpretations of stress range distribution caused by all trucks were made.

2. CONCLUSIONS

Bearing in mind all the assumptions made, the study showed a possible solution in establishing a mathematical expression and corresponding mean of stress range distribution on a bridge by a graphical method. Once the mathematical expression was established, a corresponding frequency of a stress range could be identified. Once the range distribution for a bridge was identified and truck traffic flow was known, the fatigue behavior of steel could be used to predict a probable life of the bridge.

The stress range distribution for all trucks was similar to that for 3S2 trucks. The study and conclusions were based on the assumptions made and the interpretations of obtained and related data. The results showed good success which could be considered a valuable addition to the stress history research.

This study shows a graphical method in establishing a mathematical expression of stress range distribution on a bridge. The method is also believed to apply for truck weight distribution. However, as mentioned earlier in the study, weight distribution is believed to be a heterogeneous normal distribution instead of a heterogeneous Weibull distribution (extreme value distribution). Further investigation in establishing a mathematical expression for truck gross weight distribution is suggested. After the expression is established, a relationship of variables between stress range distribution and weight distribution is also suggested for an investigation. If the relationship is established, a prediction of stress range distribution can possibly be made without the requirement of stress range field data.

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LIST OF REFERENCES

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VITA

Peyabutr Sagooleim was born in Bangkok, Thailand, on June 19, 1950. He attended schools in that city until he finished his eleventh grade in 1967. He then transfered to a school in Seattle, Washington and graduated in 1968. The following September he entered the University of Washington, Seattle, Washington, and in June 1972 he received a Bachelor of Science degree in Civil Engineering. In September of the same year, he entered the Graduate School of the University of Tennessee. He received a Master of Science degree with a major in Civil Engineering in March 1974. Since March 1973, he has worked as a research assistant until the time he received his degree.

He was a member of the American Society of Civil Engineers, student chapter. Among friends and faculties during his studies in the United States, he was known as Peter.