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# DEVELOP MODIFICATION & ENHANCEMENTS TO EXISTING BRIDGE RATING PROGRAMS SALOD & FORCE

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16. Abstract
SALOD and BRUFEM are computer programs developed in research at the University of Florida sponsored by the Florida Department of Transportation. Originally a program entitled SALOD was developed. The function of SALOD is to predict a lateral load distribution factor (LLDF) for design and rating of simple span bridges. A data base of influence surfaces was developed using finite element model. The finite element model considered the three-dimensional nature of the distribution of individual wheel loads throughout the full superstructure. The data base was developed to represent existing simple span bridges in the State of Florida. SALOD has been in use by Florida DOT for several years now. They use the program to obtain lateral load distribution factors in conjunction with the rating of simple span bridges subjected to standard and overload vehicles. This volume (Volume One of Two) documents recent changes in the SALOD program. Bulb tee girders and a seventh girder for all girder types have been added to the data base. Also, a procedure is reviewed which permits consideration of bridges with more than seven girders. The program was also modified to accept a wider range of special vehicles than previously permitted. Other minor changes included adding a new standard vehicle and introducing a probability reduction factor for bridges loaded by two or more vehicles. In order to make the database of influence surfaces reasonable in size, a number of simplifying assumptions were made in the modeling. Now the BRUFEM program is being developed as a complete bridge rating program using a finite element model as the basic analysis tool. Volume Two of Two documents the original development of BRUFEM.

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# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | **LENGTH** | | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | **AREA** | | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | **MASS (weight)** | | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | **VOLUME** | | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | **TEMPERATURE (exact)** | | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

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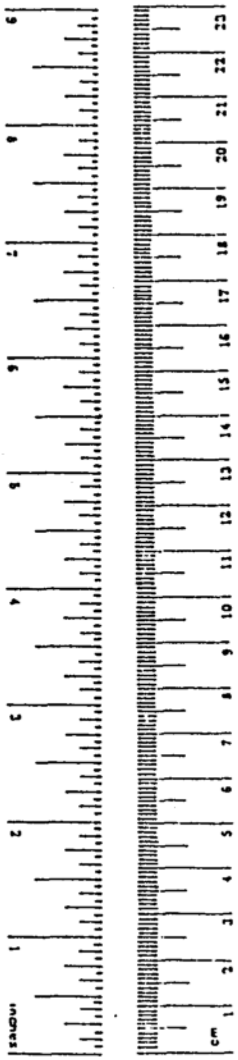
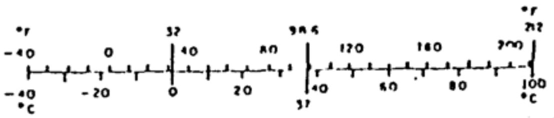
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | **LENGTH** | | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | **AREA** | | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | **MASS (weight)** | | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | **VOLUME** | | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | **TEMPERATURE (exact)** | | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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# CHAPTER I

# INTRODUCTION

## 1.1 Summary of Research Objectives

Lateral load distribution for highway bridges has been the topic of previous research over the last several years by the University of Florida (6,8,9). The lateral load distribution factors are used in the design, analysis, and rating of bridges. Guidelines published by the American Association of State and Highway Transportation Officials (1) (AASHTO) offer empirical formulae to compute lateral load distribution factors. Since AASHTO guidelines are minimum design standards, the distribution factors which are calculated must be conservative for most applications. The AASHTO formulae compute distribution factors based only on the bridge type and girder spacing. Many other factors which influence the distribution of loads such as bridge length, girder size, slab thickness, and material strengths are neglected.

The Florida Department of Transportation (FDOT) routinely uses distribution factors to perform inventory rating of bridge capacities. Inventory rating is the maximum load which a bridge can carryindefinitely when loaded with standard design vehicles (9). The FDOT also uses distribution factors to analyze bridges for an operating rating, which is the maximum load which a bridge can carry on an infrequent basis (9). Operating ratings are generally performed on heavily loaded or non-standard vehicles which request permission to cross a bridge.

The distribution factors obtained from AASHTO procedures are most often conservative. Because of the conservatism, many trial routes for an overloaded or non-standard vehicle may have to be analyzed until an acceptable route may be found. Analyzing many routes may cause unnecessary delays and/or may necessitate rerouting of non-standard or overloaded vehicles. In an effort to improve the calculation of distribution factors, FDOT has sponsored research by the University of Florida to study distribution factors and find a more accurate procedure to compute them. Better distribution factors will improve bridge ratings and may avoid unnecessary rerouting of overloaded and/or nonstandard vehicles.

The previous research work (6,9) led to the development of the - FORTRAN computer program SALOD (Structural Analysis for Load Distribution). This program is used to calculate more accurate lateral load distribution factors based on flexure for highway bridges. The SALOD program uses a database of influence surfaces for midspan moment created using the finite element method. The finite element models used to create the influence surfaces include most of the bridge parameters which affect lateral load distribution. Included in the finite element models were bridge type, girder spacing, bridge length, girder size, slab thickness, material properties and end diaphragms. By using these parameters, the distribution factors computed by the SALOD program are more accurate and not as overly conservative as those computed by the empirical formulae of AASHTO.

The program SALOD has been in use for several years now by the FDOT to obtain live load distribution factors (13). Over this time period, FDOT has discovered some areas in the program which could be expanded or improved upon. This prompted a request by the FDOT to make several modifications to the program which would allow a wider range of bridges and vehicles to be analyzed. Prior to this research the program SALOD could analyze prestressed, steel and tee beam girder bridges which have four to six girders and the program could analyze flat slab bridges.

A major research objective was to add bulb tee concrete girder bridges to the database of influence surfaces. The concrete bulb tee girder is being adopted as a standard construction system for MOT bridges. The database which was added for bulb tee concrete girders includes bridges which have four to seven girders. It was felt that it would be beneficial to add this new girder cross section to the SALOD program.

Another major research objective was to expand the current database of influence surfaces to include a seventh girder. This change would affect the prestressed, steel, and tee beam girder bridges. The program now allows bridges with from four to seven girder bridges to be analyzed directly. And, as described herein, the program may be used to find approximate distribution factors for bridges with more than seven girders.

Their were several other objectives for this research which were meant to expand the capabilities of the SALOD program. A new nonstandard vehicle input routine was added which will allow more flexible input of non-standard vehicles. To update the standard vehicles which are available in the program, a new standard vehicle was added. This new standard vehicle is the straight truck with one trailer (FDOT standard ST5). Also, a user input probability reduction factor was added when there are two or more trucks on the bridge. This allows the user to take into account the decreased probability of multiple trucks acting simultaneously, such as given in AASHTO Section 3.12.

There were several other minor modifications which have been made to improve or correct the program SALOD. All of the modifications and enhancements made to the program SALOD are discussed in detail in Chapter 3 of this report.

## 1.2 Organization of Report

Chapter 2 contains a summary of the previous research projects (6,9) on the study of lateral load distribution factors based on flexure for highway bridges. This summary includes a brief discussion on the finite element method as well as a discussion on the programs SALOD and BRUFEM (Bridge Rating Using the Finite Element Method). Chapter 3 is the major portion of the report and includes a discussion on all of the modifications and enhancements of the program SALOD. Chapter 4 describes the testing and verification of the modifications which were made to the program SALOD. It also includes discussions on how to handle bridges which have more than 7 girders. Chapter 5 summarizes all of the assumptions made during the three research projects and highlights the current capabilities of the SALOD program. Chapter 6 presents the conclusions and recommendations from this research. Appendix A contains a revised SALOD user's guide which has been updated to reflect the current capabilities and required input for the program. Appendix B contains sketches of the different bridge types along with the finite element models which were used. The sketches also show definitions of terms which are used in the report to describe the finite elements. Appendix C contains a revised listing of bridge file names in the influence surface database.

# CHAPTER II

# SUMMARY OF PREVIOUS RESEARCH

## 2.1 Introduction

Previous research work was done to study lateral load distribution on bridges. It was felt that the recommended lateral load distribution factors (LLDF's) computed by following the AASHTO procedures were overly conservative in many cases. The FDOT felt that a more accurate method should be developed. This led to the development of the computer program SALOD (6,9).

SALOD is a FORTRAN program that uses a database of influence surfaces for midspan girder moment to compute LLDF's. This database was developed by creating finite element models of the bridges and then running the models using the structural analysis programs STRUDL (12) or GTSTRUDL (4).

The previous research (6) also led to the development of a FORTRAN program called FORCE. The program FORCE has been modified in related research (7) and is now called BRUFEM (Bridge Rating Using the Finite Element Method). The program BRUFEM allows a finite element model of a bridge to be easily generated by simple input by the user of bridge geometry, properties, and loadings. The output file from the BRUFEM program is an input file that can be used for a STRUDL finite element analysis. BRUFEM was used for performing some of the checks to the modifications which have been made to SALOD in this research.

The remainder of Chapter 2 will discuss the previous research. The discussion will include a brief introduction to the finite element method and a discussion of the programs SALOD and BRUFEM, including a brief discussion of the finite element models used in these programs.

## 2.2 The Finite Element Method

The Finite Element Method (FEM) is a commonly used structural analysis procedure. This discussion is only a brief review of the FEM. A more detailed explanation of the FEM or the theory behind it may be found in many standard structural analysis texts such as references (11) or (16).

A finite element model is created by breaking down a large structural system (such as a bridge) into an equivalent system of smaller units called finite elements (such as beams and plates). These finite elements are interconnected at nodal points common to one or more elements. The boundary conditions and applied loads are specified at the nodes of the finite element model. The model is then solved for the displacements and/or forces at the nodes using a FEM analysis program such as STRUDL.

There are many standard finite elements which have already been derived based on assumed strain/displacement and stress/strain relationships. The finite elements used in a finite element model must be selected properly so that their deformational behavior will model the structural system correctly. The finite element procedure requires determination of the stiffness matrices of the individual finite elements. The FEM analysis program will take these individual stiffness matrices and assemble them to form the global stiffness matrix for the structural system. A major step in the FEM is the solution of the matrix equation F = K*d (applied nodal forces = stiffness matrix * nodal displacements). Using the direct stiffness method, the applied nodal forces and the stiffness matrix are found and then nodal displacements may be found. Once the nodal displacements are known, the internal element forces can be found. The resulting solution is an approximate one, but can be very accurate providing that the proper finite elements are chosen and providing that there are a sufficient number of finite elements for the model.

## 2.3 The Computer Program SALOD

The computer program SALOD was developed in previous research (6,9) in an effort to obtain more accurate LLDF's for bridge rating since it was felt that the AASHTO procedures were overly conservative in many cases. The AASHTO formulae for computing distribution factors are empirical and depend only on the bridge type and girder spacing. Many other factors affect the lateral distribution of loads on bridges. These factors would include bridge length, girder size, material strengths, and slab thickness.

The most accurate way to obtain LLDF's would be to run ,a full finite element analysis on the bridge in question. However, this would be expensive in terms of computer time and manpower if this was done for every bridge which required analysis. Previous research (6,9) led to the development of a relatively inexpensive and simple procedure. A database of midspan girder moment influence surfaces was created by running finite element analyses of selected bridges. The SALOD user has to input the various bridge parameters and loadings of the bridge he wishes to analyze and SALOD will then interpolate or extrapolate from the database of influence surfaces and compute the LLDF's.

To help determine a database range, a state wide bridge survey of existing bridges was performed to determine the different range of parameters such as bridge type, girder spacing, girder size, slab thickness, concrete strengths, bridge lengths, and bridge widths which existed. Using this information, -a database was created such that it would encompass most of the existing bridges. This required many assumptions regarding the different bridge parameters to be made. Most all of these assumptions were verified in the previous research (6,9).

Once a database range was selected, a finite element analysis had to be performed on each bridge in the database to obtain an influence surface of midspan girder moments for that bridge. The influence surfaces were obtained by applying the Muller=Breslau¯Principle (6). This principle simply stated is that an influence surface may be obtained by applying a unit displacement corresponding to the desired force and computing the resulting displacements. The resulting displacement values are the values of the influence surface. For the SALOD program, an influence surface for midspan girder moments was needed. Therefore, a unit rotation (displacement corresponding to the moment) was applied at midspan and the corresponding deflections were computed. These deflections were the influence surface and were stored in the database.

To develop the database of influence surfaces required that a finite element analysis had to be performed on each of the bridges in the database. The elements which were chosen for the model were beam elements for the girders and end diaphragms and plate elements for the deck slab. The beam elements are standard beam elements having three degrees of freedom at each of the two nodes. The plate elements which were used are bending plate rectangles (BPR) which have three degrees of freedom at each of the four nodes. The degrees of freedom for both element types include two rotations and one vertical displacement at each node.

Each of the different bridge types were modeled in a slightly different way. The models which were used are shown in the figures in Appendix B. All the girder type bridges were modeled in two dimensions with composite girder properties being used. These composite girder properties were transformed into the modulus of the deck slab by using the modular ratio (n = Eg/Es). In the modular ration equation, Eg is the modulus of elasticity of the girder and Ec is the modulus of elasticity of the deck slab. The prestressed and steel girder bridges were modeled using end diaphragms. The prestressed and tee beam concrete girder bridges were modeled with thickened. plate elements over the girders to take into account the lateral stiffness of the girder flange. Refer to the previous research reports (6,9) for a more detailed description of the modeling.

The finite element procedure allows for symmetry to be used if the proper boundary conditions are applied. For the finite element models which were run, longitudinal symmetry about midspan was used so that only a half-span model was required. Once the finite element analysis was performed, the output from STRUDL was edited and the displacements were stored in the database as midspan girder moment influence surfaces.

The SALOD program works by having the user input the type and geometry of the bridge to be analyzed. SALOD then takes the geometry of the input bridge and interpolates or extrapolates from the database the bridges which are closest to the input bridge. This interpolation or extrapolation results in an influence surface being generated for the bridge being analyzed. The user then inputs the vehicles (three vehicles maximum) which are on the bridge. SALOD takes the. first vehicle input as the reference vehicle and computes the simple beam midspan girder moment for this vehicle. SALOD then takes the vehicle system which is on the bridge and shifts it longitudinally and transversely to obtain the maximum midspan girder moments for each girder. The midspan girder moments are computed by distributing each wheel load to the finite element nodes and then multiplying each nodal load by the corresponding influence surface value. These values are then summed up to obtain the midspan girder moment. The LLDF's for each girder are computed by taking half of the midspan girder moment and dividing it by the simple beam moment of the reference vehicle. For flat slab bridges, the effective width is computed instead of the lateral load distribution factors.

The LLDF's which are computed by the SALOD program are calculated at the midspan of the bridge. However, it is well known that the maximum moment due to a series (train) of concentrated loads does not necessarily occur at midspan. Studies performed in previous research (9) indicated that while the assumption that the maximum moment occurs at midspan may produce a significant difference in the maximum moments, there is a negligible change in the distribution factors.

To obtain more accurate moments than those given by the SALOD program, the user should use the LLDF's output from the SALOD program with the "wheel loads" of the reference vehicle as would be done if the AASHTO LLDF's were being used. In other words, the user should multiply the reference vehicle wheel loads by the LLDF's obtained from the SALOD program and then perform a standard beam analysis for these wheel loads which will determine the position and magnitude of the maximum moment. It should be noted that the results from SALOD are only valid for the computation of the design live load moment due to the vehicle system and that impact and structure dead loads are neglected.

### 2.4 The Computer Programs FORCE and BRUFEM

Previous research (6) lead to the development of a FORTRAN program called FORCE which was created to perform shear studies. FORCE was a program which created an input file for STRUDL runs of bridges loaded with vehicles. This program has been modified in related research (7) and is now called BRUFEM (Bridge Rating Using the Finite Element Method). BRUFEM was used in this research to verify some of the modifications and enhancements which have been to the SALOD program.

The program BRUFEM allows the user to input the bridge type, geometry, materials, and vehicle loadings on a bridge which is to be analyzed. The vehicle loadings are similar to those in SALOD, with both standard and non-standard vehicles being available. From the user input information, the program then generates a full span finite element model input file for STRUDL. The program is very powerful and flexible and allows for the creation of input files for complicated bridges very easily.

The BRUFEM program was developed to have more capabilities than the SALOD program. These extra capabilities allow BRUFEM to model bridges with continuity of the girders, skew, intermediate diaphragms, and edge stiffeners or parapets. However, for bridges in which the SALOD program is applicable, most of the assumptions made for the BRUFEM program are the same as those for the SALOD program. There are some differences in the assumptions that should be pointed out. BRUFEM uses a different plate bending element for the deck slab. It uses bending plate parallelogram (BPP) elements since they can be used in bridges with skew. These elements degenerate into the BPR elements which were used in creating the database for SALOD since there is no skew in the SALOD models. Also, instead of using thickened plate bending elements over the girders, BRUFEM uses lateral beam elements. It is felt that using lateral beam elements over the girders is more appropriate than thickened elements to model the transverse stiffness of the beam flanges. Because of these minor modeling changes the comparisons between the SAL00 analysis and the BRUFEM analysis may be off a few percent. Examples of such comparisons are presented in Chapter 4.

# CHAPTER III

# MODIFICATIONS TO THE SALOD COMPUTER PROGRAM

## 3.1 Introduction

The primary objective of this research was to make enhancements and modifications to the SALOD program which were deemed desirable by FDOT personnel. The major modifications which have been made are the addition of bulb tee concrete girders and the addition of a seventh girder for prestressed, steel, and tee beam girders to the database of influence surfaces. Several other minor modifications were made which include the addition of a multi gage non-standard vehicle, probability reductions for multiple vehicles, a new standard vehicle, increasing overall program efficiency, and corrections of other program problems.

All modifications which were made to the SALOD program were meant to expand the capabilities of the program. The general concept of the program has not been changed, rather it has been expanded. A user familiar with the previous version of the program will find that options have been added, but none have been removed. Each of the modifications and enhancements which were made to the program SALOD will be discussed in detail in the sections which follow.

## 3.2 Addition of the Bulb Tee Girders

As mentioned in the introduction, the addition of bulb tee girders to the program SALOD was a major modification. This addition was necessary since FDOT is adopting the bulb tee girder as one of their standard construction systems.

Some of the decisions which had to be made in order to model the bulb tee girders included the range of girder lengths, girder spacings, and girder types. The type of finite element model which was to be used in forming the database using the program STRUDL also had to be determined. These decisions will be discussed in the sections that follow.

### 3.2.1 Range of the Bulb Tee Girder Database

Since the bulb tee girders would be a new addition to the SALOD program, a database of midspan girder moment influence surfaces had to be generated. The database would be generated using the same procedures as in the original research. The first step in generating the database was to select the range of span lengths, girder spacing, and girder types which would be used.

In the previous research a parameter survey was made by sending questionnaires to all Florida District Engineers. The purpose of the survey was to obtain data on the types of existing bridges in the state. Part of this survey data was then used to develop the database ranges based on girder types, girder spacing, and span lengths.

For the bulb tee girders, a survey was not made since the bulb tee cross section is a new section and there would not be enough information gathered from a survey. The database range for the bulb tee girders was developed by reviewing the survey data for the prestressed, steel and tee beam girder bridges. Using engineering judgments and the previous survey data, a database range for the bulb tee girders was developed and is shown in Figure 3.1.

TYPE 1 GIRDERS
(54" DEEP)

| SPAN LENGTH | GIRDER SPACING 5.0’ | 8.0’ | 11.0’ |
|---|---|---|---|
| 60’ | X | X | X |
| 90’ | X | X | X |
| 120’ | X | X | X |

TYPE 2 GIRDERS
(63" DEEP)

| SPAN LENGTH | GIRDER SPACING 5.0’ | 8.0’ | 11.0’ |
|---|---|---|---|
| 60’ | X | X | X |
| 90’ | X | X | X |
| 120’ | X | X | X |
| 150’ | X | X | X |

TYPE 3 GIRDERS
(72" DEEP)

| SPAN LENGTH | GIRDER SPACING 5.0’ | 8.0’ | 11.0’ |
|---|---|---|---|
| 90’ | X | X | X |
| 120’ | X | X | X |
| 150’ | X | X | X |

Figure 3.1 BULB TEE CONCRETE GIRDER BRIDGE SPAN LENGTH AND GIRDER SPACING COMBINATIONS

### 3.2.2 F.E. Modeling of the Bulb Tee Concrete Girders

The bulb tee database was developed in the same manner as the previous databases. This involved creating finite element models of the bridges and then analyzing the bridges using the finite element program STRUDL. The finite element model which was selected to model the bulb tee bridge consists of beam elements for the girders and end diaphragms, and plate bending elements for the deck slab. Refer to Figures B.1 and B.2 in Appendix B for sketches showing the finite element modeling used for the bulb tee concrete girder bridges.

There are two different ways which the composite action of the girders and deck slab could be modeled using the beam and plate bending elements. The first method would be to analyze the bridge as a three dimensional model, where the beam and plate bending elements would be input with their actual properties and then give the eccentricities between the beam and plate bending element centroids. The second analysis method would be a two dimensional (2D) model. Using this 2D model, the composite girder properties would be calculated and then transformed into the modulus of the slab elements by use of the modular ratio n=Eg/Es. It was decided to follow the previous research (6,9) and use a 2D model with the composite girder properties being used for the beam elements.

For the bridge diaphragms which span transversely between girder centerlines, it was determined that since intermediate diaphragms vary considerably in both location and size, that only end diaphragms would be used in the finite element model. This is the same assumption made for the development of the other influence surface databases. The beam elements which were used for the end diaphragms had the same properties as the diaphragms for the prestressed and steel girder bridges which are in the existing database. The end diaphragms were assumed to be concrete having cross sectional dimensions of 8" x 54" and having a strong axis moment of inertia of 105,000 in. $^4$ and a torsional stiffness of 9000 in.$^4$.

The plate bending elements which were used for the concrete deck slab were plate bending rectangle (BPR) elements. Six plate elements of equal width were placed between the girder centerlines, and one additional plate element on the outside of each exterior girder centerline. This modeling is similar to that used in developing the steel girder bridge database. However, in order to take into account the stiffness of the bulb tee girder flange, the slab elements over the girder flange were artificially thickened. The thickness used for the thickened plate elements was computed by taking the average thickness of the slab and the girder flange over the width of the plate element. A sketch of these thickened elements is shown in Figure 3.2, and the actual thicknesses used are shown in Table 3.1.

Table 3.1 Bulb Tee Thickened Plate Bending Elements

| GIRDER SPACING (ft) | PLATE ELEMENT WIDTH (in) | PL. ELEMENT THICKNESS (in) | | |
|---|---|---|---|---|
| | | $T_1$ | $T_2$ | $T_3$ |
| 5 | 10.0 | 12.42 | 10.80 | 7.98 |
| 8 | 16.0 | 11.83 | 8.42 | 7.00 |
| 11 | 22.0 | 11.26 | 7.21 | 7.00 |

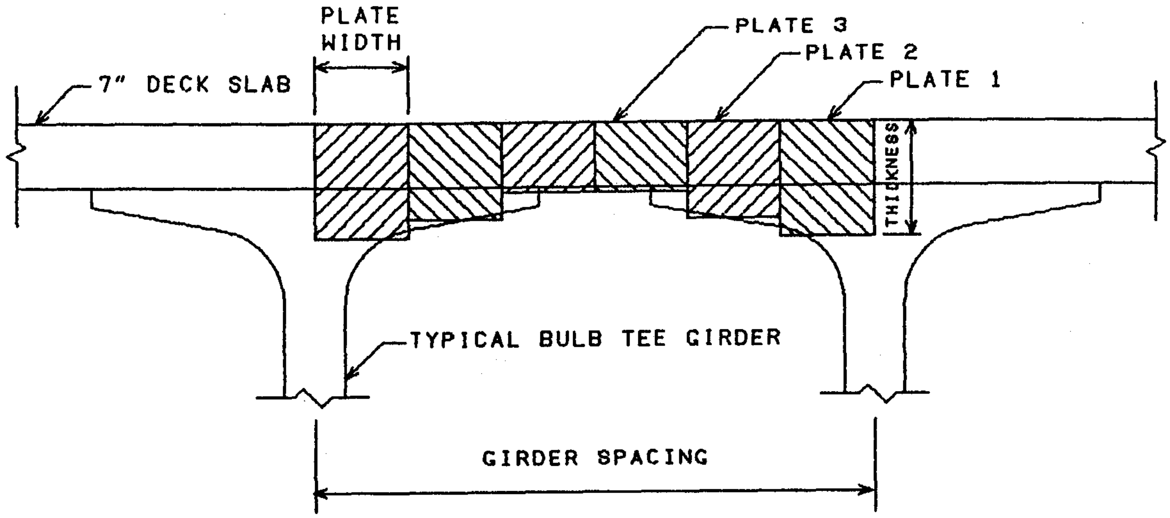


Figure 3.2 SKETCH SHOWING THICKENED PLATE BENDING ELEMENTS FOR CONCRETE BULB TEE GIRDER FINITE ELEMENT MODEL

### 3.2.3 Calculation of Bulb Tee Concrete Girder Properties

The properties of the bulb tee girders which were needed were the area, strong and weak axis moments of inertia, and the torsional stiffness. Once the individual girder properties were known they were then used to compute the composite girder properties. Since a two dimensional model was being used, these composite girder properties were then transformed into the slab modulus of elasticity by using the modular ratio, n.

To save time and insure accuracy, the area, strong axis moment of inertia, and the weak axis moment of inertia were calculated used a section property program called SECT2 (5). A sketch of the typical bulb tee section which was analyzed is shown in Figure 3.3. The results of this analysis are shown in Table 3.2.

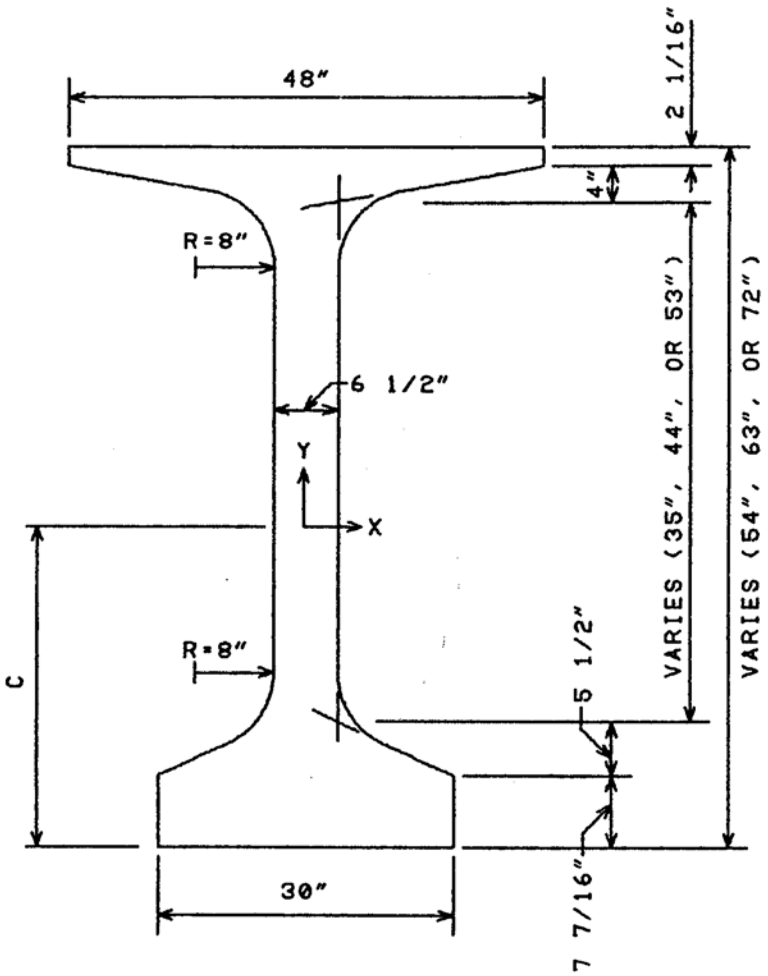


Figure 3.3 SKETCH SHOWING TYPICAL BULB TEE CROSS SECTION

Table 3.2 Concrete Bulb Tee Girder Properties

| BULB TEE TYPE | DEPTH (in.) | C (in.) | AREA (in.$^2$) | $I_x$ (in.$^4$) | $I_y$ (in.$^4$) | J (in.$^4$) |
|---|---|---|---|---|---|---|
| 1 | 54 | 25.97 | 785.24 | 312925. | 51709. | 26941. |
| 2 | 63 | 30.21 | 843.74 | 460028. | 51915. | 25883. |
| 3 | 72 | 34.48 | 902.24 | 641202. | 52121. | 28033. |

The torsional stiffness, J, for the concrete bulb tee girders were calculated using a finite element program which is described in a previous research report (15).

Because the bridge was modeled in two dimensions rather than three, the composite girder properties of the girders had to be calculated. These composite properties were computed following AASHTO procedures (Section 10.38.3) for effective slab width. The effective width was computed as the smaller of:

(1) The girder spacing
(2) 12 times the slab thickness
(3) The span length divided by 4

Once the effective slab width was known, the composite section properties were calculated. Since the actual edge conditions might vary considerably in practice, it would be difficult to develop a database of influence surfaces which could cover all of the possible edge conditions. Therefore it was assumed that the exterior girders had the same effective width as interior girders. This deviates from the AASHTO procedures, however it was felt that using the full effective width for the exterior girder will cancel out the effects of neglecting any parapets or other edge conditions that might exist in the actual bridge.

Once the composite section properties were computed, they were then transformed into the slab modulus using the modular ratio, n=Eg/Es. The torsional stiffness was not adjusted for composite action because previous research (10,14) had shown that the torsional properties of the girders had a minor influence on lateral load distribution.

## 3.3 Addition of the Seventh Girder to the Existing Database

The other major modification which was made to the SALOD program in this research was the addition of a seventh girder to the existing databases for the prestressed, steel, and tee beam girder bridges. The finite element models and assumptions which were used for the addition of the seventh girder are the same ones used in the previous research to develop the database for bridges with four to six girders (6,9).

### 3.3.1 Prestressed Concrete Girders

Refer to Figures B.1 and B.3 in Appendix B for sketches showing the finite element models used. The prestressed concrete girder bridges were modeled using thickened plate elements over the girders. There were six plate elements between girder centerlines with two different transverse plate sizes. The model included concrete end diaphragms. The properties for the beam elements along the girder were the composite beam properties which were transformed into the slab modulus.

### 3.3.2 Steel Girders

Refer to Figures B.1 and B.4 in Appendix B for sketches showing the finite element models used. The steel girder bridges were modeled using six plate bending elements between the girder centerlines. The plates were all of equal thickness and width. End diaphragms were modeled with beam elements. The transformed composite properties of the girder were input for the longitudinal beam elements.

### 3.3.3 Tee Beam Concrete Girder

Refer to Figures B.1 and B.5 in Appendix B for sketches showing the finite element models used. The concrete tee beam bridges were modeled using thickened plate bending elements over the girders. The thickened plate elements had a thickness equal to twice the slab thickness. The composite properties of the girders were used, however they did not had to be transformed since the girder and slab are monolithic and have the same concrete strength. As was done in the previous research (9), the longitudinal slab moments were accounted for by factoring the girder moment obtained by the ratio of the composite to non-composite girder moments of inertia. It should also be noted that the finite element analysis for the addition of the seventh girder to the tee beam database was performed using STRUDL and BPR plate bending elements. The previous research (9) had used GTSTRUDL and BPHQ plate bending elements to develop the database for the tee beam bridges with four to six girders.

## 3.4 Non-Standard Multi-Gage Vehicle Option

In order to make the SALOD program handle a wider range of nonstandard vehicles, a new vehicle input routine was added to the existing vehicle input routine. The old routine allowed for the input of axles which had only one axle gage and only one wheel spacing per axle. However, feedback from FDOT personnel using the SALOD program indicated that some special purpose vehicles could not be analyzed through this limited form of input. It was decided to add a new non-standard vehicle input routine which allows input of vehicles which have multi-gage axles. It should be noted that the old non-standard vehicle routine is still present in the program. The user has the option of selecting either the old single gage axle input or the new multi-gage option. It is highly recommended that the single gage option be used when it possible since it requires considerably less input.

To create a more general input for non-standard vehicles, the input routine was modified to allow the input of axles which had up to 7 axle gages and 8 wheel spacings. A discussion of how to use this new option is in the revised user's manual in Appendix A. Included are sketches and examples on using this multi-gage axle option.

In making the changes to the non-standard vehicle input routine, several restrictions were modified. The old routine restricted the user to input non-standard vehicles which had a maximum of 9 axle groups, 6 axles per axle group, and 12 wheels per axle. For single gage nonstandard vehicles the new restrictions are a maximum of 9 axle groups and 500 wheels total (no limit on # axles/group or # wheels/axle). For the new multi-gage non-standard vehicle the restrictions are a maximum of 9 axle groups, 7 axle gages, 8 wheel groups per axle, and 500 wheels total.

An additional feature which was added to the multi-gage option is the ability to duplicate an axle group if the geometry and loading is the same as a previously defined axle group. This situation would occur for example on a double trailer truck (ST5) in which the tandems on each trailer are identical but must be input as two axle groups. The user now has the ability to define the first axle group geometry and loading and then duplicate that input for the second axle group.

### 3.5 Probability Reduction for Multiple Vehicles

The AASHTO code in Section 3.12 allows for a reduction in the load intensity when there are multiple lanes loaded simultaneously. This reduction is allowed because of the improbability of coincident maximum loading (1). It was felt that the SALOD program should be modified to allow a similar reduction.

A new option was added to the SALOD program will allow the user to input a reduction factor when there are two or more vehicles on the bridge. The program was written to remain general, so the user may input the recommended AASHTO reduction factor of 10% or the user may wish to input his own reduction factor which is based on another code or research. The distribution factors which are calculated in the SALOD program are then reduced by the desired percentage. The distribution factors which are displayed have a note reminding the user that the results were reduced and by what percentage.

### 3.6 New Standard Vehicle - ST5

In order to keep the SALOD program up to date with current FDOT operating practices, a new standard vehicle has been added to the program's standard vehicle selection. This new vehicle is the straight truck with one trailer and 5 axles. The FDOT designation for this vehicle is 'ST5' and this is the designation used in the program. A sketch of the vehicle is shown in Figure 3.4 which includes the axle loads and spacing used in the program.

This new vehicle is used in the program as a standard vehicle and is used in the same manner as before. A description of how to use the standard vehicle option is included in the revised SALOD user's guide in Appendix A.

### 3.7 Program Efficiency

While working with the FORTRAN source code for the SALOD program, and effort was made to program all new routines as efficiently as possible. Also, when inefficiencies in the old routines were

STRAIGHT TRUCK WITH ONE TRAILER

5 AXLES (STS)

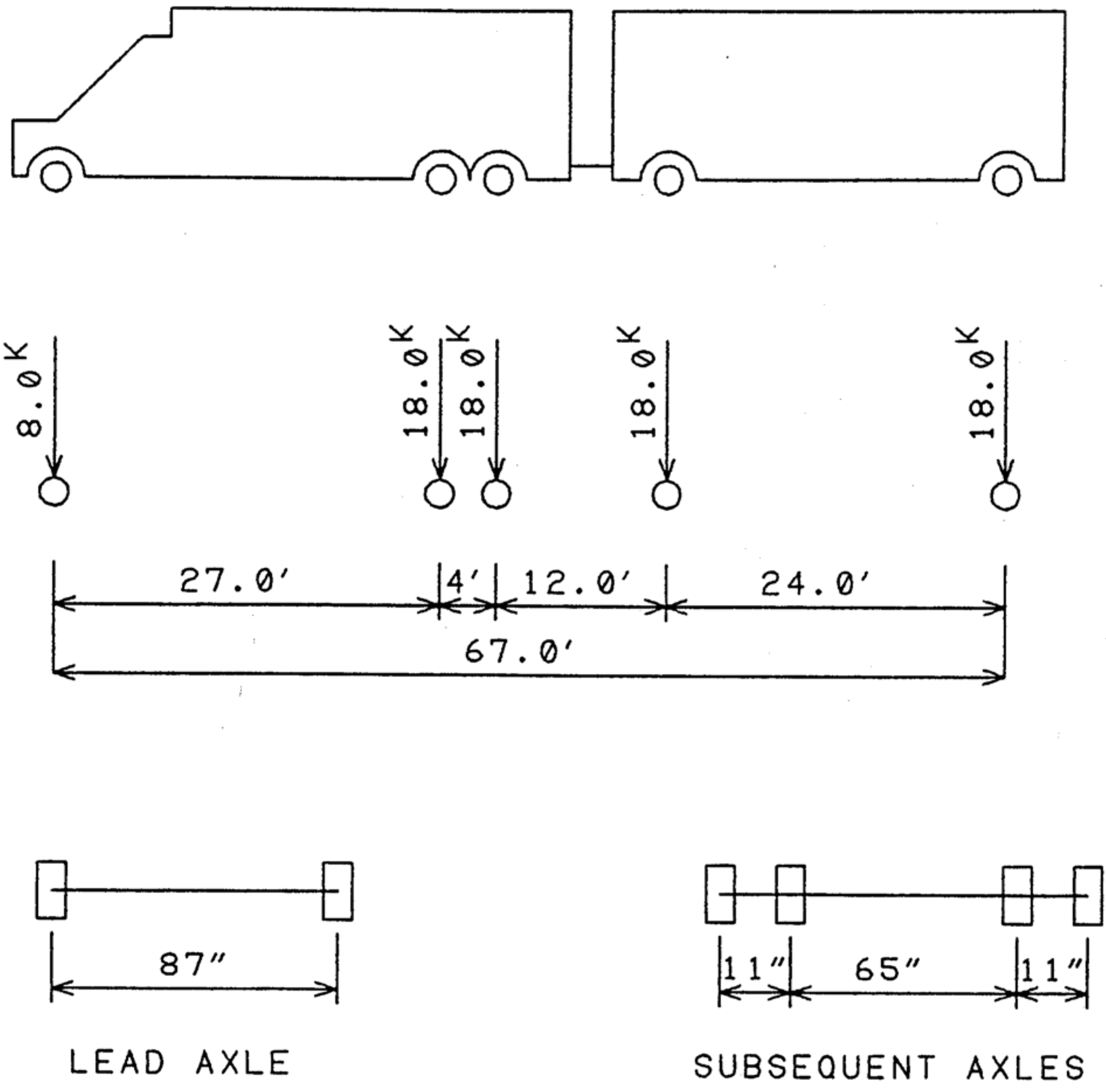


Figure 3.4 SKETCH OF NEW STANDARD VEHICLE - ST5

discovered, they were modified and made more efficient. The efficiency improvements will decrease the calculation times on most bridge types and geometries. Some of the efficiency improvements (3) which were made include:

(1) Removing unnecessary calculations from inside loops.
(2) Reducing the number of multiplies and divides in the program.
(3) Corrections in the dimensions of variables to reduce the space required for program execution.
(4) Improving the branch structure of the program
(5) Removing duplicate or unnecessary variables

### 3.8 Other Bugs, Errors, and Modifications

While working with the program, previous reports (6,9), and previous data, several minor errors were discovered. Some of these errors were in the existing database of influence surfaces. Other minor problems were discovered in the program. All of these problems were small and most were insignificant. When possible the program was corrected and a small study was done to check the significance of the error. These discoveries will be discussed in the paragraphs which follow.

One problem which was discovered in the existing database was that the torsional stiffness for the prestressed concrete girder bridges were not transformed into the slab modulus. Previous studies (10,14) have shown that minor variations in the torsional stiffness will not affect the calculated distribution factors significantly. One study (10) even recommends that the torsional stiffness be neglected all together. The torsional properties for the girders which were used are too low by a factor equal to the modular ratio (n=Eg/Es). This factor for the prestressed bridges is equal to 1.21. Since the torsional stiffness of the girder is only a very small percentage (usually about 5.0 %) of the flexural stiffness of the girder, it has very little affect on the overall behavior of the bridge.

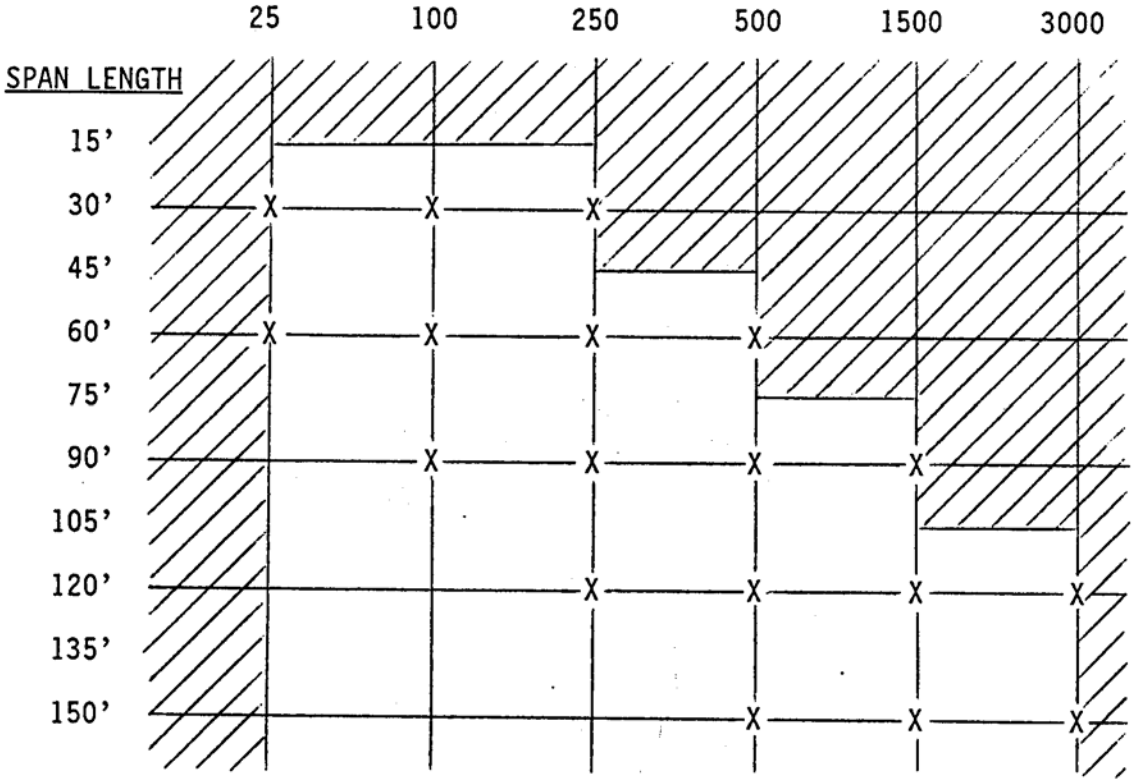
While developing the database of influence surfaces for the concrete bulb tee girders, a mistake was made in some of the influence surfaces. Like the error for the prestressed girders discussed in the previous paragraph, the torsional stiffness was not transformed into the slab modulus. This problem was discovered midway in the database development and affects all bulb tee girders which had 4 or 5 girders and less than 11' spacing. A brief study was performed to compare the effect of using the correct and incorrect torsional stiffness for the girder. The study compared the values of the influence surfaces and found that the difference between the two was less than 2% maximum, and a 1% average. Therefore it was decided that the existing databases which were incorrect would not be changed since the error was small.

While working with the program, it was discovered that there was an error in the steel bridge routine. A small bug was found in the calculation of the interpolation ratios for steel girder bridges which had a transformed moment of inertia between the range of 500,000 in.$^4$ and 1,500,000 in.$^4$. This bug caused the interpolation ratio that was calculated to be slightly in error. A short study of the problem showed that this program bug did not cause significant errors in the calculated distribution factors. This bug has since been corrected.

A minor modification was made to the program for the steel girder bridge routine. While working with the steel database it was noticed that the previous report had stated significant errors would occur when interpolation occurred between moments of inertia on bridges with short spans, but failed to put all the necessary checks in the program to prevent possible misuse of the program. The program has been modified to include a range check of the steel database. A revised sketch of the steel database showing these new limitations is shown in Figure 3.5. If the user accidentally selects a bridge in this range, the user has the option to either exit the program or to restart the input.

While reviewing the old reports and the existing databases, it was discovered that the listing of the concrete tee beam database which appeared in both of the previous reports (6,9) incorrectly showed fifty foot spans. However, the only span lengths which are in the database are 20', 40' and 60' spans. And the SALOD program has always used these span lengths.

COMPOSITE MOMENT OF INERTIA x 1000 in. $^4$



NOTE: Shaded area represents the range of the database which has been restricted from use.

Figure 3.5 REVISED STEEL GIRDER BRIDGE SPAN LENGTH AND GIRDER SPACING COMBINATIONS (9)

# CHAPTER IV

# VERIFICATIONS AND TESTING OF SALOD

## 4.1 Introduction

The objective of this research was to make modifications and enhancements to the program SALOD. Each modification or enhancement which was made had to be verified. Most of these verifications were made to ensure that the actual SALOD program was working correctly after changes were made. These verifications were made while working with the FORTRAN source code for the SALOD program and are not presented in this report since there were many checks made which do not affect the usage of the SALOD program.

However, it was felt that the new bulb tee database of midspan girder moment influence surfaces should be verified to assure that the database was developed and stored properly. It was also felt that studies were necessary to give guidance on the use of the SALOD program when the bridge or vehicle system being analyzed is out of the range of the SALOD program.

The information presented in the chapter will include discussions on the verification of the bulb tee database of midspan girder moment influence surfaces, guidance on how to handle bridges which more than seven girders, and how to handle bridges in which the vehicle system cannot be placed on the bridge due to spacing limitations.

### 4.2 Verification of the Bulb Tee Database

The addition of the bulb tee concrete girder bridges to the SALOD program was a major objective of this research. Therefore it was felt that the addition of the bulb tee concrete girder bridges to the database of midspan girder moment influence surfaces should be verified carefully.

As discussed in Chapter 3, the database of influence surfaces for the bulb tee concrete girder bridges was created by running a finite element analysis of each bridge in the database range. The finite element model used for the bulb tee bridges is shown in Figures B.1 and B.2 and was discussed earlier in Section 3.2. The finite element input files used for the STRUDL analyses were created by hand for each of the 120 bridges in the bulb tee database range and were developed using symmetry so that only a half span model had to be run. The output from the STRUDL run was then edited and the displacements were stored as the influence surface in the database.

To verify the accuracy of the database, ten bridges in the database were randomly selected to encompass as many different span lengths, girder types, girder spacing, and number of girders as possible. ASALOD run was performed on each of the ten bridges which were loaded with one HS20 truck. The truck positions, simple beam moments, and distribution factors were recorded. Then, using the BRUFEM program, a full span finite element analysis was performed on each of the ten bridges using the same vehicle positions and loads as were used in the SALOD run. The midspan girder moments for the full finite analysis model were recorded and the distribution factors were calculated by hand.

The database was then checked by comparing the distribution factors from the ten SALOD runs to those from the ten full span finite element analyses performed using the BRUFEM program. In comparing the distribution factors by the two methods it was found that the distribution factors varied from 0.8 to 2.8 percent. However, it should be noted that the SALOD and BRUFEM finite element models were slightly different. The primary difference in the models is that BRUFEM uses lateral beam elements instead of thickened plate bending elements over the girders to model the extra stiffness associated with the girder flange. The differences in the distribution factors can be partially attributed to these modeling differences. It was concluded from the study of the random sampling of bulb tee bridges that the database of influence surfaces was created and stored properly.

### 4.3 Bridges Having More Than Seven Girders

The SALOD program is currently capable of handling bridges which have four to seven girders. It was felt that some guidance should be given to users who must analyze bridges with more than seven girders. In the previous research (6), similar guidance was given on bridges which had seven girders when SALOD was only capable of analyzing bridges which had up to six girders.

It was decided to extend the study performed in the previous research (6). The previous study examined four prestressed concrete girder bridges. These four bridges had Type 3 AASHTO girders and were loaded with two HS20 vehicles. The range of span lengths was selected as 30.0 and 90.0 feet and the range of girder spacing was selected as 4.5 and 7.0 feet. The range of bridges selected will allow conclusions to be drawn for using a seven girder SALOD solution to obtain approximate distribution factors for bridges with more than seven girders.

The previous research performed 6 girder SALOD solutions, 6 girder STRUDL solutions, and 7 girder STRUM solutions on the selected bridges. The extension of the research performed in this report was made by performing 7 girder SALOD solutions, 7 girder STRUDL solutions, and 8 girder STRUDL solutions on the selected bridges.

The STRUDL analyses which were performed in the previous research were full span models which were modeled in exactly the same way as the models which were used in the creation of the SALOD database. The STRUDL analyses which were performed in this research were full span models in which the BRUFEM program was used to create the STRUDL input file. As discussed in Sections 2.4 and 4.2, the BRUFEM model which was created is different than the model used to create the SALOD database. The major difference being that the SALOD model uses thickened plate bending elements over the girders whereas the BRUFEM model uses lateral beam elements over the girders to account for the lateral stiffness of the girder flanges. Because of the modeling differences, some minor differences in the results were to be expected.

The results of the analyses performed in the previous research and in this research are presented in Table 4.1. The results which are presented are the midspan girder moments for each of the girders in the four bridges which were analyzed. It should be noted that an analysis was not made for every girder or bridge since the objective of the analysis was to determine the critical midspan girder moments.

The results for the seven and eight girder analyses performed in this research compare well with the exception of the STRUDL analyses for

Table 4.1 Results of Eight Girder Extrapolation Study
Showing Midspan Girder Moments

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### GIRDER # 1 (Exterior)

| SPAN | SPCG | 6 GIRDER SALOD | 6 GIRDER STRUDL | 7 GIRDER SALOD | 7 GIRDER** STRUDL | 8 GIRDER** STRUDL |
|---|---|---|---|---|---|---|
| 30’ | 4.5’ | 1376 | - | 1376 | 1402 | 1402 |
| 30’ | 7.0’ | 1658 | - | 1658 | 1666 | 1666 |
| 90’ | 4.5’ | 6488 | - | 6496 | 6856 | 6857 |
| 90’ | 7.0’ | 8922 | - | 8909 | 9238 | 9233 |

### GIRDER # 2 (1st Interior)

| SPAN | SPCG | 6 GIRDER SALOD | 6 GIRDER STRUDL | 7 GIRDER SALOD | 7 GIRDER STRUDL | 8 GIRDER** STRUDL |
|---|---|---|---|---|---|---|
| 30’ | 4.5’ | 1203 | - | 1203 | - | - |
| 30’ | 7.0’ | 2101 | - | 2102 | - | - |
| 90’ | 4.5’ | 5859 | - | 5779 | - | 6024 |
| 90’ | 7.0’ | 8342 | - | 8311 | - | 8658 |

### GIRDER # 3 (2nd Interior)

| SPAN | SPCG | 6 GIRDER SALOD | 6 GIRDER* STRUDL | 7 GIRDER SALOD | 7 GIRDER STRUDL | 8 GIRDER** STRUDL |
|---|---|---|---|---|---|---|
| 30’ | 4.5’ | 1523 | 1484 | 1523 | - | 1558 |
| 30’ | 7.0’ | 2328 | 2329 | 2329 | - | 2283 |
| 90’ | 4.5’ | 5909 | 5881 | 5705 | - | 5921 |
| 90’ | 7.0’ | 7801 | 7726 | 7737 | - | 7951 |

### GIRDER # 4 (3rd Interior)

| SPAN | SPCG | 6 GIRDER SALOD | 6 GIRDER STRUDL | 7 GIRDER SALOD | 7 GIRDER* STRUDL | 8 GIRDER** STRUDL |
|---|---|---|---|---|---|---|
| 30’ | 4.5’ | N/A | N/A | 1579 | 1524 | 1577 |
| 30’ | 7.0’ | N/A | N/A | 2329 | 2238 | 2284 |
| 90’ | 4.5’ | N/A | N/A | 5444 | 5412 | - |
| 90’ | 7.0’ | N/A | N/A | 7568 | 7492 | - |

NOTES: ** Model was developed using the BRUFEM program so the SALOD and STRUDL models were slightly different.

* Model was ran in previous research (6) and the SALOD and STRUDL models were the same.

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girder # 1 (exterior girder). In comparing the SALOD solutions to the STRUDL solutions, there were differences of up to five percent between the midspan girder moments. It was suspected that these differences were due to the modeling differences between the SALOD solution and the eight girder STRUDL solution.

To verify the assumption that the modeling differences were to blame for the differences in the midspan girder moments for the exterior girder, a short study was performed. The bridge with seven girders, 90.0 foot span length, and 4.5 foot girder spacing was selected for the study because this particular bridge had the largest differences in midspan girder moments. A STRUDL model for this bridge was developed so that it would be modeled exactly as the SALOD model. A STRUDL run was then performed on this bridge. The results of the STRUDL analysis gave a midspan girder moment of 6422 k-ft which is almost exactly the same as the SALOD midspan girder moment of 6496 k-ft. Therefore it was concluded that the differences in the midspan girder moments for the exterior girder was due to the modeling differences between the SALOD and STRUDL solutions performed in this research.

Conclusions can now be drawn on the ability to use a seven girder SALOD solution to approximate a solution for bridges with eight or more girders. The values in Table 4.1 are for midspan girder moment but the conclusions presented will be in terms of distribution factors which are directly related to midspan girder moment.

From Table 4.1 it can be concluded that the distribution factors for the exterior girders are approximately constant regardless of the number of girders. For the bridges which have a 90.0 foot span, the midspan girder moments show a decreasing trend when going from the exterior girders to the interior girders. Therefore, for bridges with longer spans, it would be conservative to use the distribution factors obtained from a seven girder SALOD solution for the first interior girder (girder # 2) for all interior girders on bridges with eight girders. For the bridges which have 30.0 foot spans, the midspan girder moments show an increasing trend when going from the exterior girders to the interior girders. Therefore, for shorter spans, it would be conservative to use the distribution factors obtained from a seven girder SALOD solution for the interior most girder for all interior girders on bridges with eight girders.

In all cases the variations between six, seven, and eight girder solutions were small. These variations are primarily due to the minor modeling differences rather than the structural behavior of the bridges. Thus, it is felt that generally the seven girder SALOD solution will give a valid approximation for the distribution factors in bridges with more than seven girders. However, if extremely accurate LLDF's for bridges with more than seven girders are desired, it is recommended that the BRUFEM program be used to perform a full finite element analysis on the bridge in question.

In the previous research (6) a potential problem was discovered. It would be beneficial to describe how to handle this problem in this report since this report is a summary of the SALOD program. The problem now occurs when a bridge with more than seven girders is to be analyzed with three vehicles placed on the bridge. If a seven girder approximate SALOD solution is to be performed, the three vehicles might not fit on the SALOD model of the bridge. A study was performed in the previous research (6) to determine the best approach to the problem. The approach is summarized in the paragraphs below and is illustrated in Figure A.1 (Appendix A - SALOD USER'S GUIDE).

The recommendation from the previous study was to use a combination of two SALOD solutions. To obtain distribution factors for exterior girders, a two vehicle solution should be used.

To obtain distribution factors for the interior girders, an additional three vehicle solution should be made. For the three vehicle solution, the overhang should be artificially widened to allow the three vehicles to be placed on the bridge without exceeding the clearance limits. The clearance limits require that the minimum bridge width of 34.0 feet be used. The widened overhang should be computed by subtracting the total bridge width between the two exterior girder centerlines from the 34.0 feet total width. This number is the width of the overhangs on both sides of the bridge and should be divided by two to obtain the widened overhang which is to be used. On shorter spans the two vehicle solution should be checked to see if the interior girder distribution factor is more critical than that obtained from the three vehicle solution.

# CHAPTER V

# SUMMARY OF THE PROGRAM ‘SALOD’

## 5.1 Introduction

Research has been performed by the University of Florida over the last several years to study the lateral load distribution of loads on bridges for the FDOT. This research has led to the development of the LLDF program SALOD. The original SALOD program has been modified by this research and by the previous research (6). There are no further modifications to the SALOD program proposed at this time. Therefore it das felt that this report would be a good place to summarize all of the assumptions and capabilities of the SALOD program.

This chapter will summarize the assumptions made for the SALOD program, the finite element models and assumptions which were used, and the current capabilities of the SALOD program.

## 5.2 Assumptions Made for the SALOD Program

The program SALOD was developed to help compute more accurate lateral load distribution factors for simple span bridges than those obtained by using the empirical formulae of AASHTO. The SALOD program is a relatively inexpensive and easy to use program. The program works by accessing a database of midspan girder moment influence surfaces. 'he user of the SALOD program inputs the geometry of the bridge that he rashes to analyze. The SALOD program then creates an influence surface or that bridge by interpolating or extrapolating from the database the fridges which most closely match the input bridge. The user then inputs the vehicle system which is on the bridge. The SALOD program then shifts the vehicle system both transversely and longitudinally until the maximum midspan girder moment is found. The SALOD program assumes that the maximum moment occurs at midspan. The distribution factors are then computed.

The SALOD program allows up to three vehicles to be placed on the bridge simultaneously. The vehicles are assumed to occupy a twelve foot travel lane. Within the travel lane is a ten foot load lane. The ten foot load lane may be shifted to any position within the travel lane. The critical loading which is obtained is based on the number of vehicles input by the user. The SALOD program does not check to see if the vehicle system input by the user is the critical vehicle system. The critical vehicle system may have fewer or greater vehicles than those input by the user.

### 5.3 The Finite Element Models and Assumptions Used

Finite element models had to be developed for each bridge type so that a finite element analysis could be performed to develop the database of midspan girder moment influence surfaces. With the exception of the tee beam database developed in the previous research (9), all of the finite element analyses were performed using STRUDL. The tee beam database developed in the previous research used GTSTRUDL to perform the finite element analyses.

All of the bridges which were in the database were developed without considering any skew of the bridge. It was assumed that all the finite element models which were developed and analyzed exhibited linear and elastic behavior. It was also assumed that the concrete deck slab remained uncracked.

The finite element method allows symmetry to be used if the proper boundary conditions are applied. Since the bridges analyzed were all symmetric, symmetry was used in all of the models. This meant that only a half span model had to be created. The half span models which were used had 10 element in the longitudinal direction. Also, since there was transverse symmetry in the bridges, influence surfaces for only approximately half of the girders were required to be stored. The geometrical layout of full span models for the various bridge types is shown in Figure B.l of Appendix B.

The finite element models used beam elements to represent the girders and end diaphragms. The concrete deck slabs were modeled by using plate bending elements.- The beam elements which were used had two nodes with three degrees of freedom at each node. The plate bending elements which were used were plate bending rectangle (BPR) elements which have four nodes with three degrees of freedom at each node. The three degrees of freedom at each node of the beam and plate bending elements include two rotations and one vertical displacement. It should be noted that the tee beam database developed in the previous research (9) used bending plate hybrid quadrilateral (BPHQ) elements for the deck slab.

The finite element models which were used for the prestressed, tee beam, and bulb tee concrete girder bridges used thickened plate bending elements over the girders. This was done to account for the lateral stiffness of the concrete girder flanges.

For the girder type bridges which were analyzed, it was assumed that the girders and slabs acted compositely. Therefore, composite section properties were required. To obtain these composite properties the effective width of the deck slab over the girders had to be found. These effective widths were found by following AASHTO procedures. However, for exterior girders there was a deviation from AASHTO procedures. It was assumed that the exterior girders had the same effective width as the interior girders. This assumption is based on the fact that edge effects such as parapets were neglected. It was felt that neglecting any edge stiffness of the parapets would justify using the full effective width obtained for interior girders for the exterior girders. This meant that the girder properties for interior and exterior girders were the same for the purpose of analysis.

All bridges have intermediate diaphragms along the length of the bridges. These intermediate diaphragms vary considerably in both size and location so it was impractical to develop a database which included intermediate diaphragms. Instead, end diaphragms were used on the prestressed, steel, and bulb tee girder bridges. The cross sectional properties of the end diaphragms were based on an 8" x 54" section and this was the same for all models. The end diaphragms on the tee beam models were neglected '(9).

The sub-sections which follow discuss additional finite element modeling assumptions which were not covered in the proceeding discussion. There is a sub-section for each of the different bridge types.

### 5.3.1 Bulb Tee Concrete Girder Bridges

The bulb tee concrete girder bridges were modeled using thickened plate bending elements, end diaphragms, and composite girder properties. The thickened plate elements were discussed and shown in Section 3.2.2. The concrete deck slab was assumed to be seven inches thick and had a concrete strength of f 'c = 3400 psi. The girders for the bulb tee bridges were assumed to have a concrete strength of f 'c = 5000 psi.

### 5.3.2 Prestressed Concrete Girder Bridges

The prestressed concrete girder bridges were modeled using thickened plate bending elements, end diaphragms, and composite girder properties. There were two thickened plate elements over the girder flanges and four plate elements between the girder flanges. The deck slab was assumed to be seven inches thick and had a concrete strength of f 'c=3400 psi. The depth of the thickened plate elements was computed by averaging the depth of the slab and girder flange. The prestressed girders were assumed to have a concrete strength of f 'c = 5000 psi.

### 5.3.3 Steel Girder Bridges

The steel girder bridges were modeled using composite girder properties and end diaphragms. Thickened plate elements were not used for the steel girder bridges. The deck slab was assumed to be seven inches thick having a concrete strength of f 'c = 3400 psi. There were six equally spaced plate element between the girder centerlines. The steel girders were assumed to have a modulus of Eg = 29,000,000 psi. The torsional stiffness used for the steel girders was assumed to be constant for all bridges and had a value of 20.0 in. $^4$.

### 5.3.4 Concrete Tee Beam Girder Bridges

The concrete tee beam girder bridges were modeled using thickened plate bending elements and gross section properties. The deck slab was assumed to be seven and one-half inches thick. The thickened plate bending elements used over the girders was assumed to be twice the slab thickness. The bridges were assumed to be cast-in-place-and the concrete was assumed to have a strength of f 'c = 3400 psi. The torsional stiffness of the girders was assumed to be constant for all bridges and had a value of 10,000 in.$^4$. The slab was assumed to carry some of the moment at the centerline of the bridge. To account for the slab carrying some of the moment, the girder moment values were adjusted. The adjustment was made by multiplying the girder moment by the ratio of the composite girder moment of inertia to the non-composite moment of inertia. The girder spacing to girder width was assumed to be 5 (S/B = 5) for all bridges in-the tee beam database.

### 5.3.5 Concrete Flat Slab Bridges

The concrete flat slab bridges were modeled using only constant thickness plate bending elements. The finite element grid which was used had five elements in the longitudinal direction and ten elements in the transverse direction. There were no beam elements used since the flat slab bridges do not have girders or diaphragms.

### 5.4 Current Capabilities of the Program 'SALOD'

Currently the SALOD program can analyze prestressed, steel, concrete tee beam, and bulb tee type girder bridges. The program can also analyze concrete flat slab bridges. For the girder type bridges, the SALOD program can directly obtain LLDF's for bridges which have four to seven girders. The SALOD program can also be used to estimate approximate LLDF's for girder type bridges with more than seven girders as discussed in Section 4.3. For concrete flat slab bridges, effective widths are computed.

The program allows for up to three vehicles to be placed on the bridge simultaneously. The vehicles may be any combination of standard and/or non-standard vehicles. The PDOT standard vehicles which are available in the program are SU2, SU3, SU4, C3, C4, C5, H20, HS20, and

M. The program also allows the input of non-standard vehicles using wither a single axle gage model or a multi-gage model. The first vehicle which is input is the reference vehicle and is used in computing the simple beam moment. When there are two or more vehicles on the )ridge, the user may input a probability reduction factor.

# CHAPTER VI

# CONCLUSIONS AND RECOMMENDATIONS

The objectives of this research were to make modifications and enhancements to the SALOD program. These changes to the SALOD program were meant to expand the capabilities of the program. The general concept of the program was not changed. Therefore, user's familiar with the program will find that the changes made will be easy to understand and implement. The changes which were made will allow a wider range of bridges and vehicles to be analyzed.

The major modification to the program was the expansion of the midspan girder moment database of influence surfaces for girder type bridges. A new girder cross section, the bulb tee, was added to the database. Also, the existing database for girder type bridges was expanded to include a seventh girder. This change affects the prestressed, tee beam, and steel girder databases. The new database ranges allows bridges with four to seven girders to be directly analyzed.

For girder type bridges with more than seven girders, the SALOD program may be used to determine approximate distribution factors. A short study was performed to develop guidelines to obtain these approximate distribution factors. The discussion on the study to obtain these approximate distribution factors for bridges with more than seven girders was presented in Section 4.3.

To expand the range of vehicles which may be placed on the bridge, several modifications were made. The first modification was the addition of a new standard vehicle to the program. This new standard vehicle is the straight truck with one trailer and five axles (FDOT standard ST5). The second modification was the addition of a new input routine for non-standard vehicles. This new input routine allows vehicles to be input with multi-gage axles. This modification allows great flexibility in the input of non-standard vehicles.

Another modification which was made to the SALOD program was the addition of a probability reduction factor. This factor is based on the factors used in AASHTO Section 3.12. When there are two or morevehicles on the bridge, the user may input a probability reduction factor for multiple vehicles. The user may input the specified reduction based on AASHTO or other research. The distribution factors which are then calculated will then be reduced by the appropriate amount.

The SALOD program is a very simple and easy program to use. The program allows lateral load distribution factors which are more accurate and generally less conservative than those obtained by AASHTO formulae to be easily obtained. The program can directly compute distribution factors for girder type bridges with' four to seven girders. Approximate distribution factors may be obtained for bridges with more than seven girders. For flat slab bridges, the SALOD program computes the effective widths which are required.

If the bridge to be analyzed is out of the database range or there is any doubt-to the accuracy of the distribution factors obtained, the user may wish to use the program BRUFEM. The program BRUFEM which has been developed in related research allows for the easy generation of a full span finite element model input file which can be analyzed using the STRUDL program.

### 1. Execution Procedures

To begin execution of the, program, the user must enter the following commands at the 'READY' prompt:

```
READ
Y
%MAI
NT
READ
Y
%SAL
OD
```

The SALOD program will now begin execution with an introductory message being shown on the screen (not shown here). Once program execution begins, the user must respond to the input prompts as described in the remainder of this user's guide. The numerical input data must have at least one space between entries. If an input prompt requires multiple values to be input, the data may either be input on one line with one or more spaces between each entry, or the data may be input one entry per line, pressing the enter key after each entry. It is suggested that if multiple values are required, input them on one line. This will avoid any problems with the prompt scrolling off the screen. For clarity, each line which requires user input will be highlighted by '* INPUT *' in the left margin.

### 2. Input of Bridge Geometry

The first input which is necessary is to identify the type of bridge which is to be analyzed. The following prompt will appear on the screen:

Overhang - the distance in feet from the center of the exterior girder to the edge of the clear roadway.
(+:edge is beyond exterior girder,
-:edge is inside the exterior girder)

## 2.1 Prestressed concrete girder bridge data (PRE)

(See Figure B.3)

```
          ENTER THE FOLLOWING PRESTRESSED GIRDER DATA:

          NO. OF GIRDS   GIRD TYPE    GIRD SPCG   SPAN LENGTH   OVERHANG
          (4 TO 7)      (2,3, OR 4)     (FT)         (FT)         (FT)
* INPUT *    X               X          XX.XX        XX.XX        XX.XX
```

Where GIRD TYPE is the standard AASHTO girder type for prestressed concrete girders.

## 2.2 Cast-in-place tee beam concrete girder bridge data (TBE)

(See figure B.5)

```
          ENTER THE FOLLOWING TEE BEAM GIRDER DATA:

          NO. OF GIRDS  GIRD SPCG  SPAN  OVERHANG  WEB WIDTH  WEB DEPTH
            (4 TO 7)       (FT)     (FT)    (FT)       (IN)       (IN)
* INPUT *      X          XX.XX    XX.XX   XX.XX      XX.XX      XX.XX
```

## 2.3 Steel girder bridge data (STL)

(See Figure B.4)

```
          ENTER THE FOLLOWING STEEL GIRDER DATA:

          COMPOSITE OR NON-COMPOSITE? (C OR N)
* INPUT *   C (or N)
```

where: C = composite action
N = non-composite action

```
          NO. OF GIRDS   GIRD SPACING   SPAN LENGTH   OVERHANG
          (4 TO 7)          (FT)           (FT)         (FT)
* INPUT *     X             XX.XX          XX.XX        XX.XX
```

For composite steel girder bridges only:

```
          INPUT THE FOLLOWING DATA:

          DIST FROM BOTTOM OF SLAB TO TOP OF GIRDER STEEL (INCHES)
* INPUT *   X.XX
```

Note that + = Slab is above top flange of steel
- = Slab is embedded (below) top flange of steel

For composite or non-composite steel girder bridges, input the following girder data:

```
          HOW MANY STEEL PLATE SECTIONS IN THE BEAM ?
* INPUT *   X

          INPUT THE WIDTH AND HEIGHT OF EACH PLATE SECTION
          NUMBERING FROM THE TOP TO BOTTOM OF THE GIRDER.

               INPUT FOR PLATE # i:
               PL WIDTH     PL HEIGHT
                 (IN)         (IN)
* INPUT *       XX.XX        XX.XX
```

This plate width and plate height input request will be displayed once for each plate.

## 2.4 Flat slab concrete bridge data (FLT)

(See Figure B.6)

```
          INPUT THE FOLLOWING FLAT SLAB DATA:

          WIDTH   SPAN LENGTH   WIDTH OF PARAPET
          (FT)       (FT)             (FT)
* INPUT * XX.XX     XX.XX            XX.XX
```

Where width of parapet is defined as the distance in feet from the edge of the bridge slab to the edge of the clear roadway.

## 2.5 Bulb tee concrete girder bridge data (BLB)

(See Figure B.2)

```
          ENTER THE FOLLOWING BULB TEE BRIDGE DATA:

          NO. OF GIRDS      GIRD SPCG     GIRDER TYPE WHERE 1=54" DEEP
          (4 TO 7)           (FT)         (1,2, OR 3)       2=63" DEEP
                                                            3=72" DEEP
* INPUT *    X              XX.XX              X

          SPAN LENGTH    OVERHANG
            (FT)           (FT)
* INPUT *  XX.XX          XX.XX
```

## 3. Output Options

An output option question is displayed to determine whether there will be minimum or maximum output on the hard copy.

```
          DO YOU WANT MINIMUM OF MAXIMUM OUTPUT? (ENTER MIN OR MAX)
* INPUT *   MIN (or MAX)
```

"MIN" output will produce a hardcopy of the results which is basically the same output which appears on the screen during the execution of the program. The hardcopy will include an echo print of the input data along with the calculated distribution factors or effective widths.

"MAX" output will generate considerably more output and should be primarily used for debugging or to help in validating questionable output. The hard copy includes the minimum output along with information on the wheel coordinates and loads of the individual vehicles and vehicle system as it is shifted.

4. Vehicle Data

The user has the option of either reusing the vehicle data from the preceding SALOD run (after using the restart option), or the user may input new vehicle data. The following prompt must be answered to determine if the old vehicle data will be reused:

```
                 INPUT NEW VEHICLE DATA? (Y OR N)
  * INPUT *   Y (or N)
```

If the user wishes to reuse the old vehicle data, the rest of Section 4 on vehicle input will be bypassed. It should be pointed out here that old vehicle data is generated only after the restart option has been used. There is no vehicle data available for the first time SALOD is executed.

The user has the option to store one non-standard vehicle on a temporary file which is available only for the current SALOD session. If the non-standard vehicle is stored, it can subsequently be 'accessed as a standard vehicle with the designation 'TEMP'. This data is temporary and is only stored for the current SALOD session or until a new temporary vehicle is stored.

```
                 STORE NEW TEMPORARY STANDARD VEHICLE
DATA? (Y OR N) * INPUT *  Y (or N)
```

If a new stored temporary vehicle is desired, the series of questions shown in 4.3 must be answered and the following message will appear after the data has been input:

```
 TEMPORARY VEHICLE HAS BEEN STORED AS STANDARD
VEHICLE, TEMP
```

Now the user may select up to 3 vehicles to be placed on the bridge simultaneously. There may be any combination of standard and/or non-standard vehicles. The first vehicle which is input is the reference vehicle and is used in the calculation of the SALOD distribution factors.

Answer the following:

HOW MANY VEHICLES ARE ON THE BRIDGE SIMULTANEOUSLY?
1,2, OR 3)

* INPUT * X

NOTE: If a seven girder approximate solution is being used for a bridge with more than seven girders and the vehicle system will not fit, refer to Section 4.3 and to Figure A.1

A new option has been added to the SALOD program allowing for a user input reduction in the distribution factor if there are two of more trucks on the bridge. If the user wishes to use the probability reduction, the distribution factors which are calculated will be reduced by the amount specified and a message will be displayed reminding the user that the results were reduced. If there are more than two trucks on the bridge, the user must respond to the following prompt:

DO YOU WISH TO REDUCE THE CALCULATED DISTRIBUTION FACTOR SINCE THERE ARE TWO OR MORE TRUCKS (Y OR N)?

*INPUT * Y (or N)

If the user wishes to reduce the distribution factor, then the following question must be answered.

ENTER THE PERCENT REDUCTION THAT YOU WISH TO APPLY TO THE CALCULATED DISTRIBUTION FACTORS (eg 10.5 = 10.50

* INPUT * XX.X

SALOD now loops through the following set of questions for each vehicle:

4.1 <u>Identify each vehicle as a standard or non-standard</u>

Answer the following:

IS VEHICLE NUMBER x A STANDARD VEHICLE (Y OR N)

* INPUT * Y (or N)

4.2 <u>Standard vehicle input</u>

Answer the following:

VEHICLE TYPE? (SU2,SU3,SU4,C3,C4,C5,H20,HS20,TEMP,ST5) (See Appendix E of reference 9 and Figure 3.4)

* INPUT * XXXX

For standard vehicles, the remainder of the vehicle data questions are bypassed and the loop restarts at, 4.1 if there are more vehicles.

### 4.3 Non-standard vehicle input

Answer the following:

```
            DOES THE NON-STANDARD TRUCK HAVE A "S"INGLE AXLE
            GAGE (OLD SALOD VERSION) OR DOES IT HAVE A "M"ULTIPLE
            GAGE AXLE (NEW SALOD VERSION) (S OR M) ?
* INPUT *     S (or M)
```

If the non-standard vehicle has a single axle gage, the user must respond to the questions in 4.3.1. If the non-standard vehicle has multiple axle gages, the user must respond to the questions in 4.3.2.

#### 4.3.1 Non-standard vehicle with a single axle gage

Note that this is the same input as the old SALOD version. A sketch of the single gage non-standard vehicle is shown in Figure A.2 showing the meanings of the terms used in the input.

Answer the following:

```
            INPUT THE FOLLOWING VEHICLE DATA:
            NO. OF AXLE GROUPS EXCLUDING LEAD AXLE (<=9)
 * INPUT *     X

            INPUT FOR THE LEAD AXLE:
            AXLE LOAD (KIPS) AXLE GAGE(FT) WHEEL SPACING(FT) NO. WHEELS *
INPUT *       XX.XX          XX.XX          XX.XX             X

            INPUT FOR SUBSEQUENT AXLE GROUPS:
            AXLE LOAD (KIPS) (1ST GROUP, 2ND GROUP,...,ETC.)
 * INPUT *    XX.XX   XX.XX   XX.XX   XX.XX

            AXLE GAGE (FT) (1ST GROUP, 2ND GROUP,....ETC.)
* INPUT *     XX.XX   XX.XX   XX.XX   XX.XX

            WHEEL SPACING (FT) (1ST GROUP, 2ND GROUP,...ETC)
* INPUT *     XX.XX   XX.XX   XX.XX   XX.XX

            NO. OF WHEELS PER AXLE (1ST GROUP, 2ND GROUP,..ETC.)
 * INPUT *    X     X     X     X

            NO. OF AXLES PER GROUP (1ST GROUP, 2ND GROUP,..ETC.)
* INPUT *     X     X     X     X

            ENTER THE FOLLOWING INFO. ON THE LONGITUDINAL AXLE SPACINGS
            SPACING BETWEEN AXLE GROUPS(FT)   (1ST GROUP, 2ND,GROUP....ETC.)
* INPUT *     XX.XX   XX.XX   XX.XX   XX.XX
```

```
          AXLE SPACING IN GROUP (FT) (1ST GROUP,2ND GROUP.... ETC.)
* INPUT *   XX.XX   XX.XX   XX.XX   XX.XX
```

For non-standard, single gage vehicles, the remainder of the vehicle data questions are bypassed and the loop restarts at 4.1 if there are more vehicles.

4.3.2 <u>Non-standard vehicle with a multiple gage axle</u>

Note that this is a new option added to this version of the SALOD program. A sketch of this new vehicle type is shown in Figure A.3. An example of the multi gage non-standard vehicle is shown in Figure A.4

```
          INPUT THE FOLLOWING VEHICLE DATA:
          NO. OF AXLE GROUPS EXCLUDING LEAD AXLE (<=9)
 * INPUT *     X

          ENTER THE FOLLOWING DATA FOR THE LEAD AXLE
         ----------------------------------------------------------------

         AXLE LOAD (KIPS)   # OF AXLE GAGES
 * INPUT *      XX.XX            X

         THE NAG AXLE GAGE(S) IN FEET
 * INPUT *      XX.XX          XX.XX

          THE NAG+1 WHEEL SPACINGS (FT)
 * INPUT *      XX.XX          XX.XX          XX.XX

           THE NUMBER OF WHEELS FOR EACH OF THE NAG+1 WHEEL GROUPS
 * INPUT *     X         X             X
```

The following is looped on for the number of axle groups:

```
         ENTER THE FOLLOWING FOR AXLE GROUP i

         ----------------------------------------------------------------
  AXLE LOAD (KIPS),# AXLES IN GROUP i,# AXLE GAGES IN GROUP i
*INPUT *    XX.XX             XX.XX       XX.XX

        THE NAG AXLE GAGE(S) IN FEET
* INPUT *             XX.XX      XX.XX

        THE NAG+1 WHEEL SPACINGS (FT)
* INPUT *             XX.XX      XX.XX      XX.XX

        THE NUMBER OF WHEELS FOR EACH OF THE NAG+1 WHEEL GROUPS
* INPUT *             X              X            X
```

When the number of axle groups is greater than 2, the following input question is displayed for each additional axle. This will allow the user to duplicate the axle data of any previously defined axle group.

IS AXLE GROUP i A DUPLICATE TO ANY PREVIOUSLY DEFINED AXLE GROUP (Y OR N)?

* INPUT * Y (or N)

If the axle is a duplicate, the user must input the axle group number of the previously defined axle. To be a duplicate, the groups must have the exact same axle load, wheel spacing, and number of wheels. If the axle is not a duplicate, the program restarts at the loop on the number of axle groups.

WHICH PREVIOUSLY DEFINED AXLE GROUP NUMBER IS AXLE GROUP i IDENTICAL TO ?

* INPUT *   X

Once all axles have been looped on, the following questions on longitudinal spacing must be answered:

ENTER THE FOLLOWING INFO. ON THE LONGITUDINAL AXLE
SPACINGS

```
            ------------------------------------------------------

          SPACING BETWEEN AXLE GROUPS(FT) (1ST GROUP, 2ND,GROUP,...ETC.)
* INPUT *   XX.XX      XX.XX      XX.XX

          AXLE SPACING IN GROUP (FT)     (1ST GROUP,2ND GROUP.... ETC.)
* INPUT *   XX.XX      XX.XX      XX.XX
```

For non-standard, multiple gage vehicles, the loop restarts at 4.1 if there are more vehicles.

5. Restart Option

The user may input a new set of vehicles on the same bridge without re-inputting the bridge data by answering the following question appropriately:

INPUT NEW VEHICLE DATA ON THE SAME BRIDGE (Y OR N)

* INPUT *   Y (or N)

A "Y" answer restarts the vehicle data input loop (at 4.1) and execution continues in the usual manor. For a "N" answer, a print prompt (shown below) appears from which the user may obtain a hard copy of the output:

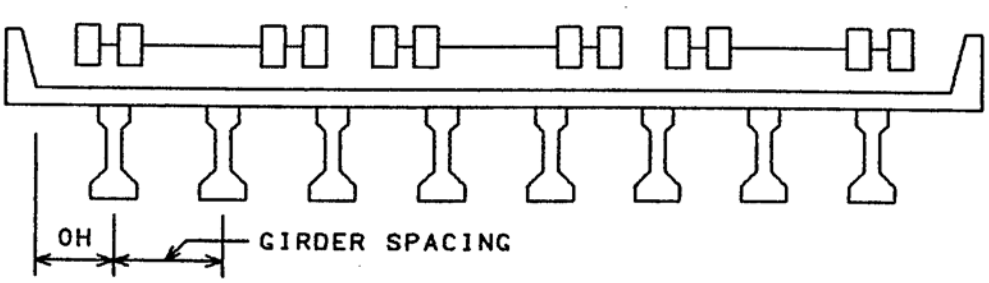
DO YOU WANT A HARD COPY OF OUTPUT (Y OR N)

* INPUT *   Y (or N)

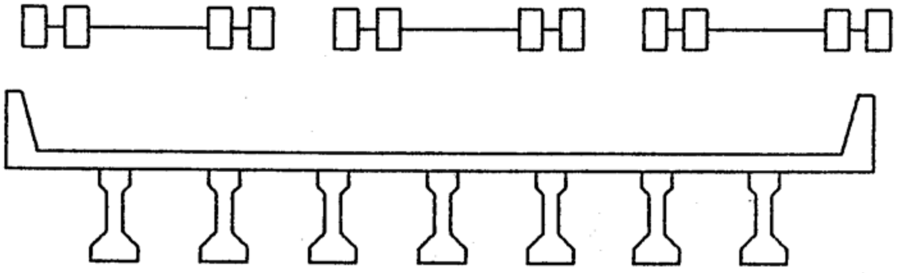
Then the user has the option to continue with another analysis. Answer the following:

DO YOU WISH TO CONTINUE (Y OR N)
* INPUT * Y (or N)

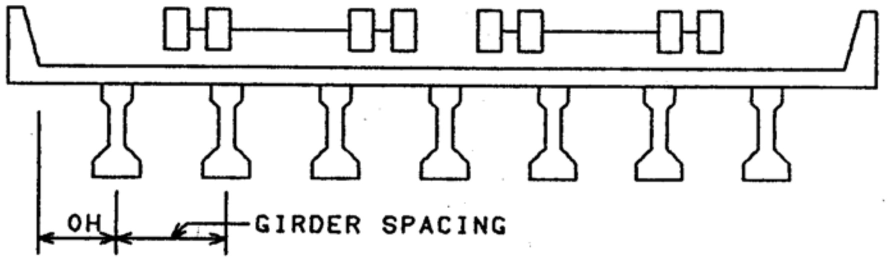
For a "Y" answer, the current vehicle data may be reused in a subsequent run. A "N" answer will terminate the execution of the program.



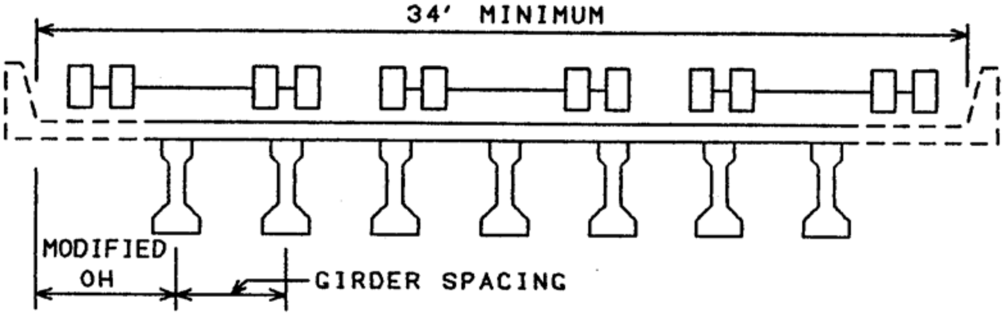
(A) ACTUAL BRIDGE WITH MORE THAN SEVEN GIRDERS



(B) MODELING PROBLEM WITH SEVEN GIRDER APPROXIMATE SOLUTION

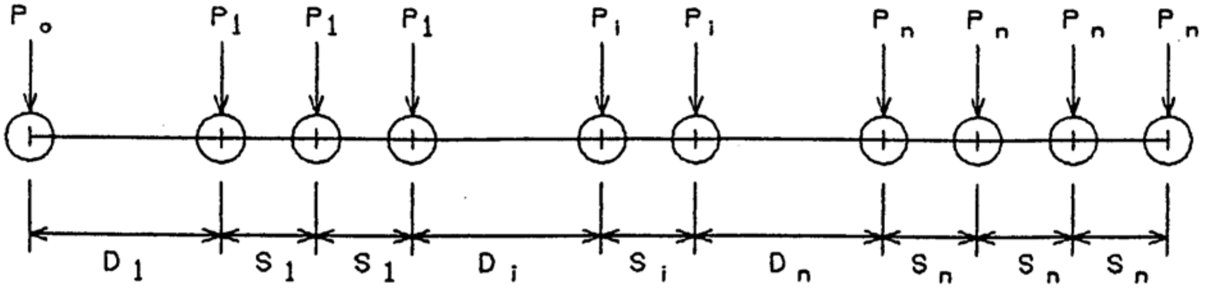


(C) TWO VEHICLE SOLUTION

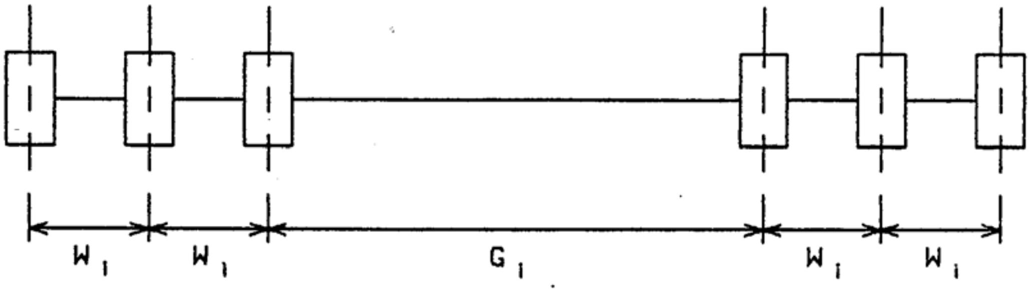


(D) THREE VEHICLE SOLUTION FOR INTERIOR GIRDERS ONLY Figure

A.1 VEHICLE PLACEMENT ON SEVEN GIRDER APPROXIMATE SOLUTION



AXLE LOADS AND LONGITUDINAL SPACINGS

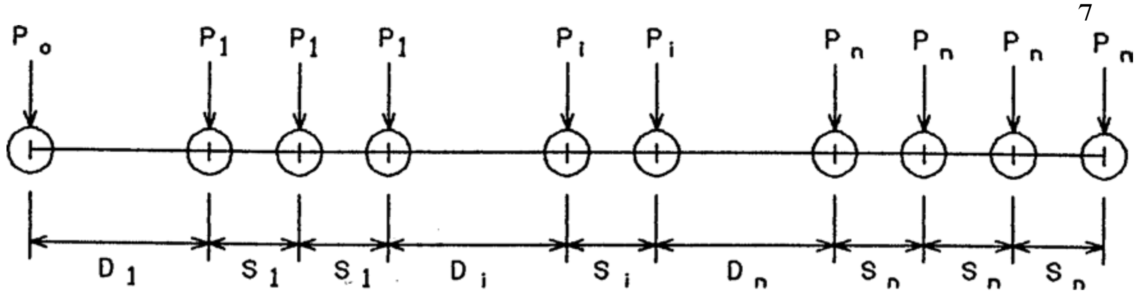


WHEEL SPACING FOR AXLE i

**NOTES**

$i$ : AXLE GROUP NUMBER
$n$ : NUMBER OF AXLE GROUPS
$D_i$ : AXLE GROUP SPACING
$S_i$ : AXLE SPACING
$NA_i$ : NUMBER OF AXLES PER AXLE GROUP
$P_o$ : AXLE LOAD FOR LEAD AXLE
$P_i$ : AXLE LOAD FOR SUBSEQUENT AXLES
$W_i$ : WHEEL SPACING ON AN AXLE
$G_i$ : AXLE GAGE
$NW_i$ : NUMBER OF WHEELS ON AN AXLE

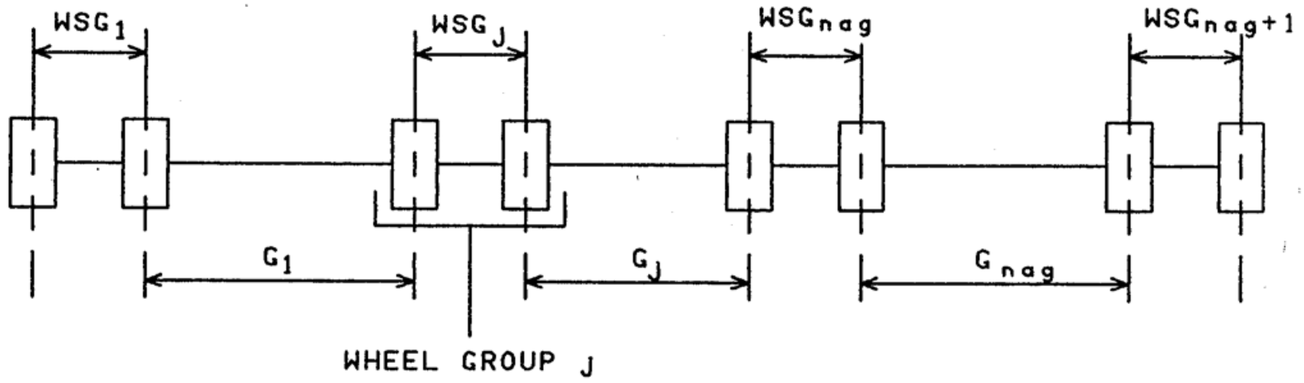
Figure A.2 DESCRIPTION OF SINGLE GAGE NON-STANDARD VEHICLE (9)



AXLE LOADS AND LONGITUDINAL SPACINGS

NOTES ON LONGITUDINAL SPACINGS

i : AXLE GROUP NUMBER
n : NUMBER OF AXLE GROUPS
$D_i$ : AXLE GROUP SPACING
$S_i$ : AXLE SPACING IN GROUP i
$NA_i$ : NUMBER OF AXLES PER AXLE GROUP
$P_o$ : AXLE LOAD FOR LEAD AXLE
$P_i$ : AXLE LOAD FOR SUBSEQUENT AXLES



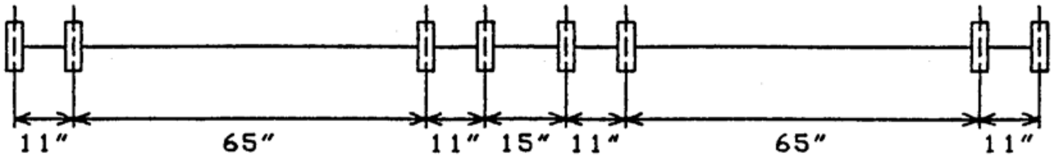
TRANSVERSE WHEEL SPACINGS FOR AXLE i

NOTES ON TRANSVERSE SPACINGS

NAG : NUMBER OF AXLE GAGES ON AXLE
$G_j$ : AXLE GAGE FOR GAGE NUMBER
$N4_J$ : NUMBER OF WHEELS IN WHEEL GROUP
$WSG_j$ : WHEEL SPACING IN WHEEL GROUP

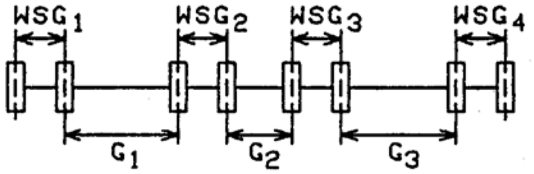
Figure A.3 DESCRIPTION OF MULTI-GAGE NON-STANDARD VEHICLE

SHOWN BELOW IS A SKETCH SIMILAR TO AN ACTUAL AXLE WHICH HAD TO ANALYZED. TWO DESCRIPTIVE EXAMPLES WILL BE PRESENTED TO SHOW DIFFERENT WAYS OF INPUTTING THE AXLE USING THE MULTI-GAGE OPTION.



### EXAMPLE # 1 - USING 3 AXLE GAGES:

NAG = 3 (# OF AXLE GAGES)
WHERE $G_1$ = 65"
$G_2$ = 15"
$G_3$ = 65"
# WHEEL GROUPS = NAG+1 = 4
WHERE $WSG_1$ = 11" $NWG_1$ = 2
$WSG_2$ = 11" $NWG_2$ = 2
$WSG_3$ = 11" $NWG_3$ = 2
$WSG_4$ = 11" $NWG_4$ = 2



### EXAMPLE # 2 - USING 5 AXLE GAGES:

NAG = 5 (# OF AXLE GAGES)
WHERE $G_1$ = 65"
$G_2$ = 11"
$G_3$ = 15"
$G_4$ = 11"
$G_5$ = 65"
# WHEEL GROUPS = NAG+1 = 6
WHERE $WSG_1$ = 11" $NWG_1$ = 2
$WSG_2$ = 0" $NWG_2$ = 1
$WSG_3$ = 0" $NWG_3$ = 1
$WSG_4$ = 0" $NWG_4$ = 1
$WSG_5$ = 0" $NWG_5$ = 1
$WSG_6$ = 11" $NWG_6$ = 2

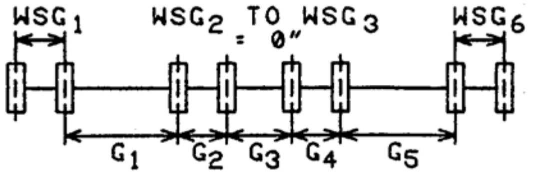


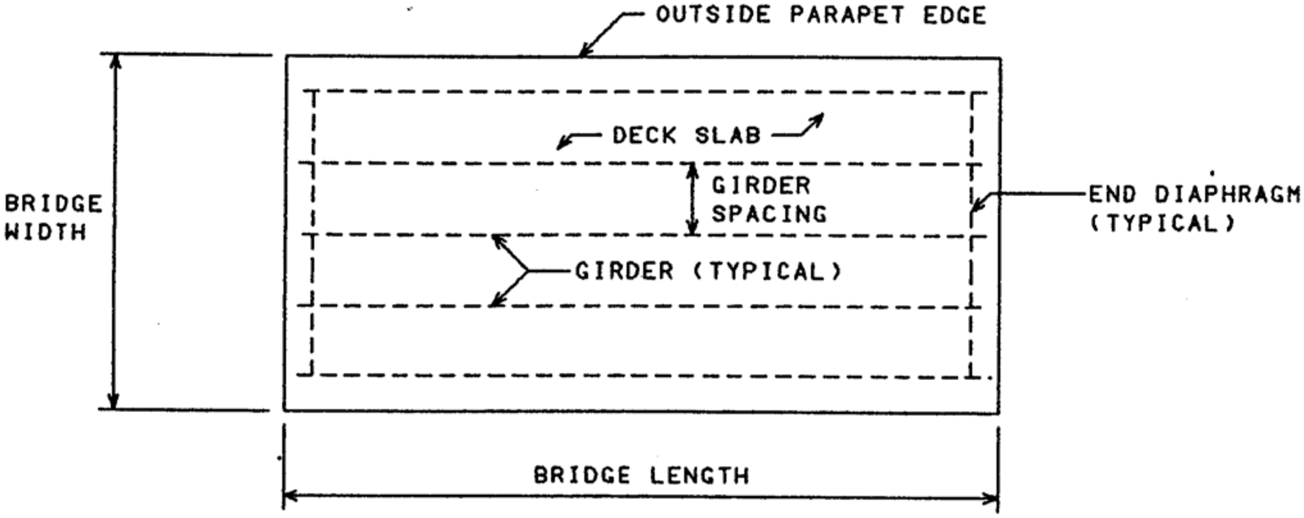
Figure A.4 EXAMPLES OF MULTI-GAGE NON-STANDARD VEHICLE

# APPENDIX B

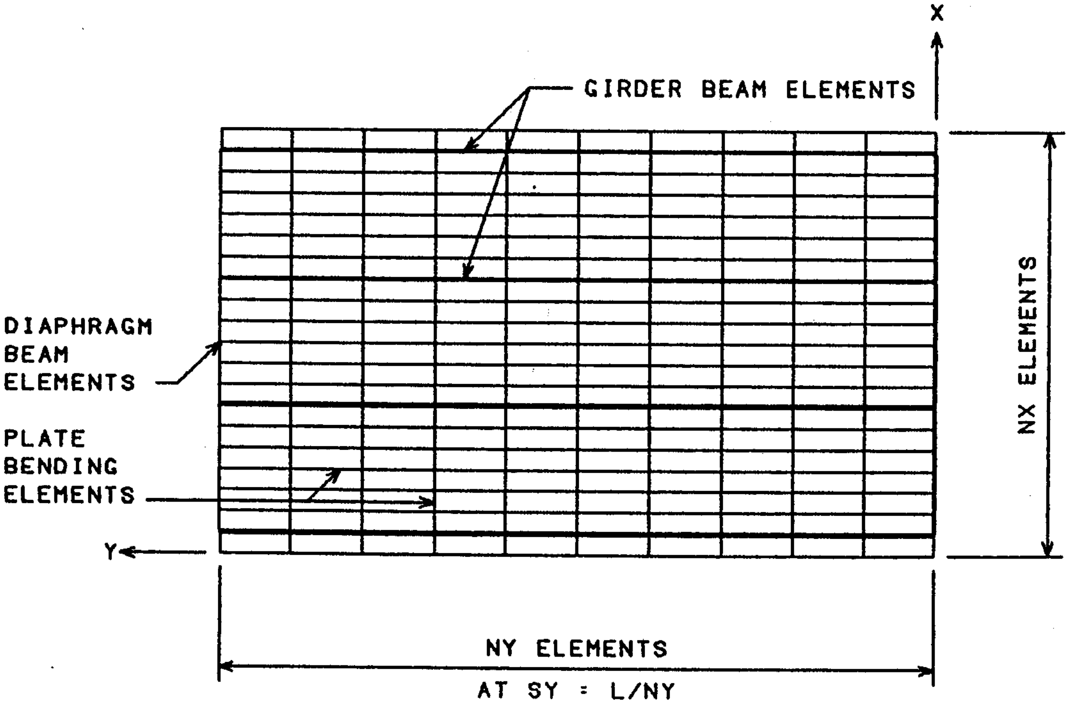
# FIGURES OF BRIDGE COMPONENTS AND F.E. MODELS

This appendix contains figures which show the different bridge components and the different finite element models which were used in this and previous research. Many of these figures are from the previous research reports (6,9) although they have been modified slightly. These figures are referenced throughout the report to illustrate either the terms used or to show the finite element models used.

The figures included in this appendix are a typical plan view of a bridge deck as well as cross sections through the bridge for each of the five different bridge types.

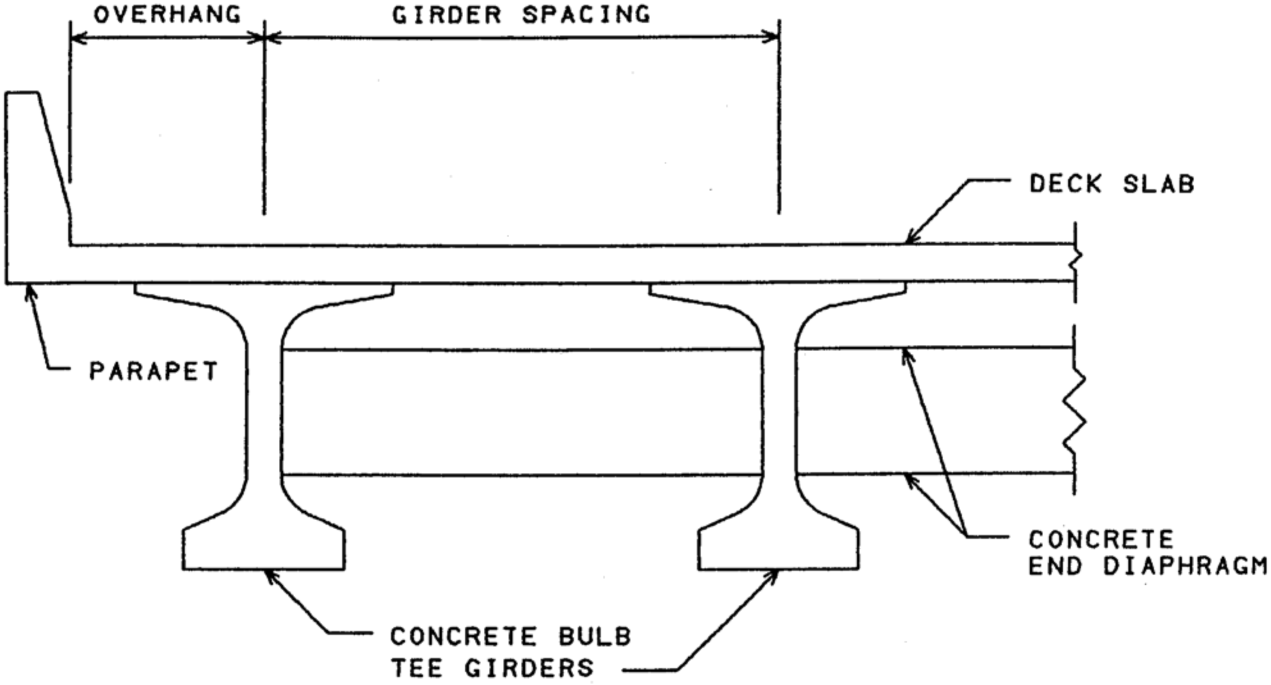


TYPICAL PLAN VIEW OF BRIDGE COMPONENTS

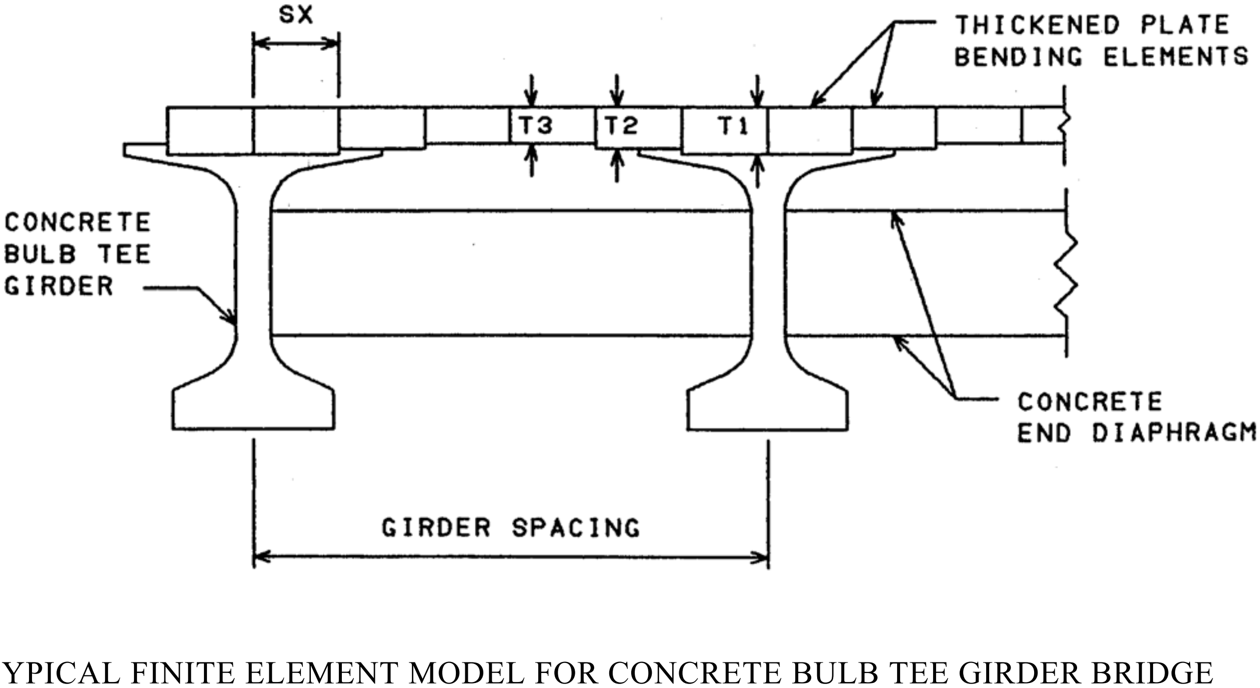


TYPICAL PLAN VIEW OF FINITE ELEMENTS

Figure B.1 TYPICAL BRIDGE DECK COMPONENTS AND FINITE

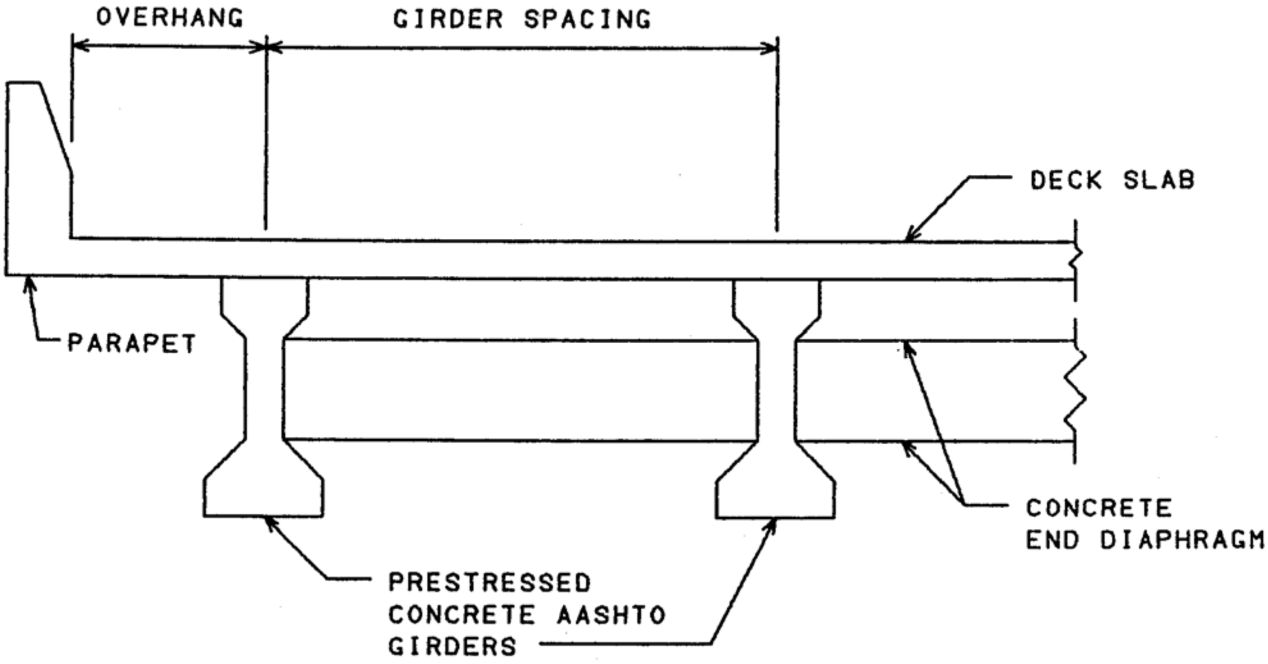


TYPICAL CONCRETE BULB TEE GIRDER BRIDGE COMPONENTS

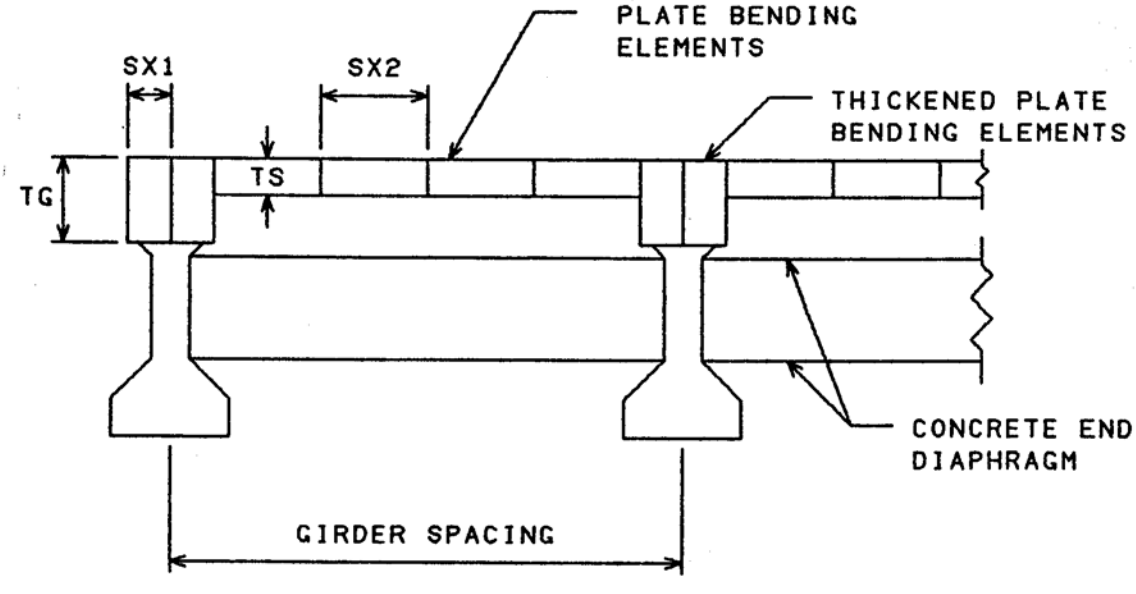


TYPICAL FINITE ELEMENT MODEL FOR CONCRETE BULB TEE GIRDER BRIDGE

Figure B.2 TYPICAL BULB TEE GIRDER BRIDGE CROSS SECTION SHOWING ACTUAL BRIDGE COMPONENTS AND FINITE ELEMENT MODEL USED

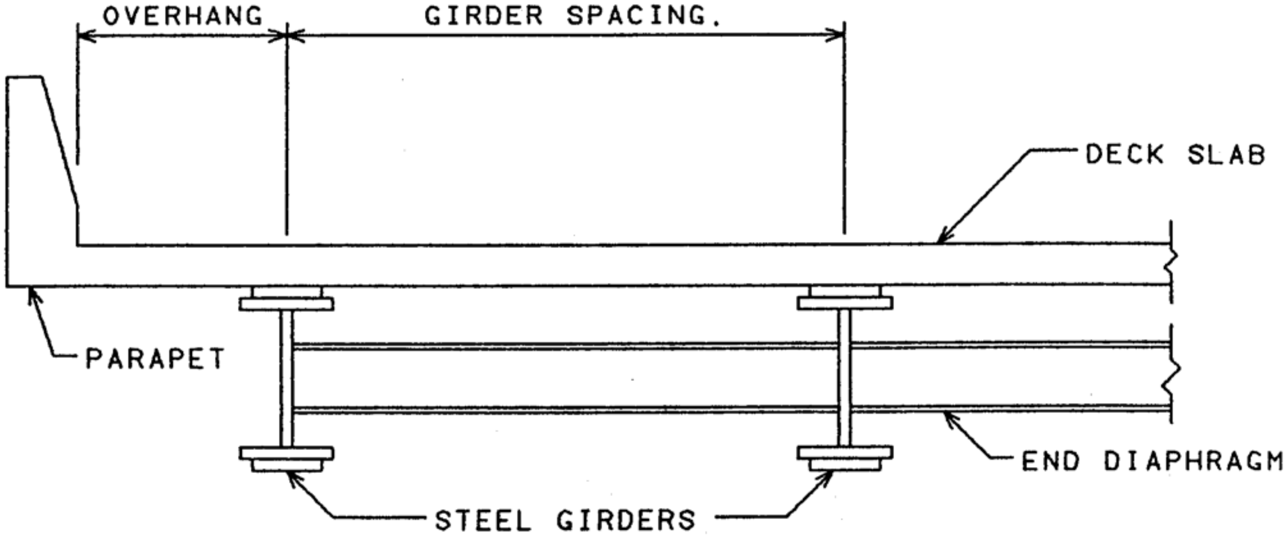


TYPICAL PRESTRESSED CONCRETE GIRDER BRIDGE COMPONENTS

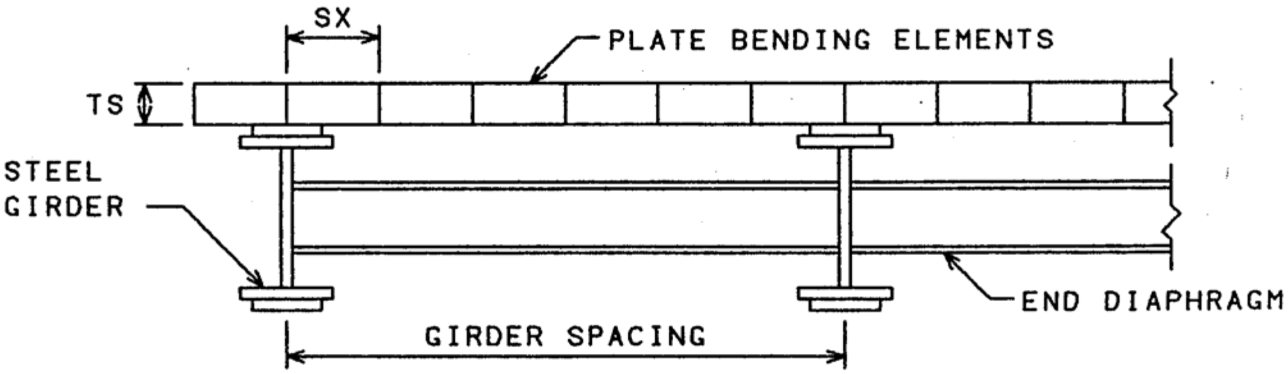


TYPICAL FINITE ELEMENT MODEL FOR PRESTRESSED CONCRETE GIRDER BRIDGE

Figure B.3 TYPICAL PRESTRESSED GIRDER BRIDGE CROSS SECTION SHOWING ACTUAL BRIDGE COMPONENTS AND FINITE ELEMENT MODEL USED

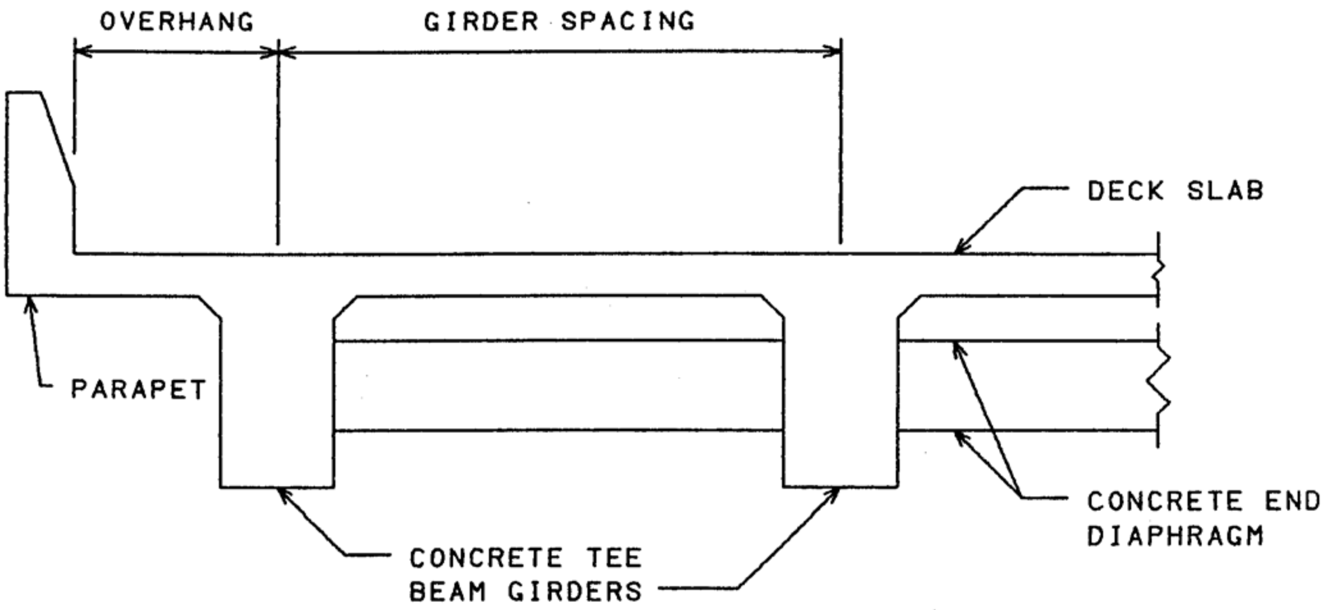


TYPICAL STEEL GIRDER BRIDGE COMPONENTS

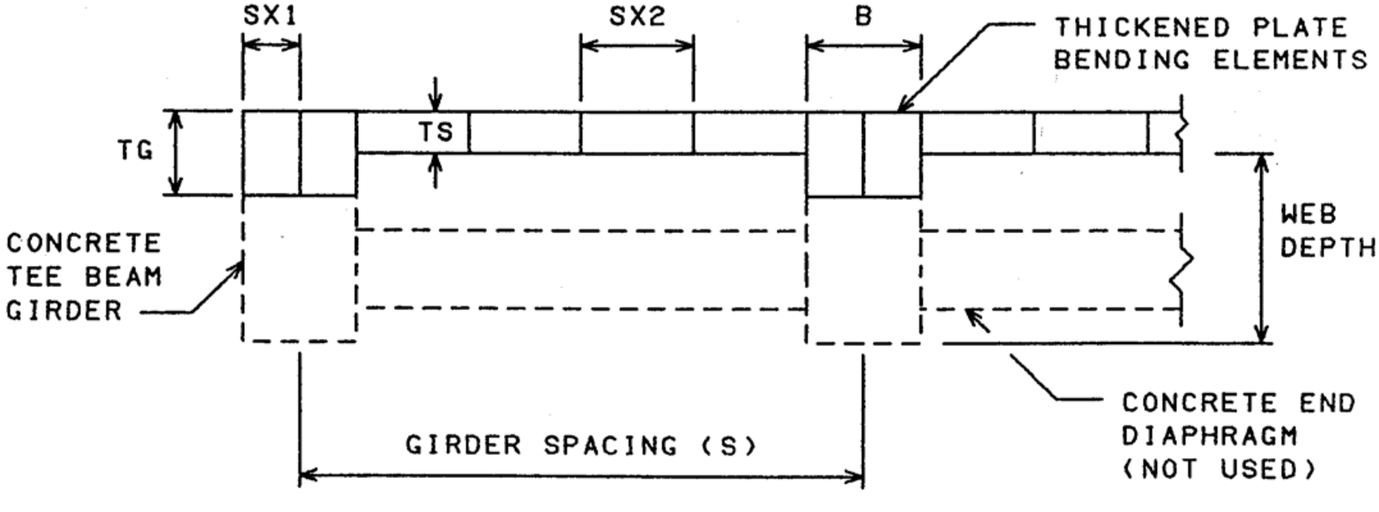


TYPICAL FINITE ELEMENT MODEL FOR STEEL GIRDER BRIDGE

Figure B.4 TYPICAL STEEL GIRDER BRIDGE CROSS SECTION SHOWING ACTUAL BRIDGE COMPONENTS AND FINITE ELEMENT MODEL USED

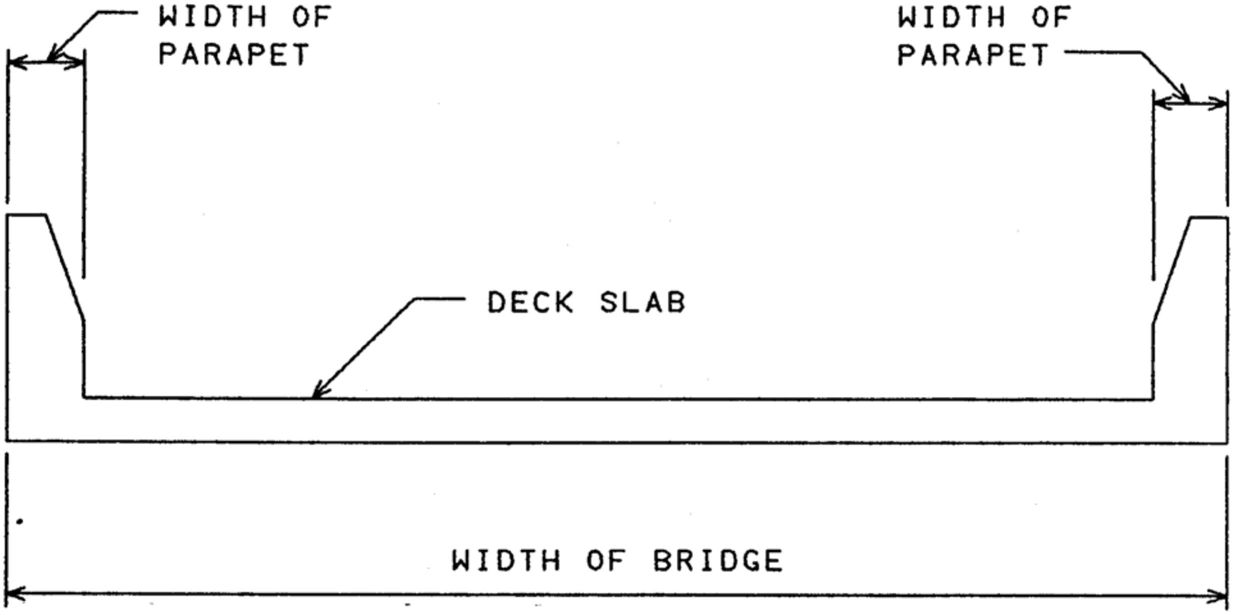


TYPICAL CONCRETE TEE BEAM GIRDER BRIDGE COMPONENTS

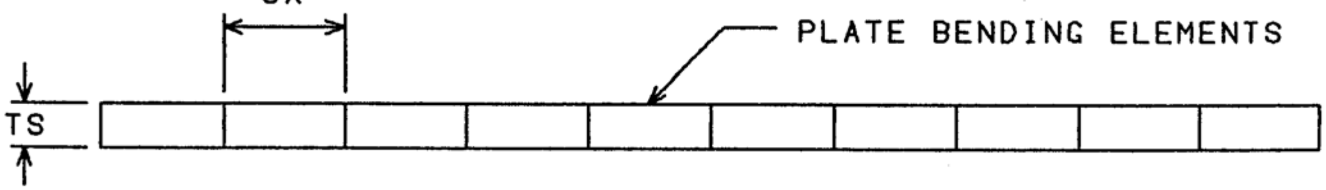


TYPICAL FINITE ELEMENT MODEL FOR CONCRETE TEE BEAM GIRDER BRIDGE

Figure B.5 TYPICAL CONCRETE TEE BEAM GIRDER BRIDGE CROSS SECTION SHOWING ACTUAL BRIDGE COMPONENTS AND FINITE ELEMENT MODEL USED



TYPICAL FLAT SLAB CONCRETE BRIDGE COMPONENTS



TYPICAL FINITE ELEMENT MODEL FOR FLAT SLAB CONCRETE BRIDGE

Figure B.6 TYPICAL CONCRETE FLAT SLAB BRIDGE CROSS SECTION SHOWING ACTUAL BRIDGE COMPONENTS AND FINITE ELEMENT MODEL USED

# APPENDIX C

# DESCRIPTION OF DATABASE FILE NAMES

This appendix contains a revised listing of the influence file names from the current database.

## Bridge Identification

An eight character name is used to identify all of the bridge file names in the database of influence surfaces. The file name which is used contains pertinent information to help identify the bridges based on the parameters in the file name. The file names all consist of a letter followed by seven digits.- The letters which are used are:

"B" = bulb tee concrete girder bridges
"P" = prestressed concrete girder bridges
"S" = steel girder bridges
"T" = concrete tee beam girder bridges
"F" = flat slab bridges

The first three digits of the file name represent the span length of the bridge. The fourth digit represents the number of girders in the bridge. The fifth digit indicates either the girder type or moment of inertia. The last two digits represent the girder spacing. To illustrate how a file name identification works, here is an example: B0605105 describes the following bridge:

B = bulb tee concrete girder bridge
060 = span length of 60 feet
5 = five girders
1 = type 1 bulb tee girder (54" deep)
05 = girder spacing of 5 feet

Table C.1 Bulb tee concrete girder bridge file name listing.

| MODEL TITLE* | SPAN LENGTH | GIRD TYPE | GIRDER SPACING | SX (in) | SY (in) | Ix ($in^4$) | Iy ($in^4$) |
|---|---|---|---|---|---|---|---|
| B060#105 | 60’ | 1 | 5.0’ | 10.0 | 36 | 26941 | 670957 |
| B060#108 | 60’ | 1 | 8.0’ | 16.0 | 36 | 26941 | 773914 |
| B060#111 | 60’ | 1 | 11.0’ | 22.0 | 36 | 26941 | 789500 |
| B060#205 | 60’ | 2 | 5.0’ | 10.0 | 36 | 25883 | 951782 |
| B060#208 | 60’ | 2 | 8.0’ | 16.0 | 36 | 25883 | 1094847 |
| B060#211 | 60’ | 2 | 11.0’ | 22.0 | 36 | 25883 | 1116680 |
| B090#105 | 90’ | 1 | 5.0’ | 10.0 | 54 | 26941 | 670957 |
| B090#108 | 90’ | 1 | 8.0’ | 16.0 | 54 | 26941 | 773914 |
| B090#111 | 90’ | 1 | 11.0’ | 22.0 | 54 | 26941 | 789500 |
| B090#205 | 90’ | 2 | 5.0’ | 10.0 | 54 | 25883 | 951782 |
| B090#208 | 90’ | 2 | 8.0’ | 16.0 | 54 | 25883 | 1094847 |
| B090#211 | 90’ | 2 | 11.0’ | 22.0 | 54 | 25883 | 1116680 |
| B090#305 | 90’ | 3 | 5.0’ | 10.0 | 54 | 28033 | 1289953 |
| B090#308 | 90’ | 3 | 8.0’ | 16.0 | 54 | 28033 | 1480798 |
| B090#311 | 90’ | 3 | 11.0’ | 22.0 | 54 | 28033 | 1510147 |
| B120#105 | 120’ | 1 | 5.0’ | 10.0 | 72 | 26941 | 670957 |
| B120#108 | 120’ | 1 | 8.0’ | 16.0 | 72 | 26941 | 773914 |
| B120#111 | 120’ | 1 | 11.0’ | 22.0 | 72 | 26941 | 789500 |
| B120#205 | 120’ | 2 | 5.0’ | 10.0 | 72 | 25883 | 951782 |
| B120#208 | 120’ | 2 | 8.0’ | 16.0 | 72 | 25883 | 1094847 |
| B120#211 | 120’ | 2 | 11.0’ | 22.0 | 72 | 25883 | 1116680 |
| B120#305 | 120’ | 3 | 5.0’ | 10.0 | 72 | 28033 | 1289953 |
| B120#308 | 120’ | 3 | 8.0’ | 16.0 | 72 | 28033 | 1480798 |
| B120#311 | 120’ | 3 | 11.0’ | 22.0 | 72 | 28033 | 1510147 |
| B150#205 | 150’ | 2 | 5.0’ | 10.0 | 90 | 25883 | 951782 |
| B150#208 | 150’ | 2 | 8.0’ | 16.0 | 90 | 25883 | 1094847 |
| B150#211 | 150’ | 2 | 11.0’ | 22.0 | 90 | 25883 | 1116680 |
| B150#305 | 150’ | 3 | 5.0’ | 10.0 | 90 | 28033 | 1289953 |
| B150#308 | 150’ | 3 | 8.0’ | 16.0 | 90 | 28033 | 1480798 |
| B150#311 | 150’ | 3 | 11.0’ | 22.0 | 90 | 28033 | 1510147 |

Bulb tee concrete girder bridge data:
slab thickness = 7.0 in.
f'c slab = 3400 psi
f'c girder = 5000 psi

NOTES:
# = Number of girders: 4, 5, 6, or 7
Iy = Flexural moment of inertia (in terms of slab E)
Ix = Torsional moment of inertia (in terms of girder E)

See Table 3.1 for thickened slab elements.

For definitions of SY and SX refer to Figures B.1 and B.2.

* See beginning of Appendix C for description of model title.

Table C.2 Bulb tee concrete girder model depths.

| girder depth variable(*) | actual girder depth |
|---|---|
| 1 | 54" |
| 2 | 63" |
| 3 | 72" |

* girder depth variable corresponds to the 5th digit of the model title

Table C.3 Prestressed concrete girder bridge file name listing (9)

| MODEL TITLE* | SPAN LENGTH | GIRD TYPE | GIRD SPCG | SX1 (in) | SX2 (in) | SY (in) | $I_x$ ($in^4$) | $I_y$ ($in.^4$) | TG (in) |
|---|---|---|---|---|---|---|---|---|---|
| P030#345 | 30’ | III | 4.5’ | 8.0 | 9.5 | 18.0 | 19428 | 341402 | 16.25 |
| P030#370 | 30’ | III | 7.0’ | 8.0 | 17.0 | 18.0 | 19428 | 399881 | 16.25 |
| P030#395 | 30’ | III | 9.5’ | 8.0 | 24.5 | 18.0 | 19428 | 409358 | 16.25 |
| P030#245 | 30’ | II | 4.5’ | 6.0 | 10.5 | 18.0 | 8748 | 175121 | 14.50 |
| P030#270 | 30’ | II | 7.0’ | 6.0 | 18.0 | 18.0 | 8748 | 203540 | 14.50 |
| P030#295 | 30’ | II | 9.5’ | 6.0 | 25.5 | 18.0 | 8748 | 207935 | 14.50 |
| P060#445 | 60’ | IV | 4.5’ | 10.0 | 8.5 | 36.0 | 37673 | 598976 | 18.00 |
| P060#470 | 60’ | IV | 7.0’ | 10.0 | 16.0 | 36.0 | 37673 | 699955 | 18.00 |
| P060#495 | 60’ | IV | 9.5’ | 10.0 | 23.5 | 36.0 | 37673 | 722446 | 18.00 |
| P060#345 | 60’ | III | 4.5’ | 8.0 | 9.5 | 36.0 | 19428 | 341402 | 16.25 |
| P060#370 | 60’ | III | 7.0’ | 8.0 | 17.0 | 36.0 | 19428 | 399881 | 16.25 |
| P060#395 | 60’ | III | 9.5’ | 8.0 | 24.5 | 36.0 | 19428 | 410880 | 16.25 |
| P060#245 | 60’ | II | 4.5’ | 6.0 | 10.5 | 36.0 | 8748 | 175121 | 14.50 |
| P060#270 | 60’ | II | 7.0’ | 6.0 | 18.0 | 36.0 | 8748 | 203540 | 14.50 |
| P060#295 | 60’ | II | 9.5’ | 6.0 | 25.5 | 36.0 | 8748 | 207935 | 14.50 |
| P090#445 | 90’ | IV | 4.5’ | 10.0 | 8.5 | 54.0 | 37673 | 598976 | 18.00 |
| P090#470 | 90’ | IV | 7.0’ | 10.0 | 16.0 | 54.0 | 37673 | 699955 | 18.00 |
| P090#495 | 90’ | IV | 9.5’ | 10.0 | 23.5 | 54.0 | 37673 | 722446 | 18.00 |
| P090#345 | 90’ | III | 4.5’ | 8.0 | 9.5 | 54.0 | 19428 | 341402 | 16.25 |
| P090#370 | 90’ | III | 7.0’ | 8.0 | 17.0 | 54.0 | 19428 | 399881 | 16.25 |
| P090#395 | 90’ | III | 9.5’ | 8.0 | 24.5 | 54.0 | 19428 | 410880 | 16.25 |
| P120#445 | 120’ | IV | 4.5’ | 10.0 | 8.5 | 72.0 | 37673 | 598976 | 18.00 |
| P120#470 | 120’ | IV | 7.0’ | 10.0 | 16.0 | 72.0 | 37673 | 699955 | 18.00 |
| P120#345 | 120’ | III | 4.5’ | 8.0 | 9.5 | 72.0 | 19428 | 341402 | 16.25 |
| P120#370 | 120’ | III | 7.0’ | 8.0 | 17.0 | 72.0 | 19428 | 399881 | 16.25 |

Prestressed concrete girder bridge data:

| | |
|---|---|
| Slab thickness | = 7.0 in. |
| Slab f'c | = 3,400.0 psi |
| Girder f'c | = 5,000.0 psi |

NOTES:

# = Number of girders: 4, 5, 6, or 7
Ix = Torsional moment of inertia (in terms of girder E)
Iy = Flexural moment of inertia (in terms of slab E)
TG = Thickness of thickened "BPR" elements

For definitions of SY, SX1, and SX2 refer to Figures B.1 and B.3.

* See beginning of Appendix C for description of model title.

## Table C.4 Steel girder bridge file name listing (9)

| MODEL TITLE* | SPAN LENGTH | SY (in) | Iy (x 1000 in$^4$) | GIRDER SPACING | SX (in) |
|---|---|---|---|---|---|
| S030#1xx | 30’ | 18 | 25 | 4.5’ | 9.0 |
| S030#2xx | 30’ | 18 | 100 | 7.0’ | 14.0 |
| S030#3xx | 30’ | 18 | 250 | 9.5’ | 19.0 |
| S060#1xx | 60’ | 36 | 25 | | |
| S060#2xx | 60’ | 36 | 100 | | |
| S060#3xx | 60’ | 36 | 250 | | |
| S060#4xx | 60’ | 36 | 500 | | |
| S090#2xx | 90’ | 54 | 100 | | |
| S090#3xx | 90’ | 54 | 250 | | |
| S090#4xx | 90’ | 54 | 500 | | |
| S090#5xx | 90’ | 54 | 1500 | | |
| S120#3xx | 120’ | 72 | 250 | | |
| S120#4xx | 120’ | 72 | 500 | | |
| S120#5xx | 120’ | 72 | 1500 | | |
| S120#6xx | 120’ | 72 | 3000 | | |
| S150#4xx | 150’ | 90 | 500 | | |
| S150#5xx | 150’ | 90 | 1500 | | |
| S150#6xx | 150’ | 90 | 3000 | | |

NOTE:
All deck elements have the same width, SX, for steel girder bridges.

Steel girder bridge data:

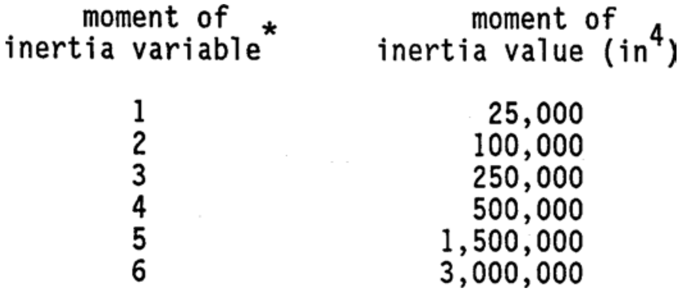
| | |
|---|---|
| Slab thickness | = 7.0 in. |
| Slab f'c | = 3,400.0 psi |
| Steel Eg | = 29,000.0 ksi |

NOTES:
Iy = Flexural moment of inertia (in terms of slab E)
\# = Number of girders: 4, 5, 6, or 7
xx= Girder spacings: 4.5' = 45
7.0'= 70
9.5' = 95

* See beginning of Appendix C for description of model title.

For definitions of SY and SX refer to Figures B.1 and B.4.

Table C.5 Steel girder bridge model moments of inertia (9)



| moment of inertia variable* | moment of inertia value (in$^4$) |
|---|---|
| 1 | 25,000 |
| 2 | 100,000 |
| 3 | 250,000 |
| 4 | 500,000 |
| 5 | 1,500,000 |
| 6 | 3,000,000 |

* 5th digit of model title is a moment of inertia variable corresponding to the strong axis composite moment of inertia (Iy) value.

Table C.6 Concrete tee beam girder bridge file name listing (9)

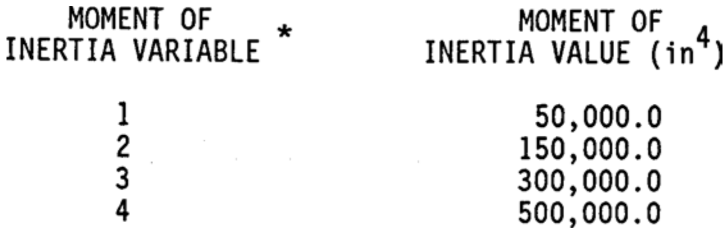
| MODEL* TITLE | SPAN LENGTH | GIRDER SPACING | SX1 (in.) | SX2 (in.) | SY (in.) | COMPOSITE M.I. ($in^4$) |
|---|---|---|---|---|---|---|
| T020#145 | 20’ | 4.5’ | 5.4 | 10.8 | 12.0 | 50,000.0 |
| T020#245 | 20’ | 4.5’ | 5.4 | 10.8 | 12.0 | 150,000.0 |
| T020#345 | 20’ | 4.5’ | 5.4 | 10.8 | 12.0 | 300,000.0 |
| T020#445 | 20’ | 4.5’ | 5.4 | 10.8 | 12.0 | 500,000.0 |
| T020#170 | 20’ | 7.0’ | 8.4 | 16.8 | 12.0 | 50,000.0 |
| T020#270 | 20’ | 7.0’ | 8.4 | 16.8 | 12.0 | 150,000.0 |
| T020#370 | 20’ | 7.0’ | 8.4 | 16.8 | 12.0 | 300,000.0 |
| T020#470 | 20’ | 7.0’ | 8.4 | 16.8 | 12.0 | 500,000.0 |
| T020#195 | 20’ | 9.5’ | 11.4 | 22.8 | 12.0 | 50,000.0 |
| T020#295 | 20’ | 9.5’ | 11.4 | 22.8 | 12.0 | 150,000.0 |
| T020#395 | 20’ | 9.5’ | 11.4 | 22.8 | 12.0 | 300,000.0 |
| T020#495 | 20’ | 9.5’ | 11.4 | 22.8 | 12.0 | 500,000.0 |
| T040#145 | 40’ | 4.5’ | 5.4 | 10.8 | 24.0 | 50,000.0 |
| T040#245 | 40’ | 4.5’ | 5.4 | 10.8 | 24.0 | 150,000.0 |
| T040#345 | 40’ | 4.5’ | 5.4 | 10.8 | 24.0 | 300,000.0 |
| T040#445 | 40’ | 4.5’ | 5.4 | 10.8 | 24.0 | 500,000.0 |
| T040#170 | 40’ | 7.0’ | 8.4 | 16.8 | 24.0 | 50,000.0 |
| T040#270 | 40’ | 7.0’ | 8.4 | 16.8 | 24.0 | 150,000.0 |
| T040#370 | 40’ | 7.0’ | 8.4 | 16.8 | 24.0 | 300,000.0 |
| T040#470 | 40’ | 7.0’ | 8.4 | 16.8 | 24.0 | 500,000.0 |
| T040#195 | 40’ | 9.5’ | 11.4 | 22.8 | 24.0 | 50,000.0 |
| T040#295 | 40’ | 9.5’ | 11.4 | 22.8 | 24.0 | 150,000.0 |
| T040#395 | 40’ | 9.5’ | 11.4 | 22.8 | 24.0 | 300,000.0 |
| T040#495 | 40’ | 9.5’ | 11.4 | 22.8 | 24.0 | 500,000.0 |
| T060#145 | 60’ | 4.5’ | 5.4 | 10.8 | 36.0 | 50,000.0 |
| T060#245 | 60’ | 4.5’ | 5.4 | 10.8 | 36.0 | 150,000.0 |
| T060#345 | 60’ | 4.5’ | 5.4 | 10.8 | 36.0 | 300,000.0 |
| T060#445 | 60’ | 4.5’ | 5.4 | 10.8 | 36.0 | 500,000.0 |
| T060#170 | 60’ | 7.0’ | 8.4 | 16.8 | 36.0 | 50,000.0 |
| T060#270 | 60’ | 7.0’ | 8.4 | 16.8 | 36.0 | 150,000.0 |
| T060#370 | 60’ | 7.0’ | 8.4 | 16.8 | 36.0 | 300,000.0 |
| T060#470 | 60’ | 7.0’ | 8.4 | 16.8 | 36.0 | 500,000.0 |
| T060#195 | 60’ | 9.5’ | 11.4 | 22.8 | 36.0 | 50,000.0 |
| T060#295 | 60’ | 9.5’ | 11.4 | 22.8 | 36.0 | 150,000.0 |
| T060#395 | 60’ | 9.5’ | 11.4 | 22.8 | 36.0 | 300,000.0 |
| T060#495 | 60’ | 9.5’ | 11.4 | 22.8 | 36.0 | 500,000.0 |

Concrete tee beam girder bridge data:
Slab thickness = 7.5 in.
concrete f’c = 3,400.0 psi
s/b ratio = 5
girder thickness = 15.0 in.

NOTES:
# = Number of girders 4, 5, 6, or 7

For definitions of SY, SX1, and SX2 refer to Figures B.1 and B.5.

Table C.7 Concrete tee beam bridge model moments of inertia (9)



| MOMENT OF INERTIA VARIABLE * | MOMENT OF INERTIA VALUE ($in^4$) |
|---|---|
| 1 | 50,000.0 |
| 2 | 150,000.0 |
| 3 | 300,000.0 |
| 4 | 500,000.0 |

* Corresponds to the fifth digit of the tee beam model title.

Table C.8 Concrete flat slab bridge file name listing (9)

| TITLE* | WIDTH (FT) | SPAN (FT) | WIDTH/SPAN |
|---|---|---|---|
| FSLAB050 | 30 | 60 | 0.50 |
| FSLAB075 | 30 | 40 | 0.75 |
| FSLAB100 | 30 | 30 | 1.00 |
| FSLAB150 | 30 | 20 | 1.50 |
| FSLAB200 | 30 | 15 | 2.00 |
| FSLAB250 | 30 | 12 | 2.50 |
| FSLAB300 | 30 | 10 | 3.00 |

* The last three digits represent the width-to-span ratio

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