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<td>9. Performing Organization Name and Address</td>
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<td>16. Abstract</td>
<td>This report gives the theoretical background and a description of a computer program, DYMOL, along with its revisions. This program was originally written to calculate the dynamic forces applied normal to a rigid surface by moving traffic. Revisions are made in the program to include the flexibility (stiffness, damping and inertia effect) of the riding surface, and a special subroutine is added to generate typical grade crossing profiles. Input formats, program listing and a glossary of variables are given for the use of the program. Also included with the report are the descriptions of the program's subroutines and functions and method of calculation of dynamic loads along with Maysmeter readings.</td>
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COMPUTATION OF DYNAMIC LOADS AT GRADE CROSSINGS;
A USER'S MANUAL OF THE COMPUTER PROGRAM

by

Aziz Ahmad
Robert L. Lytton

Research Report Number 164-2

Structural and Geometric Design of
Highway-Railroad Grade Crossings

Research Project 2-18-74-164

conducted for
The State Department of Highways and Public Transportation
in cooperation with the
U.S. Department of Transportation

by the
Texas Transportation Institute
Texas A&M University
College Station, Texas

January, 1976
PREFACE

This report is the second in a series issued under Research Study 2-18-74-164, "Structural and Geometric Design of Highway-Railroad Grade Crossings." This research is sponsored by the State Department of Highways and Public Transportation in cooperation with the Federal Highway Administration to study the problems encountered at highway-railroad grade crossings and to recommend improvements in analysis and design procedure.

ACKNOWLEDGEMENT

The authors sincerely appreciate the assistance and helpful suggestions given by Mr. Dale L. Schafer in computer programming.

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.
Abstract

This report gives the theoretical background and a description of a computer program, DYMOL, along with its revisions. This program was originally written to calculate the dynamic forces applied normal to a rigid surface by moving traffic. Revisions are made in the program to include the flexibility (stiffness, damping and inertia effect) of the riding surface, and a special subroutine is added to generate typical grade crossing profiles. Input formats, program listing and a glossary of variables are given for the use of the program. Also included with the report are the descriptions of the program's subroutines and functions and method of calculation of dynamic loads along with Maysmeter readings.
Summary

This report is a user's manual for a revised computer program DYMOL. Input formats, program listing and a glossary of variables are included along with an explanation of the function of each of the program's subroutines.

Highway pavements and structures are always subjected to dynamic wheel loadings due to the traffic moving over them, but their present structural design procedures are mostly based on static loading criteria for stress analysis and for materials evaluation. A reliable technique to measure the locations and magnitudes of these dynamic loadings is desired to achieve an improved and realistic design procedure.

Dynamic loads mainly depend on characteristics of the vehicle, surface roughness and vehicle speed. Computer program DYMOL was written to calculate the dynamic loads applied normal to the surface of highway and other structures by moving traffic. In this version of the program vehicles with two axles are simulated considering them to be damped oscillatory systems with several degrees of freedom. These mathematical simulation models are run over different surface profiles (natural or artificial) with different vehicle speeds. Differential equations of motion are written for each degree of freedom in the model. These equations are solved numerically to obtain dynamic wheel loads over a surface due to moving vehicles. The original program DYMOL was written to calculate dynamic loads applied normal to a rigid surface. The following revisions are made in the program to increase its usefulness to the design of railroad grade crossings:

1. Flexibility of the riding surface (stiffness, damping and inertia effect) is included in the program.
2. A special subroutine is added to generate the profiles of typical grade crossings.
Implementation Statement

The program DYMOL was originally written and later revised in the expectation that design engineers would be able to predict the actual dynamic wheel loading pattern created on a surface of highway pavement or a structure due to the interaction of any surface roughness and vehicle characteristics with different vehicle speeds. This would certainly help arriving at an improved and a realistic design procedure. This program may be used to evaluate an existing pavement or a structure and maintenance operation can be carried out to minimize the surface roughness which causes excessive dynamic loads. Due to the required geometrics, the differential settlements caused by highway and railway traffic, and other practical construction complexities the railroad grade crossings are always a source of higher dynamic loads than on a typical pavement. DYMOL is used in this project to study the influence of different grade crossing profiles upon dynamic tire forces acting normal to the surface. Some typical results are shown in Research Report 164-1. This computer program requires approximately 100,000 bytes of memory.
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INTRODUCTION

This report is written as a user's guide to the revised computer program DYMOL. Program input data and its format are shown here. Remarks and units of input variables are included to help reduce the time for setting up the data.

DYMOL was originally developed by Nasser I. Al-Rashid (1) at the University of Texas at Austin. This was written to calculate the dynamic forces applied normal to the surface of highway pavements and other structures by moving traffic. However, certain revisions were made in the program to increase its flexibility and usefulness. A complete description of the original program DYMOL along with its revisions are documented in this report. Organization of this report is as follows.

a) Description of the original program DYMOL
b) Revisions of the program DYMOL
c) Description of Subroutines and Functions
d) Input description
e) Description of FORTRAN variables that are used in the program
f) Calculation of dynamic loads on each wheel along with Maysmeter reading
g) FORTRAN Listing for Program DYMOL.
DESCRIPTION OF THE COMPUTER PROGRAM

Description of the Original Program DYMOL

This program was originally written for five classes of vehicles. However, vehicles with two axles are simulated in this version of the program by considering them to be damped oscillatory systems with several degrees of freedom. Figure 1 shows the two-axle vehicle model. In this model the vehicle is represented by three distinct masses: (1) the main body, (2) the front axle, and (3) the rear axle. The main body is considered to be rigid. It rests on two axles through four springs, and a shock absorber is connected in parallel with each spring. Again, the two axles rest on at least four tires which are simulated by springs and dashpots. These springs and shock absorbers (or dashpots) may be different for different wheels. The following movements of these three masses are used to calculate the dynamic loads for each wheel:

1. Main body translation in the vertical plane;
2. Main body pitching (rotation about a lateral axis of the body);
3. Main body rolling (rotation about a longitudinal axis of the body);
4. Front axle translation in the vertical plane;
5. Rear axle translation in the vertical plane;
6. Rolling of the front axle;
7. Rolling of the rear axle.

The last four motions of the axle may be accounted for by considering vertical translation of each of the individual wheels. The masses (main body, front axle and rear axle) are excited by surface profiles, which causes vibration in them. Differential equations of motion are set up for each individual mass. These equations are solved by numerical method, resulting in the total dynamic loads for each wheel. General Motors profilometer data from natural surfaces which have been digitized on magnetic tape can be used as input in the program.
These data are averaged for each contact length between the wheel and the ground to calculate the wheel path excitation. Artificial profiles can also be generated internally in place of or in addition to natural surface profile input.

Revisions of the Program DYMOL

The original version of DYMOL considers the surface over which the vehicle rides to be rigid. In reality, a pavement acts more like a viscoelastic material. A definite quantity of pavement and soil mass also vibrates with the vibrating wheel while being resisted by the inertia of the pavement. Consideration of the stiffness, damping and inertia of the pavement was incorporated into the program by rewriting the basic differential equations of motion. These equations were solved by the same numerical method as before. Figure 2 shows the original and revised models of the program.

The revised simulation resulted in four additional degrees of freedom in the model one for each mass of pavement in contact with a tire. Table 1 shows the summary of the degrees of freedom of the revised DYMOL model.

Two special subroutines which generate the profiles of a typical grade-crossing and of sinusoidal curves respectively have been written and added to the DYMOL program. Figure 3 shows a typical grade-crossing profile.

Finally a set of FORTRAN statements were added to the program to accumulate the relative vertical movements of the rear axle with respect to the vehicle body. This movement is recorded by the Mays Road Meter reading in an actual vehicle as an indication of pavement roughness. The Maysmeter simulator is intended for comparison with the data from actual Maysmeter runs on any surface profile. Figure 4 shows a general flowchart of the revised computer program DYMOL.
FIGURE 1.—TWO AXLE VEHICLE USED IN COMPUTER PROGRAM DYMOL (After Reference 1)
m₁ = Mass of Vehicle Body
m₂ = Mass of Tire and 1/2 Axle
m₃ = Mass of Soil That Vibrates in Phase With the Wheel
y(t) = Excitation

2(a) Original Simulation Model

FIGURE 2 - SIMULATION MODEL
<table>
<thead>
<tr>
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<th>Mass System</th>
<th>Variables</th>
<th>Differential Eq. of Motion</th>
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<td>1. Vertical Translation of the Main body.</td>
<td>BMO</td>
<td>YO</td>
<td>1*</td>
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<tr>
<td>2. Rolling of the Main Body</td>
<td>B1X</td>
<td>PHIX</td>
<td>2</td>
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<td>3. Pitching of the Main Body</td>
<td>B1Z</td>
<td>PHIZ</td>
<td>3</td>
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<td>BM1R</td>
<td>Y1R</td>
<td>4</td>
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<td>5. Vertical Translation of Front Left Wheel</td>
<td>BM1L</td>
<td>Y1L</td>
<td>5</td>
</tr>
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<td>6. Vertical Translation of Rear Right Wheel</td>
<td>BM2R</td>
<td>Y2R</td>
<td>6</td>
</tr>
<tr>
<td>7. Vertical Translation of Rear Left Wheel</td>
<td>BM2L</td>
<td>Y2L</td>
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<tr>
<td>8. Vertical Translation of Soil Mass with Front Right Wheel</td>
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<td>PX1R</td>
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<td>9. Vertical Translation of Soil Mass with Front Left Wheel</td>
<td>BMPV1L</td>
<td>PX1L</td>
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<td>10. Vertical Translation of Soil Mass with Rear Right Wheel</td>
<td>BMPV2R</td>
<td>PX2R</td>
<td>10</td>
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<td>11. Vertical Translation of Soil Mass with Rear Left Wheel</td>
<td>BMPV2L</td>
<td>PX2L</td>
<td>11</td>
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</table>

TABLE 1. Summary of the Degrees of Freedom of the Revised DYMOL Model

* See the differential equations in Appendix B
FIGURE 3 - TYPICAL GRADE CROSSING
Fig. 4 General Flowchart of the Computer Program DYMOL
DESCRIPTION OF SUBROUTINES AND FUNCTIONS
This program comprises of the main part, seven subroutines: \textsc{Class1}, \textsc{Driver}, \textsc{Indap}, \textsc{Natpro}, \textsc{Pravg}, \textsc{Readin}, and \textsc{Tapewr} and two functions: \textsc{Fbump}, \textsc{Xbump}. Table 2 gives a cross-reference listing of the main program, subroutines and functions.

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<td>-</td>
</tr>
<tr>
<td>\textsc{Driver}</td>
<td>-</td>
</tr>
<tr>
<td>\textsc{Function FBump}</td>
<td>-</td>
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<tr>
<td>\textsc{Function XBump}</td>
<td>-</td>
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<td>\textsc{Indap}</td>
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<tr>
<td>\textsc{Tapewr}</td>
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\textbf{Table 2: Subprogram and Main Cross-Reference Table}
A brief description of all the subroutines and functions is given below:

Subroutine TAPEWR

This subroutine reads the natural roadway profiles (profilometer data) from tape no. 10 and writes them on the temporary tape no. 1, which is used later in the program. When artificial bumps are used to calculate dynamic forces, this subroutine writes zeroes for natural profiles (profilometer data) on the temporary tape no. 1.

Subroutine READIN

This subroutine reads all the input-variables. A complete description is shown in the chapter "Input Description".

Subroutine PRAVG

In this subroutine, natural profiles are read from tape no. 1, which is already written in subroutine TAPEWR. Then these values are averaged to calculate the wheel path excitation. The contact length between the wheel and the ground is considered to be eight inches and the profilometer data are assumed to be at a spacing of 2.027 inch. Therefore, four profilometer data points are averaged each time to calculate the wheel path excitation for each contact between the wheel and the ground. When artificial bumps or railroad grade crossing profiles are used, the profilometer data are zeroed (already written on the tape 1) and the subprogram FBUMP or XBUMP generates the heights of the profile. As in the case of natural profile, here also, four data points are averaged to calculate the wheel path excitation for each contact between the wheel and the ground. These averaged wheel path excitation from natural, artificial or grade crossing profiles are written on tape no. 2, for further use in the program.
Subroutine DRIVER

This subroutine calculates $V$ (Velocity, inch per second), $KSTEP$, $IFREQ$, $H$ (time step). Then all the variables such as linear and angular displacements, velocities, accelerations of vehicle body, tires and soil masses are initialized. At the end of this subroutine, $ITIME$ (number of time steps to be studied) is fixed; and then subroutine CLASS1 is called to calculate dynamic loads and Maysmeter readings.

Subroutine NATPRO

This subroutine reads the values of wheel path excitation for each time interval from tape no. 2 (on which these data have been written in subroutine PRFAVG). These values are used in subroutine CLASS1 to calculate dynamic loads and Maysmeter readings.

Subroutine INDAP

This subroutine prints out the input data along with vehicle characteristics.

Function FBUMP

This function generates the profile height at each time step, due to sinusoidal curves.

Function XBUMP

This function generates the profile height at each time step, due to railroad grade crossing.

Subroutine CLASS1

This subroutine solves the equations of motion and calculates the total dynamic loads for each wheel, due to the wheel path excitation created by natural profile, grade crossings or artificial bumps. This subroutine also accumulates the vertical movement of vehicle body with respect to the rear axle. These
accumulated movements are printed as the Maysmeter reading corresponding to each time interval.

At the beginning of this subroutine, input data are set up corresponding to each variable. Then the center of gravity of the vehicle body is located and body masses and mass moment of inertia are calculated. Subroutine INDAP is called to print out the input data. After the variables I and X3 are defined and XMAYSA and XMAYSM are initialized by zeros, the time do-loop is set up to calculate the dynamic loads on each wheel and to accumulate the Maysmeter reading. The range of this do-loop goes from 1 to ISTOP, covering the whole time limit for running the model, incremented by each time step. Subroutine NATPRO is called within the do-loop on each time step to read its corresponding values of wheelpath excitations from the tape. A detailed description of calculations of dynamic loads on each wheel and the corresponding value of Maysmeter reading is shown in Appendix B.
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2nd set (i) | 1-10 | A1 | inch |
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<td>ICLASS</td>
<td>Alphanumeric; Name, type, etc. of the vehicle used.</td>
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<td>STRBMP</td>
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<td>BMPHT</td>
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<td>NPTTS</td>
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References


APPENDIX A

FORTRAN VARIABLE DESCRIPTION
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<tr>
<th>FORTRAN VARIABLE</th>
<th>DESCRIPTION</th>
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<tbody>
<tr>
<td>A1, A2</td>
<td>Lengths of horizontal pavements before and after the grade-crossing</td>
</tr>
<tr>
<td>AMPL, AMPR</td>
<td>Amplitude of the left and right wheel path excitation respectively.</td>
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<td>AXAWT(J)</td>
<td>Weight of axle assembly, differential, brakes, tires for axle J.</td>
</tr>
<tr>
<td>AXWTL(J), AXWTR(J)</td>
<td>Vehicle static weights of left and right side of axle J respectively.</td>
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<td>B1, B2</td>
<td>Lengths of the horizontal projection of initial and final ramp of a grade-crossing respectively.</td>
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<td>BH1, BH2</td>
<td>Vertical rise of initial and final ramps respectively.</td>
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<td>BIX, BIZ</td>
<td>Body mass moment of inertias - Roll and pitch respectively.</td>
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<td>BM1L, BM1R</td>
<td>Mass of axle assembly, differential, brakes, tires, etc. of front left and front right axle respectively.</td>
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<td>BM2L, BM2R</td>
<td>Mass of axle assembly, differential, brakes, tires, etc. of rear left and rear right axle respectively.</td>
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<td>BMPV1L, BMPV1R, BMPV2L, BMPV2R</td>
<td>Mass of pavement and soil that vibrates with (front left, front right, rear left and rear right wheel respectively).</td>
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<tr>
<td>BMO</td>
<td>Mass of the vehicle body.</td>
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<td>BMPHT</td>
<td>Bump height.</td>
</tr>
<tr>
<td>BMPSA</td>
<td>Bump spacing.</td>
</tr>
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<td>BMPWDT</td>
<td>Bump width.</td>
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<td>C1, C2</td>
<td>Gap widths between 1st ramp and 1st rail and between 2nd rail and 2nd ramp respectively of a grade-crossing.</td>
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<tr>
<td>CH1, CH2</td>
<td>Depths of the gaps C1 and C2 respectively.</td>
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<td>CLOTOL</td>
<td>Closure tolerance</td>
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<td>DESCRIPTION</td>
</tr>
<tr>
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<td>-----------------------------------------------------------------------------</td>
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<tr>
<td>CPL(J), CPR(J)</td>
<td>Damping rate of pavement or soil under left and right wheel of the axle, J, respectively.</td>
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<tr>
<td>CP1L, CP1R, CP2L, CP2R</td>
<td>Damping rate of pavement or soil under (front left, front right, rear left and rear right wheel respectively).</td>
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<td>CSL(J), CSR(J)</td>
<td>Damping rate for left and right suspension of axle J respectively.</td>
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<td>Damping rate for left and right suspension of front axle.</td>
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<td>Damping rate for left and right suspension of rear axle.</td>
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<td>Damping rate of left and right tire of axle J respectively.</td>
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<td>Damping rate of (front left, front right, rear left and rear right tire respectively).</td>
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<td>D1, D2</td>
<td>Width of the gaps between first rail and horizontal mid-portion and between 2nd rail and horizontal mid-portion respectively of grade-crossing.</td>
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<td>DH1, DH2</td>
<td>Depth of the gaps D1 and D2 respectively.</td>
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<td>D1L, D1R, D2L, D2R</td>
<td>Displacement of vehicle body (front left, front right, rear left and rear right portion respectively).</td>
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<td>DD1L, DD1R, DD2L, DD2R</td>
<td>Velocity of vehicle body (front left, front right, rear left and rear right portion respectively).</td>
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<td>DYF1L, DYF1R</td>
<td>Calculated dynamic forces at left and right side of front axle respectively.</td>
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<td>DYF2L, DYF2R</td>
<td>Calculated dynamic forces at left and right side of rear axle respectively.</td>
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<td>DSTL, DSTR</td>
<td>Distance from initial point to start of left and right wheel path excitation respectively.</td>
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<td>DSPACE</td>
<td>Spacing between two data points in the natural road profile (or artificially generated profile). It is measured in inches. For GM Profilometer data, DSPACE = 2.027 inches.</td>
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<td>EE</td>
<td>Straight middle portion of pavement between two rails of a grade-crossing.</td>
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<td>FBUMP</td>
<td>Wheel path profile for artificial bump.</td>
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<td>G</td>
<td>Acceleration due to gravity in inches/sec².</td>
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<tr>
<td>H</td>
<td>Time step interval.</td>
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<tr>
<td>HT2</td>
<td>2H (Twice the time step).</td>
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<tr>
<td>H02</td>
<td>H/2 (Half the time step).</td>
</tr>
<tr>
<td>HE2</td>
<td>H² (Time step interval squared).</td>
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<tr>
<td>HHO2</td>
<td>H²/2 (Half time step interval squared).</td>
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<td>An integer used in subroutine CLASS 1, the value is fixed and equal to 1 in the subroutine.</td>
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<td>ID</td>
<td>Variable name for identification and initial description of the profilometer data.</td>
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<td>Frequency of output.</td>
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<td>This integer value is used to calculate the time step length (H). KSTEP is larger for higher speed of the vehicle.</td>
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<td>NMBMPS</td>
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<td>NPTTS</td>
<td>Number of spaces in profilometer data for each contact between the wheel and pavement.</td>
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<td>This integer number is the number of a particular record of data profile from which the input starts in the program.</td>
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<td>NTA</td>
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<td>Averaged wheel path excitation for right and left wheel respectively.</td>
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<td>PKL(J), PKR(J)</td>
<td>Stiffness of soil or pavement (subgrade reactions) under left and right wheel respectively of axle J.</td>
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<td>PHIX, PHIZ</td>
<td>Vehicle body rotation about x-axis (Roll) and z-axis (Pitch) respectively.</td>
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<td>Angular velocity of the vehicle body about x-axis and z-axis respectively.</td>
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<td>DDPHIX, DDPHIZ</td>
<td>Angular acceleration of the vehicle body about x-axis and z-axis respectively.</td>
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<td>SM1, SM2</td>
<td>Elevation difference between A1 and B1 and between A2 and B2 respectively of a grade-crossing.</td>
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<td>SPEED</td>
<td>Speed of the vehicle (miles/hour).</td>
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<td>Spacings of left and right wheel-path bumps respectively.</td>
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<td>SKL(J), SKR(J)</td>
<td>Stiffness of left and right suspension respectively of axle J.</td>
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<td>SK1L, SK1R</td>
<td>Stiffness of left and right suspension respectively of front axle.</td>
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<tr>
<td>SK2L, SK2R</td>
<td>Stiffness of left and right suspension respectively of rear axle.</td>
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<td>Width of 1st and 2nd rail-top respectively.</td>
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<td>TH1, TH2</td>
<td>Elevation difference between T1 and EE and between T2 and EE respectively.</td>
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<td>TD1FL, TD1FR</td>
<td>Total forces at left and right side respectively of front axle.</td>
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<td>TD2FL, TD2FR</td>
<td>Total forces at left and right side respectively of rear axle.</td>
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<td>Time limit in seconds for running the vehicle.</td>
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<td>Stiffness of tire (front left, front right, rear left and rear right tire respectively).</td>
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<td>Velocity of the vehicle in inches/sec.</td>
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<td>Velocity of the vehicle in feet/sec.</td>
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<td>VMPH</td>
<td>Velocity of the vehicle in miles/hour.</td>
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<td>Wheel path excitation.</td>
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<td>Wave lengths of the left and right bumps respectively.</td>
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<td>Distance between axle 1 and axle 2.</td>
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<td>Initial left and right wheel-path excitation.</td>
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<td>Distance between C.G. and the rear axle of the vehicle.</td>
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<td>X3, XX1</td>
<td>Distance between C.G. and front axle of the vehicle.</td>
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<td>XBUMP</td>
<td>Wheel path profile for grade-crossing.</td>
</tr>
<tr>
<td>XMAYSA, XMAYS, XMAYSM</td>
<td>Maysmeter simulations calculated in the program.</td>
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<td>Displacement of C.G. of the vehicle.</td>
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<tr>
<td>DYO</td>
<td>Velocity of C.G. of the vehicle.</td>
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<tr>
<td>DDYO, ADDYO</td>
<td>Acceleration of C.G. of the vehicle.</td>
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<td>Displacements of axle (front left, front right, rear left and rear right portion respectively).</td>
</tr>
<tr>
<td>DY1L, DY1R, DY2L, DY2R</td>
<td>Velocity of axle (front left, front right, rear left, rear right portion respectively).</td>
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<tr>
<td>DZY1L, DZY1R, DZY2L, DZY2R</td>
<td>Acceleration of axle (front left, front right, rear left, rear right respectively).</td>
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</table>
APPENDIX B

CALCULATION OF DYNAMIC LOADS ON EACH WHEEL ALONG WITH MAYSMETER READINGS
The following are the differential equations of motion due to different degrees of freedom in the revised model of DYMOL as shown in Table 1.

\[ SK1R \left( D1R - Y1R \right) + CS1R \left( \frac{3D1R}{3t} - \frac{3Y1R}{3t} \right) + SK1L \left( D1L - Y1L \right) \]
\[ + CS1L \left( \frac{3D1L}{3t} - \frac{3Y1L}{3t} \right) + SK2R \left( D2R - Y2R \right) + CS2R \left( \frac{3D2R}{3t} - \frac{3Y2R}{3t} \right) \]
\[ + SK2L \left( D2L - Y2L \right) + CS2L \left( \frac{3D2L}{3t} - \frac{3Y2L}{3t} \right) + BMO \cdot \frac{3^2Y0}{3t^2} = 0 \quad \ldots \text{Eq. (1)} \]

\[ \frac{W1}{2} \left[ SK1R \left( D1R - Y1R \right) + CS1R \left( \frac{3D1R}{3t} - \frac{3Y1R}{3t} \right) - SK1L \left( D1L - Y1L \right) \right] \]
\[ - CS1L \left( \frac{3D1L}{3t} - \frac{3Y1L}{3t} \right) + \frac{W2}{2} \left[ SK2R \left( D2R - Y2R \right) + CS2R \left( \frac{3D2R}{3t} - \frac{3Y2R}{3t} \right) \right] \]
\[ - SK2L \left( D2L - Y2L \right) - CS2L \left( \frac{3D2L}{3t} - \frac{3Y2L}{3t} \right) - BIX \cdot \frac{3^2\phi IX}{3t^2} = 0 \quad \ldots \text{Eq. (2)} \]

\[ X3 \left[ SK1R \left( D1R - Y1R \right) + CS1R \left( \frac{3D1R}{3t} - \frac{3Y1R}{3t} \right) + SK1L \left( D1L - Y1L \right) \right] \]
\[ + CS1L \left( \frac{3D1L}{3t} - \frac{3Y1L}{3t} \right) - X2 \left[ SK2R \left( D2R - Y2R \right) + CS2R \left( \frac{3D2R}{3t} - \frac{3Y2R}{3t} \right) \right] \]
\[ + SK2L \left( D2L - Y2L \right) + CS2L \left( \frac{3D2L}{3t} - \frac{3Y2L}{3t} \right) - BIZ \cdot \frac{3^2\phi IX}{3t^2} = 0 \quad \ldots \text{Eq. (3)} \]

\[ SK1R \left( D1R - Y1R \right) + CS1R \left( \frac{3D1R}{3t} - \frac{3Y1R}{3t} \right) + TK1R \left( PX1R - Y1R \right) \]
\[ + CT1R \left( \frac{3PX1R}{3t} - \frac{3Y1R}{3t} \right) - BM1R \cdot \frac{3^2Y1R}{3t^2} = 0 \quad \ldots \text{Eq. (4)} \]

\[ SK1L \left( D1L - Y1L \right) + CS1L \left( \frac{3D1L}{3t} - \frac{3Y1L}{3t} \right) + TK1L \left( PX1L - Y1L \right) \]
\[ + CT1L \left( \frac{3PX1L}{3t} - \frac{3Y1L}{3t} \right) - BM1L \cdot \frac{3^2Y1L}{3t^2} = 0 \quad \ldots \text{Eq. (5)} \]

\[ SK2R \left( D2R - Y2R \right) + CS2R \left( \frac{3D2R}{3t} - \frac{3Y2R}{3t} \right) + TK2R \left( PX2R - Y2R \right) \]
\[ + CT2R \left( \frac{3PX2R}{3t} - \frac{3Y2R}{3t} \right) - BM2R \cdot \frac{3^2Y2R}{3t^2} = 0 \quad \ldots \text{Eq. (6)} \]

\[ SK2L \left( D2L - Y2L \right) + CS2L \left( \frac{3D2L}{3t} - \frac{3Y2L}{3t} \right) + TK2L \left( PX2L - Y2L \right) \]
\[ + CT2L \left( \frac{3PX2L}{3t} - \frac{3Y2L}{3t} \right) - BM2L \cdot \frac{3^2Y2L}{3t^2} = 0 \quad \ldots \text{Eq. (7)} \]
\[
\begin{align*}
\text{PK1R (V1R - PX1R) + CP1R (}\frac{\partial V1R}{\partial t} - \frac{\partial PX1R}{\partial t}) & - \text{TK1R (PX1R - Y1R)} \\
- CT1R (\frac{\partial PX1R}{\partial t} - \frac{\partial Y1R}{\partial t}) & - \text{BMPV1R} \frac{\partial^2 PX1R}{\partial t^2} = 0 \\
\ldots \text{Eq. (8)}
\end{align*}
\]

\[
\begin{align*}
\text{PK1L (V1L - PX1L) + CP1L (}\frac{\partial V1L}{\partial t} - \frac{\partial PX1L}{\partial t}) & - \text{TK1L (PX1L - Y1L)} \\
- CT1L (\frac{\partial PX1L}{\partial t} - \frac{\partial Y1L}{\partial t}) & - \text{BMPV1L} \frac{\partial^2 PX1L}{\partial t^2} = 0 \\
\ldots \text{Eq. (9)}
\end{align*}
\]

\[
\begin{align*}
\text{PK2R (V2R - PX2R) + CP2R (}\frac{\partial V2R}{\partial t} - \frac{\partial PX2R}{\partial t}) & - \text{TK2R (PX2R - Y2R)} \\
- CT2R (\frac{\partial PX2R}{\partial t} - \frac{\partial Y2R}{\partial t}) & - \text{BMPV2R} \frac{\partial^2 PX2R}{\partial t^2} = 0 \\
\ldots \text{Eq. (10)}
\end{align*}
\]

\[
\begin{align*}
\text{PK2L (V2L - PX2L) + CP2L (}\frac{\partial V2L}{\partial t} - \frac{\partial PX2L}{\partial t}) & - \text{TK2L (PX2L - Y2L)} \\
- CT2L (\frac{\partial PX2L}{\partial t} - \frac{\partial Y2L}{\partial t}) & - \text{BMPV2L} \frac{\partial^2 PX2L}{\partial t^2} = 0 \\
\ldots \text{Eq. (11)}
\end{align*}
\]
Solution of Differential Equations of Motion

These differential equations of motion are solved by a numerical technique described by N.M. Newmark (2) in his paper entitled, "A Method of Computation for Structural Dynamics". The procedure is based on the assumption that the displacements, the velocities and the accelerations of the system are known at any particular time, \( t_i \). The values of these variables at \( t_{i+1} \) are determined from the following relationships.

\[
(Y)_{i+1} = (Y)_{i} + h(\frac{3Y}{\partial t})_{i} + h^{2}(\frac{1}{2} - \beta) (\frac{3^{2}Y}{\partial t^{2}})_{i} + h^{2}\beta (\frac{3^{2}Y}{\partial t^{2}})_{i+1} \quad \ldots \text{Eq. (A)}
\]

\[
\frac{3^{2}Y}{\partial t^{2}}_{i+1} = \frac{3^{2}Y}{\partial t^{2}}_{i} + h (1 - \nu) (\frac{3^{2}Y}{\partial t^{2}})_{i} + h\nu \frac{3^{2}Y}{\partial t^{2}}_{i+1} \quad \ldots \text{Eq. (B)}
\]

Where: \( Y \) = displacement of a mass

\[ \frac{3Y}{\partial t} = \text{velocity of a mass} \]

\[ \frac{3^{2}Y}{\partial t^{2}} = \text{acceleration of a mass} \]

\[ h = t_{i+1} - t_{i} \]

The values of \( \nu \) and \( \beta \) are used as \( 1/2 \) and \( 1/6 \) respectively which make the solution converge quickly. Figure 5 shows the flowchart of the procedure used in the numerical technique.
Assume an Initial Value for Acceleration of Each Mass

Assumed Acceleration Equals to Calculated Acceleration

Calculate the Velocity and Displacement for Each Mass by Using Eqs. (B) and (A)

Calculate the Acceleration from the Differential Equation of Motion

Yes

(Assumed Acceleration-Calculated Acceleration) > CLOTOL

No

Solution Obtained and Go To Next Time Step

Figure 5. Flowchart Showing the Steps of Numerical Technique used in DYMOL
Calculation of Total Dynamic Load on a Wheel

The vertical translations of the vehicle body, tires and soil masses are obtained by solving the differential equations of motion for a particular time step. Dynamic forces are calculated in each wheel for the same time step from the following expressions:

\[
\begin{align*}
DYF1R &= TK1R \left( PX1R - Y1R \right) + CT1R \left( \frac{\partial PX1R}{\partial t} - \frac{\partial Y1R}{\partial t} \right) \\
DYF1L &= TK1L \left( PX1L - Y1L \right) + CT1L \left( \frac{\partial PX1L}{\partial t} - \frac{\partial Y1L}{\partial t} \right) \\
DYF2R &= TK2R \left( PX2R - Y2R \right) + CT2R \left( \frac{\partial PX2R}{\partial t} - \frac{\partial Y2R}{\partial t} \right) \\
DYF2L &= TK2L \left( PX2L - Y2L \right) + CT2L \left( \frac{\partial PX2L}{\partial t} - \frac{\partial Y2L}{\partial t} \right)
\end{align*}
\]

After calculating the dynamic force component on a wheel, the total dynamic wheel load may be determined by simply adding the static and the dynamic force components as follows:

\[
\begin{align*}
TDF1R &= DYF1R + AXWTR(1) \\
TDF1L &= DYF1L + AXWTL(1) \\
TDF2R &= DYF2R + AXWTR(2) \\
TDF2L &= DYF2L + AXWTL(2)
\end{align*}
\]

Excessive roughness may cause loss of contact between the wheel and the pavement, making the total dynamic force a negative quantity. Provision is kept in the program to make the total dynamic force as zero when it becomes negative. This is done to avoid any tension force acting on the pavement since it is not possible in reality.

Maysmeter Simulation

Figure 6 shows the flowchart for Maysmeter simulation. XMAYS is the calculated difference between the vertical translation of the rear axle and rear end
of the vehicle for a particular time step, $t_i$. $XMAYSM$ is the value of $XMAYS$ in the previous time step, $t_{i-1}$. The absolute value of the difference between $XMAYS$ and $XMAYSM$ is accumulated for every time step. This accumulated value up to any time step ($XMAYSA$) is the Maysmeter reading at that time.
Initialize XMAYSA, XMAYSM

\[ XMAYS = 0.5 \left[ (Y2R + Y2L) - (D2R + D2L) \right] \]

ABSMAY = ABS (XMAYS - XMAYSM)

XMAYSA = XMAYSA + ABSMAY

PRINT XMAYSA

XMAYSM = XMAYS

Total Analysis Time Ended?

No

Yes

Return

Figure 6. Flowchart for Maysmeter Simulation
APPENDIX C

JCL AND FORTRAN LISTING FOR DYMOL
Supporting IBM Job Control Language (JCL) for the Program DYMOL is as follows:

```plaintext
//JOB
/*PASSWORD
//DYMOL EXEC FORTGCG,REGION.GO=100K
//FORT.SYSIN DD *

SOURCE DECK

//G0.FT01F001 DD UNIT=SYSDA,SPACE=(CYL,(2,2)),DISP=(NEW,PASS)
//G0.FT01F002 DD UNIT=SYSDA,SPACE=(CYL,(2,2)),DISP=(NEW,PASS)
//G0.FT02F001 DD UNIT=SYSDA,SPACE=(CYL,(2,2)),DISP=(NEW,PASS)
//G0.FT02F002 DD UNIT=SYSDA,SPACE=(CYL,(2,2)),DISP=(NEW,PASS)
//G0.FT10F001 DD UNIT=(TAPE9,,DEFER),VOL=SER=XXXXXX,DISP=(OLD,KEEP),
   //DSNAME=XXXXXX
//G0.SYSIN DD *

INPUT DATA

/*END
```
COMMON /AZ1/ FX1R,FX1L,FX2R,FX2L,CFX1R,CFX1L,CFX2R,CFX2L,1
CDPX1R,CDPX1L,DDPX2R,DDPX2L,ADPX1R,ADPX1L,ADPX2R,ADPX2L,IEND
COMMON /AZ2/ A1,A2,E1,EE,C1,C2,C1,E1,T1,T2,EE
1,NLRCSC,SW1,SW2,BH1,BH2,CH1,CH2,TH1,TH2,CH1,CH2
COMMON /AZ2/ A29/ NRCSCI,NRCSCF
COMMON /NAME /XNAME(20),XNAME(20),NEC
DIMENSION XNAME(2C)
DATA XNAME1/6C,0,1,0,0,0,0,2,0,0,0,10,3,0,2,42,120,,000,0,1
1,C1,C1,C1,C1,0,0,0,0,0,0,0,
EQUIVALENCE (XNAME(1),SPEED),(XNAME(2),PRTOUT),
*(XNAME(6),AXLACN),(XNAME(7),STRCSF),
*(XNAME(8),STRBMP),(XNAME(9),NMBMPS),
*(XNAME(10),ENFTP),(XNAME(11),BMPWCT),
*(XNAME(12),BMPWCT),(XNAME(3),PRFTEL)
REAL NMBMPS
WRITE(6,555)
555 FORMAT(1H1)
2 CONTINUE
READ(5,8CC,END=150)EMPWCT,NREC,CSPACE,NLFCSC,NRCCS,NRCRDF
XDIST=CSPACE*7EC
800 FCFMAT(C1,B,1I0,F10.2,3470)
IF( NLRCSS,EQ,'C') GC TC 111
READ(5,1010)A1,A2,B1,B2,C1,C2,D1,D2,T1,T2,EE
1010 FCFMAT(BF10.2)
READ(5,202C)SM1,SM2,BH1,EH2,CH1,CH2,TH1,TH2,CH1,CH2
2000 FCFMAT(IF1I5.1S)
x=a1+a2+b1+b2+t1+t2+c1+c2+c1+c2+EE
NREC=X/XDIST+1
111 CONTINUE
CC I=1,2C
XNAME(I)=XNAME1(I)
1 CONTINUE
CALL TAPER(NREC)
CALL READ
READ(5,500)SPEED,STREM,EMPHT,EMPWDT,BMPSA,NPTTS
500 FORMAT(5G1C,2.2,1I1C)
IF(NREC,EQ,0) GC TC 3
NMBMPS=4
3 NPTTS= E,C/DSPACE+1
CALL FFACI(NPTTS)
CALL DRVIF
IF(NLFCSS,EQ,'C') GC TO 4
IF(NREC,EQ,0) GC TO 4
WRITE(6,6CC) (XNAME(L),L=1,20)
WRITE(6,600)SPEED,STRBMP,NMBMPS,BMPHT,BMPWDT,BMPSA,NPTTS
600 FCFMAT(IX,10G13.5)
4 GC TO 2
190 STCP
END
SLERCUTINE TAPWR(NREC)
COMMON /AZ7/ XCI5T, DSPACE
COMMON /AZ9/ NFCEF1, NFCDIF
DIMENSION CARD(26)
DIMENSION TAPE1(750), TAPE2(750)
DIMENSION IC(5)
REWI ND 1
IF (NREC.LT.0) GO TO 46
IF (NREC.EQ.0) GO TO 5
IN=NREC*XCI5T
WRITE(6,1235) NREC, IN
1235 FCFMT(10X,'SLERCUTINE TAPWR = ', I3, 'RECORDS = ', I10X, I6, 
     'INCHES OF NATURAL PROFILE: ')
CC 100 I=1,750
TAPE1(I)=C.0
100 TAPE2(I)=0.0
ID(1)=0
ID(2)=NREC
IC(3)=0
ID(4)=0
ID(5)=0
WRITE(1) IC
CC 200 I=1,NREC
200 WRITE(1) TAPE1, TAPE2
6 ENDFILE 1
ENDFILE 1
REWIND 1
RETURN
5 CONTINUE
CC 1 I=1,3
READ(10,111) IC
111 FCFMT(2CA4)
WRITE(6,112) IC
112 FCFMT(1X,2CA4,//)
1 CONTINUE
FEA0(1,111) IC
17 FCFMT(511C)
NREC=IC(2)
IN=NREC*XCI5T
WRITE(6,1234) NREC, IN
1234 FCFMT(10X,'SUBRCUTINE TAPWR = ', I3, 'RECORDS = ', I10X, I6, 'INCHES OF S 
   *MCCTH FCFFILE: ')
WRITE(1) IC
CC 201 I=1,NREC
READ(10,18) TAPE1, TAPE2
IF (I.LT.NREC OR I.GT.NREC+1) GO TO 201
WRITE(1) TAPE1, TAPE2
201 CONTINUE
C ******************************************************************
CC TC 6
46 REWI ND 1
READ(1) IC
NREC=IC(2)
IN=NREC*XCI5T
WRITE(6,1235) NREC, IN
REWIND 1
18 FCFMT(2CF5.2)
RETURN
ENC
100 FORMAT(2A4)
105 FORMAT(3I10)
110 FORMAT(8E10.3)
115 FORMAT(2E10.3,4I10)
READ(1) IC
NRECRD=ID(2)
XRI=IC(4)/10000.
XL1=IC(5)/10000.
VFPS = V/12.0
VWPH = VFPS+15.0/22.0
RETURN
190 STOP
END
SUERCUTINE PRFAVG(NTA)

DIMENSION TAEF(1500),F1(750),F2(750),TEMP(100)
EQUIVALENCE (TVF,TAFE1),(TVF(1501),F1),(TVF(2251),P2),
*(TVF(3001),TEMP)

IF(NTA.EC.0) NTA=8.0/CSFACE +1
IF(NTA.LT.1.OR.NTA.GT.50) RETURN
NT2=NTA/2
NREC=1

READ(1,ENS=3) TVF
DO 13 J=1,15CC
KJ=(J-1)/2
13 TVF(J)=TVF(J)*XFAKE(8)+FELMF(KJ+1+NREC*750)

NREC=NREC+1
WRITE(2) TVF
GO TO 2

FILE 2
REWIND 2
CO 15 LL=1,NREC

BACKSPACE 1
GO TO 5CC

NT2=NTA/2
REWIND 2
NT3=NTA*2
FEJO(1) TAFE1
DO 10 J=1,NT2
F1(J)=TAEF1(2*J-1)*XFAKE(8)+FELMF(J)
10 +XUEMP(J)
1C F2(J)=TAEF1(2*J)*XFAKE(8)+FELMF(J)
1 +XUEMP(J)

SUM1 = 0.0
SUM2 = 0.0
CC 12 K=1,NTA
SUM1=SUM1+TAFE1(2*K-1)*XFAKE(8)+FELMF(K)
1 +XUEMP(K)
12 SUM2=SUM2+TAFE1(2*K)*XFAKE(8)+FELMF(K)
1 +XUEMP(K)

F1(NT2+1)=SUM1/NTA
F2(NT2+1)=SUM2/NTA

K=NT2+2
50 SUM1=SUM1+(TAFE1(2*K+NTA-2)+TAFE1(2*K+NTA-2))
* XFAKE(8)*FBLMF(K+NT2+NREC*750)+FELMF(K+NT2+NREC*750)
1 +XUEMF(K+NT2+NREC*750)+XUEMF(K+NT2+NREC*750)
SUM2=SUM2+(TAFE1(2*K+NTA-1)+TAFE1(2*K+NTA-1))
* XFAKE(8)*FBLMF(K+NT2+NREC*750)+FELMF(K+NT2+NREC*750)
1 +XUEMF(K+NT2+NREC*750)+XUEMF(K+NT2+NREC*750)
F1(K)=SUM1/NTA
F2(K)=SUM2/NTA
K=K+1
ITEST=750*NT2
IF(K.GT.ITEST)GO TO 40
GO TO 5C
40 CC 45 L=1,NT3
45 TEMP(L)=TAFE1(L+15C0=2*NTA)
READ(1,ENC=4E) TAPE1
CC 46 L=1,NTA
SUM1=SLM1+(TAFE1(2*L-1)-TEMP(2*L-1))*XFAKE(8)
* FBUMP(L+NREC+1)*750)*XFAKE(8)
1 SUM2=SUM2+(TAFE1(2*L)-TEMP(2*L))*XFAKE(8)
* FEUMP(L+NREC+1)*750)*XFAKE(8)
1 PI(K)=SUM1/NTA
F2(K)=SUM2/NTA
K=K+1
IF(K.EQ.751 ) GO TO 47
GO TO 46
47 CC 7C N=K,750
P1(N)=TAFE1(N*2-1)*XFAKE(8)+FBUMP(N+750*NREC)
1 P2(N)=TAFE1(N*2)*XFAKE(8)+FEUMP(N+750*NREC)
WRITE(2)(F1(N),F2(N),I=1,750)
ENDFILE 2
RETURN
RETURN
RETURN
PX1L=XL1
FX2R=XR1
PX2L=XL1
CFX1F=0.0
DPX1L=C.C
CPX2R=C.C
CFX2L=0.0
DDPX1R=C.C
CCFX1L=C.C
CCFX2R=0.0
DPPX1R=C.C
ACFX1L=0.0
ADPX2R=C.C
ACFX2L=0.0
FHIX=C.C
PHIZ=0.0
CFHIX=0.0
DPHIZ=C.C
CCPHIX=C.C
CCFHIZ=0.0
PV1R=XRI
PV1L=XL1
FV2R=XRI
PV2L=XL1
ACCY1R=0.0
ADCY1L=0.0
ADCY2R=C.C
ACCY2L=0.0
ADCI X=C.C
ACCI Z=0.0
YO1=0.0
DCY1=0.0
CCYO1=0.0
ADCY1=0.0
YO2=C.C
CCYO2=0.0
DYC2=C.C
ADCY2=C.C
YO1=(XL1+XRI)/2.0
YC2=YO1
PHIX1=0.0
CFPHIX1=0.0
DDPX1=C.C
ACCX1=0.0
PHIX2=0.0
DPPX2=0.0
CCFX2=0.0
ACDX2=C.C
PHIX1=ATAN((XL1+XRI)/W(1))
PHIX2=PHIX1
PHIZ1=C.C
CPHIZ1=0.0
CCFZ1=0.0
ACDZ1=C.C
PHIZ2=0.0
DPPHIZ2=0.0
CCFZ2=C.C

45
ADDZ2 = 0.0
W = 0
KCAVER = 0

\[ BETA = 1.0 / 6.0 \]
\[ T2 = 2.0 * T \]
\[ HC2 = C.5 * H \]
\[ HE2 = T * H \]
\[ H+HC2 = 0.5 * T * T \]
\[ GRAV = 3E6.4 \]

**C** SET OF RANCE OVER WHICH RESPONSE IS TO BE STUDIED.

ITIME = TLIM / H
ISTOP = ITIME - 1
NITIME = 1

**EC** CALL CLASS 1

490 CONTINUE

WRITE(6,99599)

55555 FORMAT(1H1)

RETURN

END
TK2L=TKL(2)
CS1R=CSR(1)
CS2R=CSR(2)
CS2L=CSL(1)
CS2L=CSL(2)
CT1R=CTR(1)
CT2R=CTR(2)
CT1L=CTL(1)
CT2L=CTL(2)
W1=W(1)
W2=W(2)
X12=X1(2)
AXAWT1=AXAWT(1)
AXAWT2=AXAWT(2)
AXAWT1=AXWTL(1)+AXWTR(1)
AXAWT2=AXWTL(2)+AXWTR(2)
C LOCATE THE CENTER OF GRAVITY OF THE VEHICLE BODY
ECCWT1 = AXWT1 - AXAWT1
ECCWT2 = AXWT2 - AXAWT2
BODTOT = BODWT1 + BCDWT2
X2 = ECCWT1 * X12 / BODTOT
X3 = X12 * X2
XX1=X3
XX2=X2
C CALCULATE THE BODY MASSES AND MASS MOMENT OF INERTIA
E0 = ECCCTOT / 386.4
E1R = (0.5) * AXAWT1 / 386.4
E1L = BM1R
E2R = (0.5) * AXAWT2 / 386.4
E2L = BM2R
EIX = (BM0 * (W1*W1 + W2*W2) / 24 *.0) * XFAKE(10)
EIZ = (E0 * X12 * X12 / 12.0) * XFAKE(9)
C NOW LET US PRINT THE INPUT DATA
CLASS=1
CALL INDAF
C OUTSIDE OF TIME STEPS SET THE FOLLOWING
I=1
>MAXSA = C.C
>MAXSM=C.C
CC 190 I2=1,1STCF
ICOUNT=0
CALL NATPRO
IF(IEEC.NE.0) FETUFA
>3=X1
M = M + 1
FX1R=FX1R+*CFX1R+HC2*CCFX1R
PX1L=PX1L+*DPX1L+HHC2*DDFX1L
PX2R=PX2R+*DPX2R+HHO2*DDP*2R
FX2L=FX2L+*CFX2L+HHC2*CCFX2L
CPX1R=CPX1R+HHO2*DDFX1R
CFX1L=CFX1L+*CFX1L
CPX2R=CPX2R+H*CCFX2R
CPX2L=CPX2L+H*DDP*2L
Y1R = Y1R + H * CY1R + HHQ2 * DDY1R
Y1L = Y1L + H * DYL1 + HHC2 * CDY1L
Y2R = Y2R + H * DY2R + HHO2 * CDY2R
Y2L = Y2L + H * CY2L + HHO2 * CDY2L
YC = YC + H * CYO + HHO2 * CCY0
lfO = PHIX + H * DPHIX + MH2C * DDPHIX
PHIZ = PHIZ + H * DPHIZ + HHO2 * DDPHIZ
CY1R = CY1R + F * CCY1R
DY1L = DY1L + H * CCDY1L
CY2R = CY2R + F * CCDY2R
DY2L = CY2L + H * CCDY2L
D YC = DYC + H * DDCY
CPHIX = DPHIX + F * CDPHIX
CPHIZ = DPHIZ + H * CDCPHIZ
D1R = YC = (W1/2.0) * PHIX = X3 * PHIZ
C1L = Y0 + (W1/2.0) * PHIX = X3 * PHIZ
D2R = Y0 = (W2/2.0) * PHIX + X2 * PHIZ
C2L = Y0 + (W2/2.0) * PHIX + X2 * PHIZ
CC1R = CY0 = (W1/2.0) * CPHIX = X3 * DPHIZ
DD1L = DYC = (W1/2.0) * CPHIZ = X3 * DPHIZ
CC2R = CY0 = (W2/2.0) * CPHIX + X2 * DPHIZ
CC2L = CYC = (W2/2.0) * CPHIX + X2 * DPHIZ

IF (ICOLNT.EQ.20) KONVER=1

ICCUNT=ICCLAT+1

C CALCULATE DYNAMIC FORCE ON THE PAVEMENT
CYF1R=CP1R*((VR(1,1)+PV1R)/HT2-OPX1R)+PK1R*((VR(1,1)+PX1R)
DYF1L=CF1L*((VL(1,1)+PV1L)/T2-CPX1L)+PK1L*((VL(1,1)+PX1L)
DYF2R=CP2R*((VR(2,1)+PV2R)/HT2-OPX2R)+PK2R*((VR(2,1)+PX2R)
DYF2L=CT2L*((CPX2L+PV2L)/T2-OPX2L)+PK2L*((VL(2,1)+PX2L)

C CALCULATE DYNAMIC FORCES ON THE TIRE
CYF1R=CT1R*((DFX1+DY1R)+TK1R*(FX1R=Y1R)
DYF1L=CT1L*(CPX1L+CY1L)+TK1L*(FX1L=Y1L)
DYF2R=CT2R*(DFX2+DY2R)+TK2R*(FX2R=Y2R)
DYF2L=CT2L*(CPX2L+DY2L)+TK2L*(PX2L=Y2L)

TDF1R = CYF1R + AXWTR(1)
TDF1L = DYF1L + AXWTL(1)
TDF2R = CYF2R + AXWTR(2)
TDF2L = DYF2L + AXWTL(2)

IF( TDF1R .LT. 0 ) DYF1R = AXWTR(1)
IF( TDF1L .LT. 0 ) DYF1L = AXWTL(1)
IF( TDF2R .LT. 0 ) DYF2R = AXWTR(2)
IF( TDF2L .LT. 0 ) DYF2L = AXWTL(2)

C ACCELERATION ESTIMATES FROM DIFFERENTIAL EQUATIONS OF MOTION
DDV1R = (SK1R*(D1F-Y1R) + CS1R*(CCY1R-DY1R)+CYF1R)*EM1R
CCY1L = (SK1L*(D1L-Y1L) + CS1L*(DD1L-DY1L)+DYF1L)*BM1L
CDY2R = (SK2R*(DF2-Y2R) + CS2R*(CCY2R-DY2R)+CYF2R)*EM2R
DDY2L = (SK2L*(D2L-Y2L) + CS2L*(DD2L-DY2L)+DYF2L)*EM2L

DDPHIX = (W1/2.0) * SK1R *(D1F-Y1R) = (W1/2.0) * SK1L *(D1L-Y1L)
1 + (W2/2.0) * SK2R *(DF2-Y2R) = (W2/2.0) * SK2L *(D2L-Y2L)
2 +(W1/2.0) * CS1R *(CCY1R-DY1R) = (W1/2.0) * CS1L *(DD1L-DY1L)
3 + (W2/2.0) * CS2R *(CCY2R-DY2R) = (W2/2.0) * CS2L *(DD2L-DY2L)

/ BIX

CCPHIZ=(X3 *SK1R*(D1F-Y1R)+X3 *SK1L*(D1L-Y1L)=X2*SK2R*(D2F-Y2R)
1 )=X2*SK2L*(C2L-Y2L)+X3 *CS1R*(CCY1R-DY1R)=X3 *CS1L*(DD1L-DY1L)
2 =DYL* =X2*CS2R*(DD2L-DY2R) =X2*CS2L*(DD2L-DY2L) =EIZ

CCY0 = (SK1R*(D1R-Y1R) = SK1L*(D1L-Y1L) = SK2R*(D2R-Y2R)
1 =SK2L*(C2L-Y2L) = CS1R*(DD1R-DY1R) = CS1L*(DD1L-DY1L)
2 =CS2R*(DD2R-DY2R) = CS2L*(DD2L-DY2L) ) / BMI

C CALCULATE ACCELERATION CF SCIL MASSES
DDPX1R=(DYF1R=DFV1R)/EMFV1F
CCPX1L=(CYF1L=DYF1L)/EMFV1L
CCFX2R=(DYF2R=DFV2R)/EMFV2F
DDFX2L=(DYF2L=DFV2L)/EMFV2L
C ** CHECK FOR CONVERGENCE
C
IF ( AES( ACCY1R = CCY1R ) .GT. CLCTCL ) GO TO 170
IF ( AES( ADDCY1L = DDCY1L ) .GT. CLCTCL ) GO TO 170
IF ( AES( ACCY2R = CCY2R ) .GT. CLCTCL ) GO TO 170
IF ( AES( ADDCY2L = DDCY2L ) .GT. CLCTCL ) GO TO 170
IF ( AES( ADDCYC = DDCYC ) .GT. CLCTCL ) GO TO 170
IF ( AES( ACCIX = CCF+IX ) .GT. CLCTCL ) GO TO 170
IF ( AES(ADDIZ = DDPHI2 ) .GT. CLCTCL ) GO TO 170
C
CHECK FOR CONVERGENCE OF ACCELERATION OF SOIL MASS
IF(ABS(ADPX1R=CPFX1R)*CLCTCL) GO TO 170
IF(ABS(ADPX1L=DPFX1L)*CLCTCL) GO TO 170
IF(AES(ACFX2R=CCFX2R)*CLCTCL) GO TO 170
IF(AES(ACFX2L=CCFX2L)*CLCTCL) GO TO 170
KCVER = 1
C
C ** REVISE ESTIMATES
C
17C

CY1F = CY1F + HC2 * ( CCDY1R - ADDY1R )
DY1L = DY1L + HO2 * ( CCDY1L - ADDY1L )
CY2R = CY2R + HO2 * ( CCDY2R - ADDY2R )
CY2L = CY2L + HC2 * ( CCDY2L - ADDY2L )
CYC = CYC + HO2 * ( CCY0 - ADDY0 )
CCF+IX = CCF+IX + HC2 * ( DDP+IX - ADDIX)
DPHI2 = DPHI2 + HC2 * ( DDPHI2 - ADDIZ )
Y1R = Y1R + BETA * HE2 * ( CCDY1R - ADDY1R )
Y1L = Y1L + ETAI * HE2 * ( CCDY1L - ADDY1L )
Y2R = Y2R + BETA * HE2 * ( CCDY2R - ADDY2R )
Y2L = Y2L + BETA * HE2 * ( CCDY2L - ADDY2L )
YC = YC + ETAI * HE2 * ( CCY0 - ADDY0 )
PHI2 = PHI2 + BETA*HE2* ( DDPHI2 - ADDIX )
F+I2 = F+I2 + BETA*HE2* ( CCP+I2 - ADDIZ )
C
REVISE ESTIMATES
CPX1R=CPX1R+HO2*(DDPX1R-ADPX1R)
CPX1L=DPX1L+HC2*(CCPX1L-ACFX1L)
CPX2R=CPX2R+HC2*(DDFX2R-ACFX2R)
CPX2L=CPX2L+HC2*(CCPX2L-ADPX2L)
FX1R=FX1R+EETAI*HE2*(CCFX1R-ACFX1R)
FX1L=FX1L+EETAI*HE2*(CCFX1L-ADFX1L)
FX2R=FX2R+EETAI*HE2*(CCFX2R-ADFX2R)
FX2L=FX2L+EETAI*HE2*(CCFX2L-ADPX2L)
ACFX1R=DPFX1R
ADFX1L=DPFX1L
ADFX2R=DPFX2R
ACFX2L=CCFX2L
ADCY1R=DDY1R
ADCY1L=DDY1L
ACCY2R=CCY2R
ADCY2L=DDY2L
ACCYC=CCYC
ACCIX = CCF+IX
ADDIZ = DDPHI2
IF( KCONVER .NE. 1 ) GO TO 160
KCVER = 0
IF(MNE.IFREG) GO TO 18C
TIME=I2*H
CIST = TIME * V
TCF1R = DYF1R + AXWR(1)
TDF1L = DYF1L + AXWL(1)
TDF2R = CYF2R + AXWR(2)
TDF2L = DYF2L + AXWL(2)

M = 0

X1(1) = 0.0

C NAYS METER SIMULATOR
XMAYS = 0.5*(Y2R + Y2L - C2R - C2L)

ABS(NAY) = ABS(XMAYS - XMAYSN)

XMAYS = XMAYS + ABS(NAY)

XMAYSN = XMAYS

175 WRITE (6, 125) TIME, CIST, VR(1, I), VL(1, I), VR(2, I), VL(2, I), TDF1R, 1

125 TDF1L, TDF2R, TDF2L, XMAYS, 1, CCOUNT

140 FORMAT (F10.3, F8.0, 2X, 4F8.3, 2FE0.2F5.0, 12X, 612.4, 115)

160 FV1R = VR(1, I)
PFVL = VL(1, I)

190 CONTINUE

RETURN

END
FUNCTION FBUMP(I)
COMMON / AZ7 / XDIST, DSPACE
COMMON / NAME / NAME(20), VMFT, XPRT, YPRT, BRLGTH, DSTR, XFAKE(15), NE
FBLMP=C*C
IF(XFAKE(6).GE.0) RETURN
IF(XFAKE(3).LE.0.0) RETURN
IF(XFAKE(4).GE.0.0) RETURN
CISTE=IX*DSPACE
IF ( CISTE.LT. XFAKE(3)*XFAKE(11)) RETURN
CISTL=XFAKE(3)+((XFAKE(4)-1.0)**XFAKE(7)+XFAKE(6)
IF ( CISTE.GT.CISTL) RETURN
NBLMPS=XFAKE(4)
C XFAKE(1)=AxLEnum
C XFAKE(2)=STFDSF
C XFAKE(3)=STFBMP
C XFAKE(4)=NUMBMPs
C XFAKE(5)=EMPHT
C XFAKE(6)=BMPWDT
C XFAKE(7)=EMPSPA
DC 1C JK=1,NBUMP
CISTL=XFAKE(3)+(JK-1)**XFAKE(7)
CIST2=CISTL*XFAKE(6)
IF(DIST2.GE.DISTL AND CISTE.LE.CIST2)
1 FEUMP=(XFAKE(5)*SIN(6.2E31E*(DISTB-DISTL)/(DIST2-DISTL)))
10 CONTINUE
RETURN
END
FUNCTION XEUMP(IX)
COMMON /AZ2/A1,A2,B1,B2,C1,C2,D1,D2,T1,T2,EE
1 NLCCS,SM1,SM2,EH1,EH2,CH1,CH2,TH1,TH2,DI1,DH2
COMMON /AZ7/XISTB,DSFACE
XBEOM=O.0
IF( NLCCS.EQ.0) RETURN
XISTB=IX*DSFACE
IF(XISTB.LE.A1) RETURN
XX1=A1
XX2=XX1+01
XX3=XX2+C1
XX4=XX3+T1
XX5=XX4+D1
XX6=XX5+EE
XX7=XX6+C2
XX8=XX7+T2
XX9=XX8+C2
XX10=XX9+B2
IF( XISTB.EQ.XX1 .AND. XISTB.LE.XX2 ) XBUMP=SM1+BH1/B1*(XISTB-XX1)
IF( XISTB.GT.XX2 .AND. XISTB.LE.XX3 ) XBUMP=SM1+BH1+CH1
IF( XISTB.GT.XX3 .AND. XISTB.LE.XX4 ) XBUMP=SM1+BH1+TH1
IF( XISTB.GT.XX4 .AND. XISTB.LE.XX5 ) XBUMP=SM1+BH1+DH1
IF( XISTB.GT.XX5 .AND. XISTB.LE.XX6 ) XBUMP=SM1+BH1
IF( XISTB.GT.XX6 .AND. XISTB.LE.XX7 ) XBUMP=SM1+BH1+DH2
IF( XISTB.GT.XX7 .AND. XISTB.LE.XX8 ) XBUMP=SM1+BH1+TH2
IF( XISTB.GT.XX8 .AND. XISTB.LE.XX9 ) XBUMP=SM1+EH1+CH2
IF( XISTB.GT.XX9 .AND. XISTB.LE.XX10 ) XBUMP=SM1+EH1+EH2/B2*(XISTB-XX9)
IF( XISTB.GT.XX10 ) XEUMP=SM1+EH1*(EH2+SM2)
RETURN
WRITE(6,120) EMO,W1,X12,B1Z,W2,BIX
120 FORMAT(15X,'1. BCCY MASS (EMO)', 24X,'G10.3,13X,'4. W1 =',
1. F6.1,9X,' 6. X12 =', F6.1,7X,
2. 15X,'2. ECCY MASS MCM. CF INERTIA=PITCH=(B1Z) =', G10.3,12X,
3. ' , W2 =', F6.1,7X,
4. 15X,'3. ECCY MASS MCM. OF INERTIA=RCLL=(BIX) =', G10.3,7X)
GC TC 2010
2010 CONTINUE
WRITE(6,170)
170 FCFMAT(//,10X,'II. AXLES INPUT*/,,
1. ' , AXL=','10X,'STATIC WT',1CX,' MASS ',10X,
2. ' , SUSP. STIF.',9X,'SUSP. DAMP.',9X,'TIRE STIF.',10X,
3. ' , TIRE DAMP.',10X, ' WC ',10X,' (EL) ',9X,
4. *(LE=SEC 2/IN)*,8X, (LE/IN)*,10X,*(LB/IN/SEC)*,10X,
5. *(LE/IN)*,9X,*(LE/IN/SEC)*)
BM(1)=BMIR
EM(2)=EM2R
EL(1)=EM1L
EL(2)=EM2L
CC 2020 I = 1, 2
WRITE(6,100) I,AXTR(I),EM(I),SKR(I),CSR(I),TKR(I),CTR(I),I,
1AXTL(I),EL(I),SKL(I),CXL(I),TKL(I),CTL(I)
100 FCFMAT(14,'RIGHT*,6(10X,G10.3),/,'14,'LEFT*,6(10X,G10.3))
2020 CONTINUE
WRITE(6,190) CLCTCL,IECIXT,IT,IFREQ,TLIN,IOUT
190 FCFMAT(//,1C, 'C. CONTCL INPUT*/,,
1. 10X,'I. INTEGRATION PARAMETERS', '25X,'II. OPTIONS*/,,
2. 15X,'TOLERANCE =','G10.3,23X,'1. EXCITATION TYPE','
3. 'I5,,'I5,'2. TIME INCREMENT =','G10.3,23X,
4. '2, 'CUTPUT INTERVAL',I5,,'I5,'3. TIME LIMIT =',
5. G10.3,23X,'3. FLCT CTICTION ',I5)
WRITE(6,220) VAFH,DSTF,SAFIR
220 FCFMAT(//,1C, 'C. VARIOABLE SPEED AND ROADWAY INPUT*/,,
1. 10X,'I. SPEED ', '21X,'II. EXCITATION PARAMETERS*/,,
2. 15X,'1. MHP ',9X,
3. '1. CIST. TO FIRST EXC. RIGHT =','G10.3,5X,
4. '5. RIGHT ELNP SFACING=',F10.3
WRITE(6,210) VFPS,DSTL,SAFCEL,V,WR,WR,MA,WR,NBL
210 FCFMAT(15X,'2, ',G10.3,' FT/SEC*',9X,
1. '?'2. DIST. TO FIRST EXC. LEFT =','G10.3,5X,
2. '?6. LEFT EUMP SPACING=',F10.3,15X,
3. '?3. ','G10.3,' IN/SEC*',9X,
4. '?3. RIGHT BUMPS WAVELENGTH =','G10.3,5X,
5. '?7. NUMBER OF RIGHT BUMPS=',I10,,'46X,
6. '?4. LEFT BUMPS WAVELENGTH =','G10.3,5X,
7. '?8. NUMBER OF LEFT BUMPS=',I10)
WRITE(6,1616) PK1F,PK1L,PK2F,PK2L,CP1R,CP1L,CP2R,CP2L,
1 PVWT1R,PVWT1L,PVWT2R,PVWT2L
1616 FCFMAT(//,10X,'PK1R=','F8.2,2X,'PK1L=','F8.2,2X,'PK2R=','F8.2,2X,
1. 'PK2L=','F8.2,2X,,10X,'CP1R=','F5.2,2X,'CP1L=','F5.2,2X,'CP2R=','
2. 'F5.2,2X,'CP2L=','F5.2,2X,,10X,'PVWT1R=','F8.2,2X,'PVWT1L=','F8.2,
3. '2X,'PVWT2R=','F8.2,2X,'PVWT2L=','F8.2,'//))
IF (NLCCROS.EQ.0) GC TC 2021
WRITE(6,3)A1,A2,B1,B2,C1,C2,D1,D2,T1,T2,EE
3 FCFMAT(1X,'A1=','F10.2,5X,'A2=','F10.2,5X,'B1=','F10.2,5X,'B2=','
1. F10.2,5X,'C1=','F10.2,5X,'C2=','F10.2,5X,,1X,'T1=','F10.2,5X,'T2=','F10.2,5X,
2. 'EE=','F10.2,5X,,'//)
WRITE(6,4)SH1,SH2,SH1,SH2,CH1,CH2,TH1,TH2,DT1,DT2
4 FCFMAT(1X,'SM1=','F7.3,5X,'SM2=','F7.3,5X,'BH1=','F7.3,5X,'BH2=','F7.3,5X,'CH1=','F7.3,5X,'CH2=','F7.3,5X,'TH1=','F7.3,5X,'TH2=','F7.3,5X,'//)

2021 IF (XFRT.NE.1.0) GC TO 4010
WRITE(6,230)
230 FCFMAT('///,40X,'RESPONSE OF THE MOVING VEHICLE')
GO TO 301C
301C CONTINUE
WRITE(6,500)
ECC FORMAT(27),'EXCITATIONS','30X,'TOTAL DYNAMIC FORCES','8X,'MAYSME'ER
* READING 'NC.CF')
WRITE(6,510)
510 FORMAT(5X,'TIME DIST. 1-RT. 1-LT. 2-RT. 2-LT. 1-RT. FOR ROADWAY ITERATIC
2X)
WRITE(6,520)
520 FCFMAT(5X,'SEC. IN. IN. IN. IN. IN. IN. IN. LB.'
1 LB. LB. LE. IN')
WRITE(6,530)
530 FCFMAT(4X,'----- ----- ----- ----- ---- ---- ---- ---- ----
1 ----- ----- ----- ----- ---- ---- ---- ---- ----)
IF(YPRT.NE.1.0)GC TO 2021
GC TO 4010
401C CONTINUE
RETURN
END