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Informal Report

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**Cargo Response to Railcar Impact and
Tiedown Load Analysis**

University of California

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CARGO RESPONSE TO RAILCAR IMPACT AND TIEDOWN LOAD ANALYSIS

by

Robert J. Bartholomew

ABSTRACT

An analytical study is described in which we investigated the loads produced during coupling of railcars carrying heavy shipping containers. The structural model of the impact event is represented by a lumped-parameter technique. Each discrete mass lump possesses longitudinal, vertical, and rotational degrees of freedom. The resulting computer simulation provides for nonlinear railcar coupler stiffness and linear damping forces in the coupler and container tiedowns. Results include response to parametric variations in container weight, impact speed, and tiedown stiffness. Container dynamic response and tiedown loads are found to depend heavily on these parameters. Also, railcar bending and subsequent vertical motion are shown to be important contributors to these responses. When experimentally substantiated, the model developed can serve as a useful tool in the design and evaluation of shipping container tiedown structures.

I. INTRODUCTION

When massive energy materials containers are moved by rail, consideration must be given to forces produced by railcar coupler impacts. These forces may be large and can affect the container, its tiedown structure, and the railcar. Few rational dynamic analyses exist for the problem of

dynamic interaction between these three systems. Current design practice employs static analysis procedures using empirical load factors to design tiedown systems, but no dynamic analysis has confirmed the applicability of these static analysis methods. There is a need to develop a computer model that will handle the vertical, rotational, and longitudinal motions of both the container and the railcar. This is especially important for the heavier spent nuclear fuel containers that are transported by railcar.

Task IV of the FY 1977 work proposed by Los Alamos Scientific Laboratory (LASL) to the Division of Environmental Control Technology, Department of Energy, described an analytical study of the interaction of shipping containers, both with railcar and truck tiedowns.¹ The analytical study of railcar impact during coupling was proposed for FY 1977 and is the subject of this report. The analysis of truck tiedowns is not included in this report, but the method developed here is generically the same. This report contains a summary of the railcar impact analytical study with specific conclusions, the general method of analysis, and a discussion of the analytical results. The accompanying appendices contain the basic data used to describe the analytical model, detailed equations and the digital computer mechanization of those equations, and a user's manual.

II. SUMMARY AND CONCLUSIONS

An analytical model of railcar impact during coupling was developed using a lumped structural parameter technique.² The model is appropriate for horizontally laded, flexible containers and most flatbed railcars. A vertically laded rigid container can also be simulated. A digital computer simulation of this model, RICTL, standing for Railcar Impact Container Tiedown Loads, has been developed by LASL. This simulation, as presently conceived, has provision for a nonlinear coupler as the only nonlinearity. However, the program is written so that nonlinear subroutines can be easily added to the tiedown configuration and to other longitudinal members of the railcar. With RICTL in its present form, we have studied the effects of variations in certain analytical model parameters. These parameters include container weight, impact speed, and tiedown stiffness (and corresponding damping). The effects

of varying these parameters include the response accelerations of the railcar and the container and tiedown loads. The results of these parametric studies indicate that the response accelerations and tiedown loads tend to increase with container weight, to vary approximately linearly with impact velocity, and to decrease with lower tiedown stiffness. The peak deceleration and coupler loads are relatively unaffected by these parameter changes except for their approximately linear variation with impact velocity.

The major conclusions of this study are:

- (1) Vertical plane dynamics and bending of both the railcar and the container are important.
- (2) Container accelerations and bending moments are low compared with those of the railcar. However, this was expected, because the coupler impact speeds were low. Impacts at higher speeds may result in considerably higher container loads.
- (3) The results of our simulations are comparable to results obtained using other analysis methods^{3,4} that are more limited in application. For example, these other methods do not include vertical dynamics effects.
- (4) The running time for the simulation on the computer is short, showing that economical analysis is possible.
- (5) Before RICTL can be considered as an adequate design tool to evaluate tiedown loads, a degree of correlation should be established between RICTL and actual impact tests.

III. METHOD OF ANALYSIS

The structural dynamic method of analysis used to study the problem of coupling impact for a railcar carrying an energy material shipping container is based on the lumped parameter technique of structural modeling. Figure 1 shows a side-view schematic of a specific railcar⁴ and coupler, a shipping container with its tiedown configuration, and the mass lumping schematic with degrees of freedom assigned to each lumped mass. Mass 11 represents the initially stationary train that the railcar strikes. The container geometry is based on the NFS-M100 cask system, but we considered three weights--13.6, 27.2,

Fig. 1.
Structural modeling technique for railcar, container, and coupler.

and 63.5 metric tonnes. The mass lumps 1-7 represent the moving railcar, and mass lumps 8-10 represent the shipping container. The mass lumps are interconnected by massless springs or dampers as indicated by the members designated $c_{i,j}$ between mass lumps i and j , where $i,j = 1,2,...n$. The nonlinear coupler is designated by stiffness $k_{7,11}$ and damping $c_{7,11}$ as shown in Fig. 1. The impact velocity (V_I) is given as the initial velocity in the direction shown for each of the ten masses composing the railcar-container structural dynamic system.

The lower schematic in Fig. 1 indicates the motion degrees of freedom for the system. The designation u_i refers to the positive horizontal displacement of the i^{th} mass; v_i refers to the positive vertical displacement of the i^{th} mass; and ϕ_i refers to the positive rotational motion of the i^{th} mass. V_I refers to the horizontal velocity with which the railcar carrying the shipping container strikes the initially stationary train. There are 29 degrees of freedom. The dynamic equations of motion in matrix form are:

$$[M] \ddot{\mathbf{x}} + [C] \dot{\mathbf{x}} + [K] \mathbf{x} = \mathbf{F}, \quad (1)$$

with initial conditions

$$\dot{x}_i = \dot{u}_i = V_I \quad (i = 1, 2, 3 \dots 10) \text{ and}$$

all other $\dot{x}_i = 0$.

Also, in the eleventh equation of Eqs. (1), $F_{11} = -R_F$, the sliding friction force of the initially stationary train being struck (Fig. 1). All other $\mathbf{F} = 0$. The vector $\mathbf{x}$ refers to the appropriate absolute motion of each of the 29 degrees of freedom; $[M]$ refers to the mass and mass-moment-of-inertia matrix; $[K]$ refers to the stiffness matrix; and $[C]$ refers to the damping matrix. Equations (1) constitute a set of 29 second-order nonlinear differential equations, which are solved in the digital computer program RICTL.

The mass matrix $[M]$ is a diagonal matrix with 29 elements derived from railcar and container mass and mass-moment-of-inertia data. Appendix A includes the numerical data and lumping methods used. The stiffness matrix $[K]$ is derived in the standard way² by first obtaining a transformation

matrix $[A]$ from absolute to relative coordinates. The axial and bending component stiffnesses $[k]$ are as given for beams,² and the resulting stiffness matrix $[K]$ was formulated by the matrix product

$$[K] = [A]^T [k] [A], \quad (2)$$

where $[A]^T$ is the transpose of $[A]$.

The damping matrix $[C]$ was formulated by first assuming linear viscous damping in the tiedown members and in the coupler. These are the only damping forces included. They were formed in a relative damping matrix $[r]$, and then $[C]$ was formulated by the matrix product

$$[C] = [A]^T [r] [A]. \quad (3)$$

The nonlinear spring ($k_{7,11}$) associated with the draft gear of the coupler was assumed to be a standard Miner RF-333 draft gear.³ Figure 2 shows the force deflection characteristics of this coupler. A subroutine was written that updates the $k_{7,11}$ element in $[K]$ based on the current (time dependent) relative displacement in the coupler ($u_{7,11} = u_{11} - u_7$).

A Runge-Kutta numerical integration routine was used to solve Eqs. (1). A constant time step increment was used, and the results of computer runs indicate that a sufficiently small time step for convergence does not require excessive computer time. This will be discussed later in the section on results.

The constraint forces (including tiedown loads) were computed from the following relationships for every time step:

$$\{X_{rel}\} = [A]\{X\}, \quad (4)$$

Fig. 2.
Nonlinear stiffness function for coupler.

$$\dot{X}_{rel} = [-1] \dot{X}, \quad (5)$$

$$[F] = [-1] [X_{rel}] + [V] [\dot{X}_{rel}], \quad (6)$$

where $[F]$ the constraint force vector, and

$[X_{rel}]$, $[\dot{X}_{rel}]$ the relative displacement and velocity of the ends of each member carrying a constraint force.

The detailed matrices and equations of motion are given in Appendix B. The listing of the computer program code RICTL is given in Appendix C. The RICTL user's manual is given in Appendix D.

IV. DISCUSSION OF RESULTS

The analytical results were obtained using the RICTL code with the model described in Appendix A. The study was parametric in nature with container weight, impact velocity, and tiedown stiffness and damping as parameters. The results of interest include peak values of the time profile of

- (1) horizontal deceleration of the railcar at the point of impact,
- (2) vertical response acceleration of the railcar at struck-end container attachment,
- (3) horizontal deceleration of the container c.g.,
- (4) vertical acceleration of the container c.g.,
- (5) struck-end tiedown load horizontal component,
- (6) struck-end tiedown load vertical component,
- (7) struck-end tiedown load bending moment,
- (8) coupler longitudinal force,
- (9) maximum railcar bending moment, and
- (10) maximum container bending moment.

In addition, typical time profiles of the above results for the heaviest container-railcar configuration striking an initially stationary train at the highest coupling velocity are included for the significant time portion of the impact event. The tiedown loads for the time profiles were expressed in terms of the total load of the two struck-end tiedowns (which produced the maximum

tiedown loads) and involved the axial load in each of the tiedown members $L_{5,10}$ and $L_{10,6}$. These axial loads can be converted to equivalent horizontal and vertical loads and a bending moment of a single member attached rigidly between Mass 10 and Mass 5. The relationships are:

$$F_{\text{Horiz.}} = F_{10,6} \cos \beta, \quad (7)$$

$$F_{\text{Vert.}} = F_{10,6} \sin \beta + F_{10,5}, \quad (8)$$

$$BM_5 = L_{5,10} F_{10,6} \cos \beta, \quad (9)$$

$$\sin \beta = \frac{L_{5,10}}{L_{10,6}}, \quad (10)$$

and

$$\cos \beta = \frac{L_{56}}{L_{10,6}}, \quad (11)$$

where BM_5 is the bending moment in member $L_{5,10}$.

Figure 3 shows the variation in peak acceleration with the container weight for the variables of interest. The significant result shown in Fig. 3 is that, for heavy containers, the vertical acceleration of the railcar is nearly as large as the horizontal deceleration. This result emphasizes the relative importance of vertical dynamics compared with horizontal dynamics. This implies that bending effects of the container are important in considering tiedown loads. Figure 4 shows the peak tiedown load variation with container weight. This plot confirms the fact that bending effects in the tie-downs need to be considered. Although the net vertical component is small compared with horizontal tiedown loads, the bending moment is certainly significant.

Figure 5 shows the peak coupler longitudinal forces, maximum railcar bending moment, and maximum container bending moment, each expressed as a function of container weight. For the range of weights considered, we can see that the peak coupler load increases only slightly with weight and is about 5×10^6 N (1.124×10^6 lb). The maximum railcar bending moment follows a similar variation with weight and is largest for the heaviest container,

Fig. 3.
Peak acceleration during
impact at 17.7 km/h (11 mph).

Fig. 4.
Peak tiedown loads during
impact at 17.7 km/h (11 mph).

Note: Weight of stationary train = 2.224×10^6 N (500 000 lb).
Resistance of stationary train = 4.448×10^5 N (100 000 lb).

1.75×10^6 m-N (15.49×10^6 in-lb). The values of peak coupler load and railcar bending moment are comparable to values used in the design of the railcar,⁴ namely, 4.448×10^6 N (1×10^6 lb) coupler load and 2.56×10^6 m-N (22.6×10^6 in-lb) bending moment, respectively.

Figures 6 through 8 show the variation of the same peak load variables as Figs. 3-5 with impact speed as the parameter varied. The largest container weight, 63.5 tonnes, was used for these studies. The curves all indicate that the peak loads vary linearly, or approximately linearly, with impact speed. This is an entirely predictable result, since the impulse is proportional to the momentum, which varies linearly with impact velocity. Variations from linearity are due to the peak loads being based on vibratory responses that peak at different relative times during the impact event. In the low-speed case (8 km/h), the coupler load peaks at 0.006 s when the coupler stiffness is high (10.51×10^7 N/m). In all of the higher speed cases, the coupler load peaks at 0.038 s when the coupler stiffness is low (2.1×10^7 N/m) during deflection of the draft gear. These times were obtained from a detailed computer printout of the results. In Fig. 8, the higher speed coupler loads are linearly related, but the low-speed coupler load is not on the same line. Thus, the nonlinear stiffness characteristic of the coupler accounts for the deviation from linearity of some of the peak response loads.

The peak horizontal deceleration of the railcar is linearly related to impact velocity because it occurs 40 μ s after initial impact for all impact speeds. At this time the coupler stiffness is still in the linear range, and the draft gear is undeflected. The container response acceleration peaks are linearly related to impact velocity because, although they occur at times when the draft gear is deflecting, they occur at the same time (0.012 s for horizontal response and 0.017 s for vertical response) for each impact velocity. Again, these times were obtained from a detailed computer printout of the results.

Figures 9 through 11 show the peak load variations of the 63.5-tonne container configuration with container tiedown axial stiffness. The tiedown stiffness embodies the same values of stiffness in each of the four members ℓ_{28} , ℓ_{38} , $\ell_{5,10}$, and $\ell_{10,6}$. Also, since the tiedown damping was assumed to vary with the tiedown stiffness, the damping constants were also varied by the same ratio as the stiffness. The most notable result is that response variables that depend on the tiedown interconnections to transmit

Fig. 5.
Peak component loads during
impact at 17.7 km/h (11 mph).

Fig. 6.
Peak acceleration during
impact of railcar carrying
63.5-tonne container.

Note: Weight of stationary train = 2.224×10^6 N (500 000 lb).
Resistance of stationary train = 4.448×10^5 N (100 000 lb).

Fig. 7.
Peak tiedown loads during
impact of railcar carrying
63.5-tonne container.

Fig. 8.
Peak component loads during
impact of railcar carrying
63.5-tonne container.

Note: Weight of stationary train = 2.224×10^6 N (500 000 lb).
Resistance of stationary train = 4.448×10^5 N (100 000 lb).

Fig. 9.
Peak acceleration during
impact at 17.7 km/h (11 mph)
of railcar carrying 63.5-
tonne container.

Fig. 10.
Peak tiedown loads during
impact at 17.7 km/h (11 mph)
of railcar carrying 63.5-
tonne container.

Note: Weight of stationary train = 2.224×10^6 N (500 000 lb).
Resistance of stationary train = 4.448×10^5 N (100 000 lb).

loads are markedly reduced when the tiedown stiffness is reduced. The railcar vertical acceleration plot of Fig. 9 and the tiedown load plots of Fig. 10 show this effect. The coupler load and railcar impact point deceleration were unaffected by tiedown stiffness variation.

Figures 12 through 14 show typical time profiles of the heaviest weight container-railcar configuration striking an initially stationary train at the highest coupling impact velocity (17.7 km/h or 11 mph). These plots are included to show the oscillatory behavior of the impact event. The impact deceleration has an apparent dominant frequency of 125 Hz, which is revealed initially in the tiedown load of member 10,6, the tiedown having the dominant loading. This result appears to be approximately in accord with the result obtained by Magnuson and Wilson in their model that has only longitudinal degrees of freedom for the ATMX car tiedown structure (dominant frequency of 100 Hz).³ The magnitude of peak deceleration that we obtained (54.5 g's) also compares with the Magnuson and Wilson results for cargo weights between 178 000 N and 445 000 N, which gave 52 g's, and 58 g's, respectively, for a spent fuel cask system with 3.2 mm free travel space. The configuration of Magnuson and Wilson and our configuration are not exactly the same, so a direct comparison is not possible. However, the closeness of the two results for longitudinal motion variables is of interest. For 50 ms of elapsed time (500 time steps), the CDC 7600 CPU time was slightly over two minutes so that the simulation is economical to use.

In conclusion, the results indicate that the RICTL simulation of railcar coupling impact dynamics produces results that are plausible when compared with results of other impact analyses.^{3,4} The analysis method applied to the design of cargo tiedowns should be a significant improvement over current static design methods⁵ that employ equivalent empirically derived load factors in the design of tiedowns. Also, vertical motion and bending are found to be important effects to be considered in the design of tiedown structure. More cannot be said about the adequacy of the simulation until a degree of correlation is established between the RICTL model and actual impact tests.

Fig. 11.

Peak component loads during impact at 17.7 km/h (11 mph) of railcar carrying 63.5-tonne container.

Weight of stationary train = 2.224×10^6 N (500 000 lb).

Resistance of stationary train = 4.448×10^5 N (100 000 lb).

Fig. 12.

Acceleration time profiles for railcar carrying 63.5-tonne container striking 226.8-tonne stationary train at 17.7 km/h (11 mph). Resistance of stationary train = 4.448×10^5 N (100 000 lb).

Fig. 13.
Coupler and tiedown load time profiles
for railcar carrying 63.5-tonne con-
tainer striking 226.8-tonne stationary
train at 17.7 km/h (11 mph).

Fig. 14.
Bending moment time profiles for railcar
carrying 63.5-tonne container striking
226.8-tonne stationary train at 17.7 m/h
(11 mph).

Note: Resistance of stationary train = 4.448×10^5 N (100 000 lb).

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APPENDIX A ANALYTICAL MODEL DATA

Railcar Data From Appendix L, "Stress Analysis for 50 Ton 50 Ft 6 In. Bulkhead Flat Car," Published by Association of American Railroads, January 1966.

Length between trucks = 13.132 m (519 in.)
 Container weights of 13.6, 27.2, 63.5 tonnes (30, 60, 70 tons)

Weights of railcar

- 1) Distributed weight = 15 292 N/m (37.32 lb/in.)
- 2) Bulkheads (2) = 16 414 N each at $x = 0$, $x=13.132$ m
 (3 690 lb each at $x = 0$, $x=519$ in.)
- 3) Weight of Trucks (2) = 31 805 N each at $x = 0$, $x=13.132$ m
 (7 150 lb each at $x = 0$, $x=519$ in.)

Railcar Lumping Nodes	Node i to Node j (m)	Member Length l (m)	Weight Distribution (N)	Member Sectional Areas (m ²)	Member Sect. Area Moments of Inertia (m ⁴)
1-2	0- 2.997	2.997	45 834	0.04923	0.002333
2-3	2.997- 4.794	1.797	27 481	0.0581	0.00542
3-4	4.794- 6.591	1.797	27 481	0.0581	0.00542
4-5	6.591- 8.388	1.797	27 481	0.0581	0.00542
5-6	8.388-10.185	1.797	27 481	0.0581	0.00542
6-7	10.185-13.132	2.997	45 834	0.04923	0.002333

Container Lumping Nodes	(m)	l (m)	Weight Distribution (N)			Steel Shell Sizes		
			13.6 tonne	27.2 tonne	63.5 tonne	Weight (tonnes)	d_o (m)	d_i (m)
8A- 8F ^a	3.9-5.7	1.8	44 482	88 964	207 585	13.6	0.3382	0.762
9A- 9F	5.7-7.5	1.8	44 482	88 964	207 585	27.2	1.1938	1.1176
10A-10F	7.5-9.3	1.8	44 482	88 964	207 585	63.5	1.8288	1.7272

Member Sectional Areas (m ²)					
(m)	l (m)	13.6 tonne	27.2 tonne	63.5 tonne	
8A- 8F	3.9-5.7	0.09548	0.13806	0.23387	
9A- 9F	5.7-7.5	0.09548	0.13806	0.23387	
10A-10F	7.5-9.3	0.09548	0.13806	0.23387	

Member Sectional Moments of Inertia (m ⁴)					
(m)	l (m)	13.6 tonne	27.2 tonne	63.5 tonne	
8A- 8F	3.9-5.7	0.007679	0.02312	0.11222	
9A- 9F	5.7-7.5	0.007679	0.02312	0.11222	
10A-10F	7.5-9.3	0.007679	0.02312	0.11222	

$$A = \frac{\pi (d_o^2 - d_i^2)}{4}$$

$$I = \frac{\pi (d_o^4 - d_i^4)}{64}$$

^a A = aft, F = forward extremes of the element lumped at the indicated node.

Lumped weights are obtained by:

$$W_1 = \frac{W \text{ Dist. 1-2}}{2} + 16 \ 414 + 31 \ 805 = 71,136 \text{ N} = W_7$$

$$W_2 = \frac{W \text{ Dist. 1-2}}{2} + \frac{W \text{ Dist. 2-3}}{2} = 36 \ 658 \text{ N} = W_6$$

$$W_3 = \frac{W \text{ Dist. 2-3}}{2} + \frac{W \text{ Dist. 3-4}}{2} = 27 \ 481 \text{ N} = W_4 = W_5$$

$$W_8 = W_9 = W_{10} = W \text{ Dist. 8A-8F}$$

Weight Moments of Inertia are obtained by:

$$\text{Railcar} - I_i = \frac{w_i d_i^2}{12}, \quad d_i = 0.7184 \text{ m (28.285 in.)}, \quad i = 1, 2, 3, 4, 5, 6, 7$$

$$\text{Container} - I_i = \frac{w_i d_i^2}{16}, \quad d_i = 1.8288 \text{ m (72 in.)}, \quad i = 8, 9, 10$$

Lumped Data

Railcar

Lump (i)	X_i (m)	Y_i (m)	W_i (N)	I_i (N-m ²)
1	0	0	71 136	3059.8
2	2.997	0	36 658	1576.8
3	4.794	0	27 481	1182.0
4	6.591	0	27 481	1182.0
5	8.388	0	27 481	1182.0
6	10.185	0	36 658	1576.8
7	13.182	0	71 136	3059.8

Container Weight

13.6 tonne 27.2 tonne 63.5 tonne

Lump (i)	X_i (m)	Y_i (m)	W_i (N)	W_i (N)	W_i (N)
8	4.794	0.9144	44 482	88 964	207 585
9	6.591	0.9144	44 482	88 964	207 585
10	8.388	0.9144	44 482	88 964	207 585

Container Mass Moment of Inertia

13.6 tonne 27.2 tonne 63.5 tonne

Lump (i)	X_i (m)	Y_i (m)	I_i (N-m ²)	I_i (N-m ²)	I_i (N-m ²)
8	4.794	0.9144	9 298	18 596	43 392
9	6.591	0.9144	9 298	18 596	43 392
10	8.388	0.9144	9 298	18 596	43 392

Moduli (Pa)

$$\text{Railcar } E_R = 2.0684 \times 10^{11} \text{ (30 000 000 psi)}$$

$$\text{Container } E_C = 2.0684 \times 10^{11} \text{ (30 000 000 psi)}$$

Acceleration of gravity (m/s^2)

$$g = 9.80665 \text{ (32.17 ft/s}^2\text{)}$$

Tiedown Damping (Est. $\zeta = 0.05$) - ($\frac{\text{N}}{\text{m/s}}$)

Member	0.1 Nominal	Nominal	10 Nominal
2-8	1.226×10^5	1.226×10^6	1.226×10^7
3-8	1.226×10^5	1.226×10^6	1.226×10^7
10-5	1.226×10^5	1.226×10^6	1.226×10^7
10-6	1.226×10^5	1.226×10^6	1.226×10^7

Tiedown Stiffness (N/m)

Member	0.1 Nominal	Nominal	10 Nominal
2-8	8.756×10^8	8.756×10^9	8.756×10^{10}
3-8	8.756×10^8	8.756×10^9	8.756×10^{10}
10-5	8.756×10^8	8.756×10^9	8.756×10^{10}
10-6	8.756×10^8	8.756×10^9	8.756×10^{10}

$$\text{Impact Velocity (km/h)} \quad V_I = 8, 11.3, 14.5, 17.7$$

$$\text{Stationary Train - Weight} = 226.8 \text{ tonnes} = 2.224 \times 10^6 \text{ N (500 000 lb)}$$

$$\begin{aligned} &\text{- Resistance Force (coeff. of friction of 0.2) =} \\ &4.448 \times 10^5 \text{ N (100 000 lb)} \end{aligned}$$

APPENDIX B DETAILED MATRICES AND EQUATIONS OF MOTION

The equations of motion for the railcar coupling impact dynamics problem are, as stated in the methods section of the report,

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = \{F\}. \quad (A-1)$$

For the degrees of freedom indicated in Fig. 1 of the report we have the correspondence:

$x_1 = u_1$	$x_{16} = v_6$
$x_2 = u_2$	$x_{17} = v_8$
$x_3 = u_3$	$x_{18} = v_9$
$x_4 = u_4$	$x_{19} = v_{10}$
$x_5 = u_5$	$x_{20} = \theta_1$
$x_6 = u_6$	$x_{21} = \theta_2$
$x_7 = u_7$	$x_{22} = \theta_3$
$x_8 = u_8$	$x_{23} = \theta_4$
$x_9 = u_9$	$x_{24} = \theta_5$
$x_{10} = u_{10}$	$x_{25} = \theta_6$
$x_{11} = u_{11}$	$x_{26} = \theta_7$
$x_{12} = v_2$	$x_{27} = \theta_8$
$x_{13} = v_3$	$x_{28} = \theta_9$
$x_{14} = v_4$	$x_{29} = \theta_{10}$
$x_{15} = v_5$	

The masses are:

$M_{11} = M_1$	$M_{16,16} = M_6$
$M_{22} = M_2$	$M_{17,17} = M_8$

$$M_{33} = M_3$$

$$M_{44} = M_4$$

$$M_{55} = M_5$$

$$M_{66} = M_6$$

$$M_{77} = M_7$$

$$M_{88} = M_8$$

$$M_{99} = M_9$$

$$M_{10,10} = M_{10}$$

$$M_{11,11} = M_{11}$$

$$M_{12,12} = M_2$$

$$M_{13,13} = M_3$$

$$M_{14,14} = M_4$$

$$M_{15,15} = M_5$$

$$M_{18,18} = M_9$$

$$M_{19,19} = M_{10}$$

$$M_{20,20} = I_1$$

$$M_{21,21} = I_2$$

$$M_{22,22} = I_3$$

$$M_{23,23} = I_4$$

$$M_{24,24} = I_5$$

$$M_{25,25} = I_6$$

$$M_{26,26} = I_7$$

$$M_{27,27} = I_8$$

$$M_{28,28} = I_9$$

$$M_{29,29} = I_{10}$$

All other $M_{ij} = 0$.

The damping matrix:

$$\gamma_{77} = c_{28}$$

$$\gamma_{88} = c_{38}$$

$$\gamma_{11,11} = c_{10,5}$$

$$\gamma_{12,12} = c_{10,6}$$

$$\gamma_{29,29} = c_{7,11}$$

All other $\gamma_{ij} = 0$.

The relative coordinates in terms of the absolute coordinates are given by the relations:

$$u_{12} = u_2 - u_1$$

$$u_{23} = u_3 - u_2$$

$$u_{34} = u_4 - u_3$$

$$u_{45} = u_5 - u_4$$

$$u_{56} = u_6 - u_5$$

$$u_{7,11} = u_{11} - u_7$$

$$u_{89} = u_9 - u_8$$

$$u_{9,10} = u_{10} - u_9$$

$$u_{28} = (u_8 \cos \alpha + v_8 \sin \alpha) - (u_2 \cos \alpha + v_2 \sin \alpha)$$

$$u_{38} = v_8 - v_3$$

$$u_{67} = u_7 - u_6$$

$$u_{10,5} = v_{10} - v_5$$

$$u_{10,6} = (u_6 \cos \beta - v_6 \sin \beta) - (u_{10} \cos \beta - v_{10} \sin \beta)$$

where

$$\cos \alpha = \frac{l_{23}}{l_{28}}, \sin \alpha = \frac{l_{38}}{l_{28}}, \cos \beta = \frac{l_{56}}{l_{10,6}}, \sin \beta = \frac{l_{5,10}}{l_{10,6}}$$

$$v_{12} = v_2 - l_{12} \theta_1$$

$$\theta_{12} = \theta_2 - \theta_1$$

$$v_{23} = v_3 - (v_2 + l_{23} \theta_2)$$

$$\theta_{23} = \theta_3 - \theta_2$$

$$v_{34} = v_4 - (v_3 + l_{34} \theta_3)$$

$$\theta_{34} = \theta_4 - \theta_3$$

$$v_{45} = v_5 - (v_4 + l_{45} \theta_4)$$

$$\theta_{45} = \theta_5 - \theta_4$$

$$v_{56} = v_6 - (v_5 + l_{56} \theta_5)$$

$$\theta_{56} = \theta_6 - \theta_5$$

$$v_{67} = - (v_6 + l_{67} \theta_6)$$

$$\theta_{67} = \theta_7 - \theta_6$$

$$v_{89} = v_9 - (v_8 + l_{89} \theta_8)$$

$$\theta_{89} = \theta_9 - \theta_8$$

$$v_{9,10} = v_{10} - (v_9 + l_{9,10} \theta_9)$$

$$\theta_{9,10} = \theta_{10} - \theta_9$$

The $[\beta]$ matrix is set up as follows from the relative coordinate/ absolute coordinate equations.

1. All $\beta_{ij} = 0$ except for those that follow ($\beta_{ij} \equiv \text{BETA}(i, j)$)

2. BETA (1,1) = -1.0

12. BETA (6,6) = -1.0

3. BETA (1,2) = 1.0

13. BETA (6,7) = 1.0

4. BETA (2,2) = -1.0

14. BETA (7,2) = $-l_{23}/l_{28}$

5. BETA (2,3) = 1.0

15. BETA (7,8) = l_{23}/l_{28}

6. BETA (3,3) = -1.0

16. BETA (7,12) = $-l_{38}/l_{28}$

7. BETA (3,4) = 1.0

17. BETA (7,17) = l_{38}/l_{28}

8. BETA (4,4) = -1.0

18. BETA (8,13) = -1.0

9. BETA (4,5) = 1.0

19. BETA (8,17) = 1.0

10. BETA (5,5) = -1.0

20. BETA (9,8) = -1.0

11. BETA (5,6) = 1.0

21. BETA (9,9) = 1.0

22. BETA (10,9) = -1.0	46. BETA (19,17) = -1.0
23. BETA (10,10) = 1.0	47. BETA (19,18) = 1.0
24. BETA (11,15) = -1.0	48. BETA (19,27) = $\frac{2}{89}$
25. BETA (11,19) = -1.0	49. BETA (20,18) = -1.0
26. BETA (12,6) = $-\frac{2}{56} \frac{1}{10,6}$	50. BETA (20,19) = 1.0
27. BETA (12,10) = $-\frac{2}{56} \frac{1}{10,6}$	51. BETA (20,28) = $-\frac{2}{9,10}$
28. BETA (12,16) = $-\frac{2}{5,10} \frac{1}{10,6}$	52. BETA (21,20) = -1.0
29. BETA (12,19) = $\frac{2}{5,10} \frac{1}{10,6}$	53. BETA (21,21) = 1.0
30. BETA (13,12) = 1.0	54. BETA (22,21) = -1.0
31. BETA (13,20) = $-\frac{2}{12}$	55. BETA (22,22) = 1.0
32. BETA (14,12) = -1.0	56. BETA (23,22) = -1.0
33. BETA (14,13) = 1.0	57. BETA (23,23) = 1.0
34. BETA (14,21) = $-\frac{2}{23}$	58. BETA (24,23) = -1.0
35. BETA (15,13) = -1.0	59. BETA (24,24) = 1.0
36. BETA (15,14) = 1.0	60. BETA (25,24) = -1.0
37. BETA (15,22) = $-\frac{2}{34}$	61. BETA (25,25) = 1.0
38. BETA (16,14) = -1.0	62. BETA (26,25) = -1.0
39. BETA (16,15) = 1.0	63. BETA (26,26) = 1.0
40. BETA (16,23) = $-\frac{2}{45}$	64. BETA (27,27) = -1.0
41. BETA (17,15) = -1.0	65. BETA (27,28) = 1.0
42. BETA (17,16) = 1.0	66. BETA (28,28) = -1.0
43. BETA (17,24) = $-\frac{2}{56}$	67. BETA (28,29) = 1.0
44. BETA (18,16) = -1.0	68. BETA (29,7) = -1.0
45. BETA (18,25) = $-\frac{2}{67}$	69. BETA (29,11) = 1.0

The $[\kappa]$ matrix is set up as follows from Ref. 2.

1. All $\kappa_{ij} = 0$ except for those that follow ($\kappa_{ij} \equiv \text{KAPPA}(i, j)$)
2. $\text{KAPPA}(1,1) = A_{12} E_R / \ell_{12}$

3. $\text{KAPPA} (2,2) = A_{23} E_R / \ell_{23}$
4. $\text{KAPPA} (3,3) = A_{34} E_R / \ell_{34}$
5. $\text{KAPPA} (4,4) = A_{45} E_R / \ell_{45}$
6. $\text{KAPPA} (5,5) = A_{56} E_R / \ell_{56}$
7. $\text{KAPPA} (6,6) = A_{67} E_R / \ell_{67}$
8. $\text{KAPPA} (7,7) = K_{28}$
9. $\text{KAPPA} (8,8) = K_{38}$
10. $\text{KAPPA} (9,9) = A_{89} E_c / \ell_{89}$
11. $\text{KAPPA} (10,10) = A_{9,10} E_c / \ell_{10,9}$
12. $\text{KAPPA} (11,11) = K_{10,5}$
13. $\text{KAPPA} (12,12) = K_{10,6}$
14. $\text{KAPPA} (13,13) = 12 E_R I_{12} / \ell_{12}^3$
15. $\text{KAPPA} (13,21) = -6 E_R I_{12} / \ell_{12}^2$
16. $\text{KAPPA} (14,14) = 12 E_R I_{23} / \ell_{23}^3$
17. $\text{KAPPA} (14,22) = -6 E_R I_{23} / \ell_{23}^2$
18. $\text{KAPPA} (15,15) = 12 E_R I_{34} / \ell_{34}^3$
19. $\text{KAPPA} (15,23) = -6 E_R I_{34} / \ell_{34}^2$
20. $\text{KAPPA} (16,16) = 12 E_R I_{45} / \ell_{45}^3$
21. $\text{KAPPA} (16,24) = -6 E_R I_{45} / \ell_{45}^2$
22. $\text{KAPPA} (17,17) = 12 E_R I_{56} / \ell_{56}^3$
23. $\text{KAPPA} (17,25) = -6 E_R I_{56} / \ell_{56}^2$
24. $\text{KAPPA} (18,18) = 12 E_R I_{67} / \ell_{67}^3$
25. $\text{KAPPA} (18,26) = -6 E_R I_{67} / \ell_{67}^2$
26. $\text{KAPPA} (19,19) = 12 E_c I_{89} / \ell_{89}^3$
27. $\text{KAPPA} (19,27) = -6 E_c I_{89} / \ell_{89}^2$
28. $\text{KAPPA} (20,20) = 12 E_c I_{9,10} / \ell_{9,10}^3$

29. $\text{KAPPA} (20,28) = -6 E_c I_{9,10} / l_{9,10}^2$
30. $\text{KAPPA} (21,13) = -6 E_R I_{12} / l_{12}^2$
31. $\text{KAPPA} (21,21) = 4 E_R I_{12} / l_{12}^2$
32. $\text{KAPPA} (22,14) = -6 E_R I_{23} / l_{23}^2$
33. $\text{KAPPA} (22,22) = 4 E_R I_{23} / l_{23}^2$
34. $\text{KAPPA} (23,15) = -6 E_R I_{34} / l_{34}^2$
35. $\text{KAPPA} (23,23) = 4 E_R I_{34} / l_{34}^2$
36. $\text{KAPPA} (24,16) = -6 E_R I_{45} / l_{45}^2$
37. $\text{KAPPA} (24,24) = 4 E_R I_{45} / l_{45}^2$
38. $\text{KAPPA} (25,17) = -6 E_R I_{56} / l_{56}^2$
39. $\text{KAPPA} (25,25) = 4 E_R I_{56} / l_{56}^2$
40. $\text{KAPPA} (26,18) = -6 E_R I_{67} / l_{67}^2$
41. $\text{KAPPA} (26,26) = 4 E_R I_{67} / l_{67}^2$
42. $\text{KAPPA} (27,19) = -6 E_c I_{89} / l_{89}^2$
43. $\text{KAPPA} (27,27) = 4 E_c I_{89} / l_{89}^2$
44. $\text{KAPPA} (28,20) = -6 E_c I_{9,10} / l_{9,10}^2$
45. $\text{KAPPA} (28,28) = 4 E_c I_{9,10} / l_{9,10}^2$
46. $\text{KAPPA} (29,29) = K_{7,11}$

The 29 x 29 damping and stiffness matrices are computed from:

$$[C] = [\beta^T][\gamma][\beta],$$

$$[K] = [\beta^T][\kappa][\beta],$$

where $[\beta^T]$ is the transpose of $[\beta]$.

$K(29,29)$ will be the nonlinear stiffness of the coupler $k_{7,11}$. In the solution of the equations of motion (A-1) at each time step, $u_{7,11}$ is evaluated and the data of Fig. 2 of the main report are used in tabular form for the appropriate $k_{7,11}$. This value ($u_{7,11}$) if different, is substituted into the $[K]$ matrix appropriately and iterated.

A Runge-Kutta numerical integration procedure was used in the digital code. The code and subroutines appropriate to this are presented in Appendix C.

The initial input velocity V_1 was assigned to $\dot{u}_1$ through $\dot{u}_{10}$. The resistance force R_F , which was taken to be 0.2 times the weight of mass eleven, was assigned to $F(11)$ as

$$F(11) = -R_F.$$

There are two other cases that can be simulated by RICTL. These are

- (1) The railcar striking a train free to roll, in this case $R_F = 0$, and
- (2) A train striking the railcar free to roll, in this case $\dot{u}_1$ through $\dot{u}_{10}$ are zero and $\dot{u}_{11} = -V_1$, and $R_F = 0$.

COMPUTER LISTING OF RICTL

LASL Identification No. LP-0880

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1  PROGRAM DICTL (OUTPUT, JAPEN=GRIPUT, IAPEN=5)
2
3  COMMON /COMMON /CASE,VI,VF,VIS,VT,LOH(6),TITL(8)
4  COMMON /MATRIX/ SR(9999),DAYS(999),F(333),A(333),
5  &(30)
6
7  COMMON /GENDATA/NO(11),Y(11),DNC(11),DIF(11),F,H,EC,K2N,K3N,K1N5,K1N6,
8  T6
9
10  DIMENSION T1(30),T2(30),T3(30),V1(30),V2(30),V3(30),V4(30)
11  DIMENSION A1(30),A2(30),A3(30),A4(30),NOV(30),DA(30),S(999),K(999)
12  DIMENSION T1A(30),H1(30),IA(30),I1(999)
13  DIMENSION ACC(30),C(999),ACCG(30)
14  DIMENSION FD(30),FK(30),FK1(30),FK1(30),FK1(30)
15  N=29
16
17  OPEN=H,K
18  CALL READR
19  CALL SETUP
20  DO 10 I=1,M
21    K(I)=ANAL(I)
22    CALL HFM(V,N,D,L,H)
23    T=0
24    CALL GPRD(S,K,COV,T11,N,H,N)
25    CALL GPRD(COV,T11,S,N,N,N)
26    CALL GPRD(DAY,COV,T11,H,H,N)
27    CALL GPRD(COV,T11,C,N,N,N)
28    TI=0
29    DO 30 K=1,NHS
30      CALL SHPY(A,T,V1,N,1)
31      CALL GPRD(C,A,11,H,H,1)
32      CALL STP(C,N,H,CON,SR,K,S,T11)
33      CALL GPRD(S,K,T2,N,H,1)
34      CALL GPRD(T1,T2,T3,N,1)
35      CALL GPRD(T,T3,T4,N,1)
36      CALL GPRD(K,T1,T2,H,H,1)
37      CALL SHPY(T2,D,T4,H,1)
38      CALL SHPY(A1,S,T1,N,1)
39      CALL GPRD(T1,A,T2,N,1)
40      CALL SHPY(T2,D,T2,N,1)
41      CALL SHPY(V1,S,T2,N,1)
42      CALL GPRD(X,T2,T4,N,1)
43      CALL STP(C,N,H,CON,SR,K,T11)
44      CALL GPRD(S,T4,T5,N,1)
45      CALL GPRD(T1,T2,T3,N,1)
46      CALL GPRD(T,T3,T4,N,1)
47      CALL GPRD(A,T1,T2,H,H,1)
48      CALL SHPY(T2,D,T2,N,1)
49      CALL SHPY(A2,S,T1,N,1)
50      CALL SHPY(T2,D,T2,N,1)
51      CALL GPRD(T1,A,T2,N,1)
52      CALL SHPY(V2,S,T2,H,1)
53      CALL GPRD(X,T2,T4,N,1)
54      CALL STP(C,N,H,CON,SR,K,T4,S,T11)
55      CALL GPRD(S,T4,T5,N,1)
56      CALL GPRD(T,T3,T4,N,1)
57      CALL GPRD(T1,T2,T3,N,1)
58      CALL GPRD(C,T2,T3,T4,N,1)
59

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60

CALL SHPY(12,01,01,0,1)

PROGRAM PICTL

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OF 1

TRACE

FIN 4.439/LLC

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CALL GHADD(A1,A,12,0,1)

CALL SHPY(12,01,01,0,1)

CALL GHPRD(C,12,11,0,0,1)

CALL GHADD(X,V3,1A,N,1)

CALL STIF(CNH,N,CON,SK,1A,5,T11)

CALL GHPRD(S,1A,12,0,0,1)

CALL GHADD(T,12,15,0,1)

CALL GMSUB(I,13,11,0,1)

CALL GHPRD(W,11,12,0,0,1)

CALL SHPY(12,01,01,0,1)

CALL GHADD(V1,V0,11,0,1)

CALL GHADD(V2,V1,12,0,1)

CALL SHPY(12,01,13,0,1)

CALL GHADD(11,13,12,0,1)

CALL SHPY(12,100000,0,0,1)

CALL GHADD(A1,A4,11,0,1)

CALL GHADD(A2,A3,12,0,1)

CALL SHPY(12,01,13,0,1)

CALL GHADD(11,13,12,0,1)

CALL SHPY(12,100000,0,0,1)

CALL GHADD(X,DV,X,N,1)

CALL GHADD(A,DA,X,N,1)

CALL STIF(CNH,N,CON,SK,X,5,T11)

CALL GHPRD(S,X,11,0,0,1)

CALL GHPRD(C,A,12,0,0,1)

CALL GHADD(T,12,15,0,1)

CALL GMSUB(I,13,11,0,1)

CALL GHPRD(W,11,ACC,0,0,1)

T=T+DT

J1=J1+1

IF(J1.NC,10PT(1))GO TO40

J1=0

PRINT 104,T

104 FORMAT(X,'TIME IS',F10.5,X,'SEC')/

PRINT 105

105 FORMAT(X,' NUMBER DISPLACEMENTS VELOCITIES ACCELERATIONS')/

DO 50 I=1,N

ACCG(I)=ACC(I)/6

30 PRINT 103,I,X(I),AC(I),ACCG(I)

103 FORMAT(X,I5,F15.0,F12.6,F15.7)

CALL GHPRD(DAH,CON,T11,N,N,1)

CALL GHPRD(T11,A,10,N,N,1)

CALL GHPRD(CON,X,FK1,N,N,1)

CALL GHPRD(SK,FK1,K,N,N,1)

DO 50 J=1,N

50 JT(I)=FK(I)+JPD(I)

PRINT 107

107 FORMAT(//,X,' INTERNAL LOADS')/

PRINT 108,(IT(I),I=1,29)

108 FORMAT(2X,5F14.6)

PRINT 106

106 FORMAT(//,//)

30 CONTINUE

STOP

END

FIN 0.013711L 00/01/77 015.00.00.

TRACE

OPT=1

70/76

PROGRAM RCIL

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STATEMENT LABELS

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3070 105
3125 100
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COMMON BLOCKS
CONTROL 19
NATOPS 3690
BKDATA 51

STATISTICS

PROGRAM LENGTH 1131H 0009
ROUTED LENGTH 215H 1091
SEN LABELED COMMON LENGTH 720H 3760

PROPERTIES
INSTACK
EXT REFS
EXT REFS
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2002 00
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00000177 515,42,40.

FIN 4,0,327LL

TRACE

767/6 001=1

SUBROUTINE SMPY

SUBROUTINE SMPY(A,C,N,H,N)

COMMON AC(1),R(1)

DO I=1,N

R(I)=C*A(I)

RETURN

END

SYMBOLIC REFERENCE MAP (R=1)

ENTRY POINTS

1 SMPY

VARIABLES

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STANDARD INFORMATION

DISTRIBUTION A(1), H(1), R(1)
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001-100

$$|K| = |K+N|$$

W'1=0.01-00

$1 + 21 = 21$
 $41 = 11$

13. 13 = (81) 1

$$N'1 = [1 \quad 0] \quad 0 \leq$$

1-41-61

$$p(r) = p(r) + v(r) + h(r)$$
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59 1101

[illegible]

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[illegible]

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360 SUBROUTINE CHADD  7676  OPT=1  TRACE
370
371
372 SUMMATION CHADD(A,D,R,H,N)
373 DIMENSION A(1),B(1),G(1)
374 N=NN
375 DO 10 I=1,NN
376   10 R(I)=A(I)+B(I)
377 RETURN
378 CND
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Journal of Interpersonal Violence 26(10) 1978-1997
 

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60 IF (J-K) 62, 65, 62
62 KJ=IJ-I+K
65 A(IJ)=HOLD+A(KJ)+A(IJ)
65 CONTINUE
KJ=K-N
DO 75 J=1, N
KJ=K+N
70 A(KJ)=A(KJ)/NIGA
75 CONTINUE
N=N+NIGA
A(KK)=1-N/NIGA
80 CONTINUE
K=N
100 K=(K-1)
105 IF (K) 100, 100, 105
105 I=L(K)
110 IF (I-K) 120, 120, 100
110 J0=N*(K-1)
110 J0=N*(I-1)
DO 110 J=1, N
JK=J0+J
117 JI=J0+J
HOLD=A(KJ)
JI=JI+J
A(KK)=A(JI)
120 A(JI)=HOLD
120 J=N(K)
125 IF (J-K) 100, 100, 125
125 KI=N-N
DO 130 I=1, N
KI=KI+K
HOLD=A(KI)
JI=KI-N+J
A(KI)=A(JI)
130 A(JI)=HOLD
GO TO 100
150 RETURN
END

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SYMBOLIC REFERENCE MAP (R=1)

ENTRY POINTS

MIN MAX

VARIABLES	MIN	TYPE	SYMBOLIC REFERENCE MAP (R=1)
I	1	REAL	APRAY
J	1	REAL	F.P.
K	1	REAL	F.P.
275	1	INTEGER	
304	1	INTEGER	
273	1	INTEGER	
303	1	INTEGER	
306	1	INTEGER	
276	1	INTEGER	

272	304	REAL
300	HOLD	REAL
275	IJ	INTEGER
274	I2	INTEGER
311	J1	INTEGER
302	JP	INTEGER
307	JK	INTEGER
277	K1	INTEGER

SURVEILLANCE COPY										7/6/76 OPT=1										TRACE										RTN 4,4627111										007/01/77 515,40,40																																																																																																																																																																																																																																																																																																																																																																																																																							
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507 SUBROUTINE CHINA 76/76 001=1 TRACE LTN 0.0+997ILL 09/01/77 015,00,00. PAGE

506 SUBROUTINE CHINA(A,P,N,M)

505 DIMENSION A(1),M(1)

504 10=0

503 DO 10 J=1,N

502 JJ=J-N

501 DO 10 J=1,M

500 JJ=J+M

501 JJ=JJ+1

502 10 R(10)=A(JJ)

503 RETURN

504 END

503 SYMBOLIC REFERENCE MAP (R=1)

502 ENTRY POINTS

501 3 CHINA

500 VARIABLES

501 SN TYPE

502 REAL ARRAY

503 R.E.P. R.E.P.

504 INTEGER

505 02 J

506 03 J

507 0 N

508 STATEMENT LABELS

509 0 10

510 0 10

511 LOOP LABEL INDEX

512 FROM-TO LENGTH

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R.E.P.
R.E.P.

701	SUBROUTINE READER	76776	OPT=1	SPACE	FTN 4,4+392LL1	07/11/77 515,42,40,	PAGE
702	FILE NAME			NAME			
703	OUTPUT			FILE			
704	STATEMENT LABELS						
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760      SUBROUTINE SETUP      76/76      OPT=1      IPAGE
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763      1      SUBROUTINE SETUP
764      COMMON /COMMON1/ IPAGE,VI,WF,UIS,DI,ICPT(6),TITLE(8)
765      COMMON /DATA/ C20,C30,C105,C120,C711
766      COMMON /GRDATA/ X(11),Y(11),DM(11),CT(11),CR,EC,K20,K30,K125,K100,
767
768      5      X5
769      COMMON /ADATA/ A(2,A23,A30,A45,A50,A67,A80,A910,112,125,130,145,
770      156,167,180,1910
771      COMMON /MATHX5/ SK(900),CON(900),DAM(900),APASS(900),F(12),
772      1A(30),DX(30)
773
774      10      DIMENSION BETA(20,20),KAPPA(20,20),A"(20,20),GAMMA(20,20)
775      REAL L12,L23,L34,L45,L56,L67,L20,L30,L40,L010,L510,L106
776      REAL L12,L23,L34,L45,L56,L67,L09,L010
777      REAL KAPPA,K20,K30,K125,K100
778      EQUIVALENCE (SK,KAPPA), (CON,BETA), (APASS,A"), (DAM,GAMMA)
779
780      15      DO 10 I=1,20
781      DO 10 J=1,20
782      BETA(I,J)=0.
783      KAPPA(I,J)=0.
784      A"(I,J)=0.
785
786      20      10 GAMMA(I,J)=0.
787      L12=X(2)-X(1)
788      L23=X(3)-X(2)
789      L34=X(4)-X(3)
790      L45=X(5)-X(4)
791      25      L56=X(6)-X(5)
792      L67=X(7)-X(6)
793      L20=SUM1((X(8)-X(2))**2+(Y(8)-Y(3))**2)
794      L30=Y(8)-Y(3)
795      L40=X(9)-X(8)
796      30      L910=X(10)-X(9)
797      L510=Y(10)-Y(5)
798      L100=SUM1((X(6)-X(10))**2+(Y(10)-Y(5))**2)
799      BETA(1,1)=-1.0
800      BETA(1,2)=1.0
801      35      BETA(2,2)=-1.0
802      BETA(2,3)=1.0
803      BETA(3,3)=-1.0
804      BETA(3,4)=1.0
805      BETA(4,4)=-1.0
806      40      BETA(4,5)=1.0
807      BETA(5,5)=-1.0
808      BETA(5,6)=1.0
809      BETA(6,6)=-1.0
810      BETA(6,7)=1.0
811      45      BETA(7,2)=-L23/L20
812      BETA(7,8)=L23/L20
813      BETA(7,12)=-L30/L20
814      BETA(7,17)=L30/L20
815      BETA(8,13)=-1.0
816      50      BETA(8,17)=1.0
817      BETA(9,8)=-1.0
818      BETA(9,9)=1.0
819      BETA(10,9)=-1.0
820      BETA(10,10)=1.0
821      55      BETA(11,15)=-1.0
822      BETA(11,19)=1.0
823      BETA(12,6)=L56/L100

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[illegible]

SUMMARY 5F10P 76/76 OUT=1 TRACT

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KAPPA(190,190)=-6.474*359/359.43
KAPPA(191,191)=1.248*360/360.43
KAPPA(191,191)=-6.474*360/360.43
KAPPA(192,192)=1.248*361/361.43
KAPPA(192,192)=-6.474*361/361.43
KAPPA(193,193)=1.248*362/362.43
KAPPA(193,193)=-6.474*362/362.43
KAPPA(194,194)=1.248*363/363.43
KAPPA(194,194)=-6.474*363/363.43
KAPPA(195,195)=1.248*364/364.43
KAPPA(195,195)=-6.474*364/364.43
KAPPA(196,196)=1.248*365/365.43
KAPPA(196,196)=-6.474*365/365.43
KAPPA(197,197)=1.248*366/366.43
KAPPA(197,197)=-6.474*366/366.43
KAPPA(198,198)=1.248*367/367.43
KAPPA(198,198)=-6.474*367/367.43
KAPPA(199,199)=1.248*368/368.4
```

SYNTHETIC REFERENCE MAP (R=1) 76/76 OPT=1 10ACE FIN 4.0+592111 02/01/77 515,40.00.

AMASS(L)=AM(J,1)
 AND DAMN(L)=DAMN(J,1)

COMPUTE LOUCH MATRIX IF REQUIRED

50 F(1)=0.
 00 50 1=1,20

10 F(1)=0.
 00 10 1=1,20

70 F(1)=0.
 00 70 1=1,20

105 F(1)=0.
 00 105 1=1,10

75 A(1)=0.
 00 75 1=1,10

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37/01/77 015.40.40.

FIN 4.40307111

TRACE

76/76

SURROUNDING SETUP

1006

VARIABLES SW TYPE REALLOCATION

1007

427 105 REAL

1008

430 156 REAL

1009

434 169 REAL

1010

3 415 INTEGER

1011

0 500 REAL

1012

1 01 REAL

1013

13 Y REAL

1014

ARGS 1 LIBRARY

1015

STATEMENT LABELS

1016

0 10

1017

0 40

1018

0 70

1019

412 90

1020

LENGTH

1021

FROM-TO

1022

INDEX

1023

LENGTH

1024

NOT UNDER

1025

NOT UNDER

1026

INSTACK

1027

INSTACK

1028

INSTACK

1029

INSTACK

1030

INSTACK

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PAGE

1755/SLDR - LTRP VER 1 09/21/77 515.0.11.

LINE	LOAD MAP, BLOCK ADDRESS, INCS.	BLOCK	ADDRESS	LENGTH	FILE
1104		0000	30035	24	FORTRAN
1105		0001	30041	107	FORTRAN
1106		0002	30110	66	FORTRAN
1107		0003	30206	30	FORTRAN
1108		0004	30306	27	FORTRAN
1109		0005	30355	151	FORTRAN

APPENDIX D

RICTL USER'S MANUAL

A sample FORTRAN Coding Form is attached showing data card entries. The title card (Card No. 1) is not included in this form.

If one desires to use English units, note that subroutine STIF must express the coupler stiffnesses in English units. The English units for the coupler described by Fig. 2 are:

```
IF (U. LT. - 8.) SK (NM) = 4000000.  
IF ((U. LT. - .5). AND. (U. GE. - 8.)) SK (NM) = 120000.  
IF ((U. LT. 0.). AND. (U. GE. - .5)) SK (NM) = 600000.  
IF ((U. LT. 1.). AND. (U. GE. 0.)) SK (NM) = 0.0  
IF ((U. LT. 6.5). AND. (U. GE. 1.)) SK (NM) = 500000.  
IF (U. GT. 6.5) SK (NM) = 700000.
```

The English units above are in inches for values of U, and lb/in. for values of SK (NM). The proper English units in the program are in., lb, and s. The value of g that must be input for English units is 386. (in./s^2). V_I must be in in./s.

The metric units used in this report are m, N, and s. The value of g input for metric units is 9.80665 (m/s^2). V_I must be in m/s.

CARD INPUT

Card 1 Title Card Format (8A10)
Title Card is a descriptive title up to 80 characters.

Card 2 ICASE, VI, RF, NTS, DT, IOPT (1) IOPT (6)
ICASE = 1, Car striking train free to roll Format (I5)
 = 2, Car striking train with brakes Format (I5)
 = 3, Train striking car free to roll Format (I5)
VI = Impact Velocity (in./s or m/s) Format (F10.5)
RF = Resistance force (lb or N) Format (F10.5)
NTS = Number of time steps desired Format (I5)
DT = Uniform integration time increment (s) Format (F10.5)
IOPT (1) = Printout interval desired (Number of Time Steps
 between printout) Format (I5)
IOPT (2) . . . IOPT (6) Leave blank

Cards 3,4 x (I), I = 1, 2, . . . 11

x (I) = Longitudinal coordinate of mass lumps (in, m)
Format (F10.4)

Cards 5,6 y (I), I = 1, 2, . . . 11

y (I) = Vertical coordinate of mass lumps (in, m)
Format (F10.4)

Cards 7,8 w (I), I = 1, 2, . . . 11

w (I) = Lumped weights (lb, N) Format (E12.6)

Cards 9,10 I (I), I = 1,2, . . . 11*

I (I) = Lumped weight moments of inertia (lb-in.², N-m³)
Format (E12.6)

* Note: I (11) is not used and may be left blank.

Card 11 A12, A23, A34, A45, A56, A67, A89, A910

A's = Cross-section areas of members (in.², m²)
Format (F10.4)

Card 12 I12, I23, I34, I45, I56, I67, I89, I910

I's = Cross-section moments of inertia of members (in.⁴, m⁴)
Format (F10.4)

Card 13 Er, Ec, g

Er = Railcar Young's modulus of elasticity (lb/in.²,
N/m²) Format (E12.6)
Ec = Container Young's modulus of elasticity (lb/in.²,
N/m²) Format (E12.6)
g = Acceleration due to gravity (386 in./s²,
9.80665 m/s²) Format (E12.6)

Cards 14,15,16 Leave blank but include

Card 17 C28, C38, C105, C106, C711

C's = Tiedown damping, C711 is coupler damping ($\frac{\text{lb-s}}{\text{in.}}$, $\frac{\text{N-s}}{\text{m}}$)

Format (F10.4)

Card 18 K28, K38, K105, K106

K's = Tiedown axial stiffness (lb/in. N/m) Format (F10.4)

FOURTH Ending Form

[illegible]