22 Southern Pacific Company, "Report on Freight Car Impact Tests," Office of Engineer of Research and Mechanical Standards, Motive Power Dept., San Francisco, Calif., December 31, 1954.
23 Trevisin, R. F., "Sonicar," ASME Paper No. 68-WA/RR-8.
24 Turner, D. L., "Hydraulic Buffers and the Modern Wagon," *British Transport Review IV*, Vol. 3, Dec. 1956, pp. 261–267.
25 Turner, D. L., "Hydraulic Buffers—A New Factor in Wagon Designs," Paper No. 569, *Journal Institute Locomotive Engineers*, pp. 75–100.

# APPENDIX

Case (*a*) $0 \leq t \leq t_0$

$$\ddot{x}_{2C} = P(1-\lambda) + \mu g - \frac{P(1-\lambda)(1-\cos\omega t)m_{2L}}{m_{2L}+m_{2C}} \quad (40)$$

$$\dot{x}_{2C} = \frac{-m_{2L}P(1-\lambda)}{m_{2L}+m_{2C}}\left(t - \frac{1}{\omega}\sin\omega t\right) + t[P(1-\lambda)+\mu g] \quad (41)$$

$$x_{2C} = \frac{m_{2L}P(1-\lambda)(1-\cos\omega t)}{\omega^2(m_{2L}+m_{2C})} + \frac{1}{2}t^2\left[\frac{m_{2C}P(1-\lambda)}{m_{2L}+m_{2C}} + \mu g\right] \quad (42)$$

At $t = t_0$, $x_{2C} = x_{2C0}$

$$\ddot{x}_{2C0} = \frac{\mu g m_{2L}}{m_{2C}} + \frac{F_C(m_{2C}-m_{2L})}{m_{2C}(m_{2L}+m_{2C})} \quad (43)$$

$$\dot{x}_{2C0} = F_C t_0/(m_{2L}+m_{2C}) \quad (44)$$

$$x_{2C0} = \frac{2F_C t_0^2}{m_{2C}(m_{2L}+m_{2C})}\left(\frac{m_{2L}}{\pi^2} + \frac{m_{2C}}{4}\right) - \frac{2}{\pi^2}\mu g\frac{m_{2L}}{m_{2C}}t_0^2 \quad (45)$$

Case (*b*) $t_0 \leq t \leq T$

$$\left.\begin{aligned}\ddot{x}_1 &= -F_C/m_1\\ \dot{x}_1 &= V - F_C t/m_1\\ x_1 &= Vt - F_C t^2/2m_1\end{aligned}\right\} \quad (46)$$

$$\ddot{x}_{2C} = \frac{F_C}{m_{2L}+m_{2C}} \quad (47)$$

$$\dot{x}_{2C} = \frac{F_C t}{m_{2L}+m_{2C}} \quad (48)$$

$$x_{2C} = \frac{F_C(t^2-t_0^2)}{2(m_{2L}+m_{2C})} + x_{2C0} \quad (49)$$

# DISCUSSION

## H. T. Hastings[2]

This analysis could be a very useful tool to the industry in the development of cushioned underframe designs to give adequate lading protection to known fragile commodities. A good example of the type of lading referred to would be rolls of newsprint end-loaded and double-tiered from end to end of a 60-ft box car.

Core damage is prevalent in this type of load which is a result of end-wall forces during impacts. Using Dr. Freudenstein's derivation, one of the cushioned underframe producing companies could conceivably solve one of the railroads' more perplexing lading damage problems by developing a device, or an adaptation of an existing device, oriented to a specific commodity.

Dr. Freudenstein is to be commended on this work and it is hoped the industry will put his derivation to good use.

[2] Seaboard Coastline R.R. Co., Jacksonville, Fla.

## W. P. Manos[3]

The author claims that the analysis departs from prior art in that (*a*) the ability to predict peak lading force as a function of readily measured design parameters, and (*b*) the inclusion of Coulomb damping. On April 25–26, 1963, a paper (63-RR-3) was presented in Atlanta wherein Coulomb friction was included in the analysis. The same expression for end-wall force versus cushion force was derived and correlated with experimental results.

The author applied equation (3) to experimental results pre-

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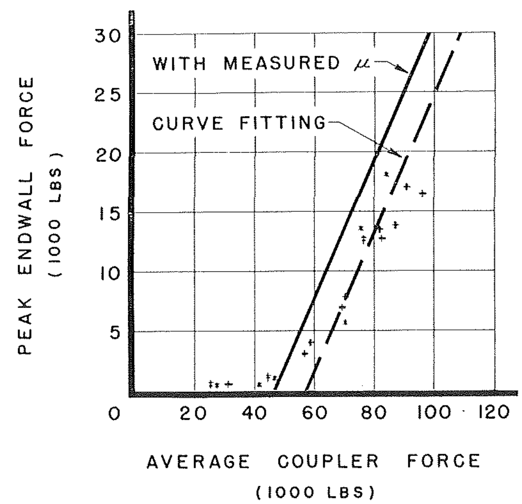
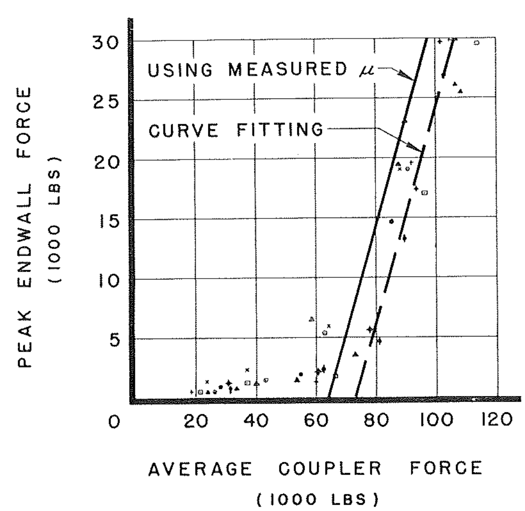



PEAK ENDWALL FORCE vs AVE. COUPLER FORCE

31,000 LB. CARTON LOAD
77,000 LB. BODY WEIGHT

Fig. 9




PEAK ENDWALL FORCE vs AVE. COUPLER FORCE

77,000 LB. CARTON LOAD
77,000 LB. BODY WEIGHT

Fig. 10

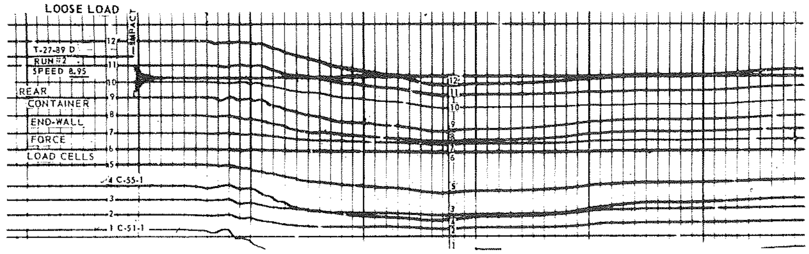



Fig. 11

sented in reference [14] and he obtained good correlation. However, this was a curve-fitting process because no friction coefficients were given. We have found that when measured friction coefficients are used equation (3) predicts higher values of end-wall force. (See Figs. 9 and 10). Typical measured values of friction coefficients for cardboard cartons sliding on cardboard are .43 to .45 static and .34 to .38 sliding.

Under impact conditions the car pitches, which reduces the floor friction forces on the cartons closer to the end-wall and increases floor forces at the opposite end. This tends to reduce the in-phase relationship of column compression. Lading looseness also affects end-wall force. Increasing lading looseness reduces end-wall force. These effects can be seen from Fig. 11. In this regard the effective mass and spring coefficients based on the fundamental mode of a continuum model are questionable.

## Author's Closure

With regard to the points raised in the discussion of Dr. W. P. Manos, the following comments are offered:

(1) ASME Paper 63-RR-3, reference to which is appreciated. This paper, entitled "Performance Tests of Long-Travel Cushion Underframes," by W. Van der Sluys, W. P. Manos, and M. G. Marshall, can be found in "ASME Miscellaneous Papers," Vol. 7T, 1963, available at the Engineering Societies Library, at the United Engineering Center in New York City.

The analysis given in paper 63-RR-3, of which I had been unaware, seems to me to be quite different in nature and scope from the present one, as the interested reader can verify for himself. I am happy to acknowledge that sliding friction was used in the analysis and that equations (27) and (28) of 66-RR-3 could be combined to yield equation (3) of the present analysis. In order to do so, it is necessary to assign a numerical value to a factor, $\alpha$, defined in 66-RR-3. The value of $\alpha$ is given in 66-RR-3 as 1.25 on the basis of experimental evidence. To obtain equation (3) from (27, 28), it is necessary to set the value of $\alpha$ at 2.

(2) The curves of the present paper were plotted for several values of the coefficients of friction. The range chosen was based largely on measured values reported in reference [10A]. The curves are not the result of a curve-fitting procedure. The conservative nature of the results based on equation (3), as reported by the discusser, was noted in the paper in the section on "Discussion of Results."

(3) The basic equations of the present paper were derived for a general system (Case A) and for a lumped-parameter system (Case B). The results, as shown, are modified little when allowance is made for the mass distribution of the lading (Case C). The results, therefore, are not restricted to correspond to the fundamental mode of a continuum model. The discusser rightly points out, however, some of the many factors which tend to complicate the problem of loading damage.

The comments of Mr. H. T. Hastings are sincerely appreciated.