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COLLAPSE CHARACTERISTICS OF CYLINDRICAL PIPES UNDER AXIAL COMPRESSION

By

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ABSTRACT

Cylindrical pipes can be regarded as the modeled members of automobile body structures. In this paper, collapse characteristics of the cylindrical pipes are studied in order to reduce the injuries caused by car crashes. Effects of the end restriction of pipes are analyzed in the static condition, and it is made clear that energy absorbability is much affected by the end condition especially in the short members. Moreover, dynamic tests are carried out and the results show the linear relation between mean collapse load and logarithmic strain rate.

§ 1. Introduction

In order to reduce the injuries caused by car crashes, we have to control the crashworthiness of automobile body structures(1)(2). Cylindrical pipes can be regarded as the modeled members of automobile body structures. In this paper, the collapse characteristics of the cylindrical pipes are studied on the following two points.

(1) Effects of end conditions of pipes.
(2) Linearity between dynamic collapse load and logarithmic impact velocity.

The former is studied theoretically and experimentally on the static characteristics, and the latter is studied experimentally.

§ 2. Principal nomenclature

D: diameter of pipe,
E: Young's modulus,

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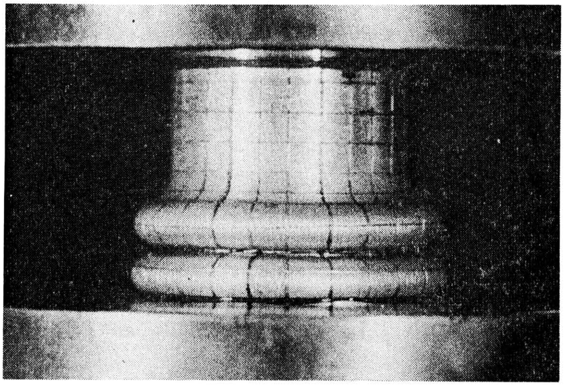

Fig. 1. Collapse of cylindrical pipe

h : length of collapse mode,
K: coefficient of absorbed energy at the end by the plate bending,
k (with suffixes): non-dimensional values which are concerned with K value,
$M=Yt^2/2\sqrt{3}$,
n : ratio of increment of pipe diameter to collapse mode length,
P: mean collapse load, t: thickness of pipe,
U: absorbed energy, v: mean crash velocity, Y: yield stress,
α, β: angle of pipe wall, ε_1: strain,
λ : displacement of collapse per unit collapse mode.

§ 3. Effects of end restriction

3.1 Essential assumptions and analytical model

(1) The deformation of the cylindrical pipe is shown in Fig. 1 and it is idealized and modeled as shown in Fig. 2.

(2) Constant K depending on end conditions is defined as follows.

K=(Actually absorbed energy by the plate bending at the end)/(Ideally absorbable bending energy at the end when the end is supported rigidly). When

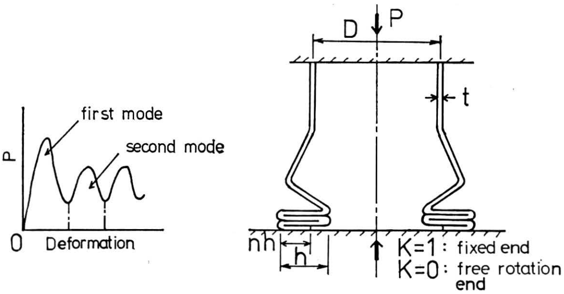

Fig. 2. Analytical model of deformed cylindrical pipe

$K=0$, the edge rotation of the end is not restrained, and the value of absorbed energy by the plate bending at the end is zero in this case. When $K=1$, the edge rotation of the end is supposed to be perfectly restrained, and the cylindrical plate at the end absorbs energy by the plate bending perfectly.

(3) It is assumed that the material is the rigid-plastic material and the method of limit-analysis can be applied.

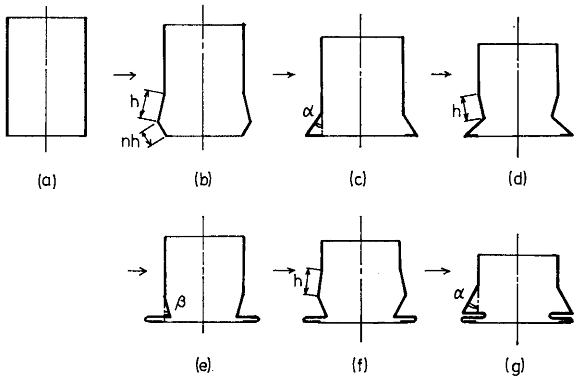

Fig. 3. Collapse mode

3.2 Calculation of energy

Absorbed energy is calculated for next two modes of collapse. The first mode is shown in Fig. 3 (a)-(c) and the second mode is shown in (c)-(g). Absorbed energy of the first mode by the plate bending is

$$U_1=K\pi DM(\pi/2)+\pi DM[(\pi/2)+\alpha]+\pi DM\alpha\,, \qquad (1)$$

and by the membrane strain is

$$U_2\fallingdotseq Y\pi h^2t(n+n^2)\,. \qquad (2)$$

Energy of the stages (c)-(e) of the second mode by the bending is

$$U_3=\pi MD[(\pi/2)-\alpha]+\pi MD[(\pi-\alpha)+(\beta-\pi/2)]+\pi MD\beta\,, \qquad (3)$$

and by the membrane strain is

$$U_4\fallingdotseq 2Y\pi h^2t(1-n)\,. \qquad (4)$$

Energy of the stages (e)-(g) by the bending is

$$U_5=\pi MD[(\pi/2)-\beta]+\pi MD[(\pi-\beta)+(\alpha-\pi/2)]+\pi MD\alpha\,, \qquad (5)$$

and by the membrane strain is

$$U_6\fallingdotseq 2Y\pi h^2tn\,. \qquad (6)$$

From Eqs. (1)-(6), n and h can be calculated under the condition of minimum energy. Defining

$$f(n,h)=\sqrt{2\lambda}P/(\pi tY)\,, \qquad (7)$$

then

$$f(n,h)=\frac{Dt(2n+K+1)}{\sqrt{3}h\sqrt{n+n^2}}+2h\sqrt{h}\,\sqrt{n+n^2}\,. \tag{8}$$

The conditions for extremum are as follows.

$$\frac{\partial f}{\partial h}=-\frac{Dt(2n+K+1)}{2\sqrt{3}\,\sqrt{n+n^2}}h^{-3/2}+3\sqrt{n+n^2}\,h^{1/2}=0, \tag{9}$$

$$\frac{\partial f}{\partial n}=\frac{-\frac{Dt}{\sqrt{3h}}\left(nK+\frac{K+1}{2}\right)+h^{3/2}\ (2n^3+3n^2+n)}{(n+n^2)^{3/2}}=0. \tag{10}$$

Consequently,

$$n=\frac{K-1+\sqrt{K^2+3}}{2}, \tag{11}$$

$$h=[(\sqrt{K^2+3}-K)Dt/(3\sqrt{3})]^{1/2}\equiv k_h\sqrt{Dt}\,. \tag{12}$$

From Eqs. (1)-(12), for the first mode,

$$U_{\mathrm{I}}=k_{U\mathrm{I}}\ (YDt^2), \tag{13}$$

$$\lambda_{\mathrm{I}}=k_{\lambda\mathrm{I}}\sqrt{Dt}, \tag{14}$$

$$P_{\mathrm{I}}=k_{P\mathrm{I}}\ (Y\sqrt{Dt^3}). \tag{15}$$

And for the second mode,

$$U_{\mathrm{II}}=k_{U\mathrm{II}}\ (YDt^2), \tag{16}$$

$$\lambda_{\mathrm{II}}=k_{\lambda\mathrm{II}}\sqrt{Dt}, \tag{17}$$

$$P_{\mathrm{II}}=k_{P\mathrm{II}}\ (Y\sqrt{Dt^3}), \tag{18}$$

where $U_{\mathrm{I}}=U_1+U_2$, $U_{\mathrm{II}}=U_3+U_4+U_5+U_6$. λ_{I} and λ_{II} are the displacements of collapse per first and second mode. P_{I} and P_{II} are the mean collapse loads per first and second mode. And k_U, k_λ, k_P, k_h, with suffix I or II are non-dimensional values and are the functions of end conditions. Detail is abridged because of these complex forms. The final results of these non-dimensional values are shown in the next paragraph with the experimental values.

3.3 Results of calculations and experiments

Experiments were carried out for alminum cylindrical pipes in the static condition. Young's modulus of the material is 7290 kgf/mm^2, and 0.2% proof stress is 34 kgf/mm^2. For the experiments of pipes with fixed ends, pipe ends are inserted into the gutters. On the other hand, for the experiments of pipes with free rotation ends, carbon annexed lubricant was applied at the ends which are on the rigid flat plates.

Figure 4 shows the examples of the load displacement curves. Figures 5-7 show the correspondence between the calculated and the experimental value.

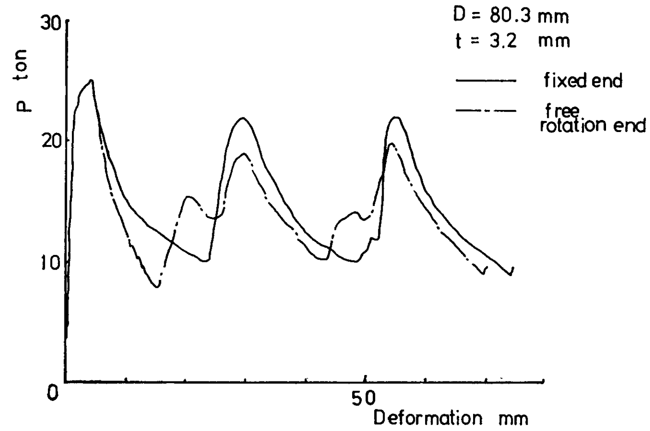

Fig. 4. Examples of load deformation curve

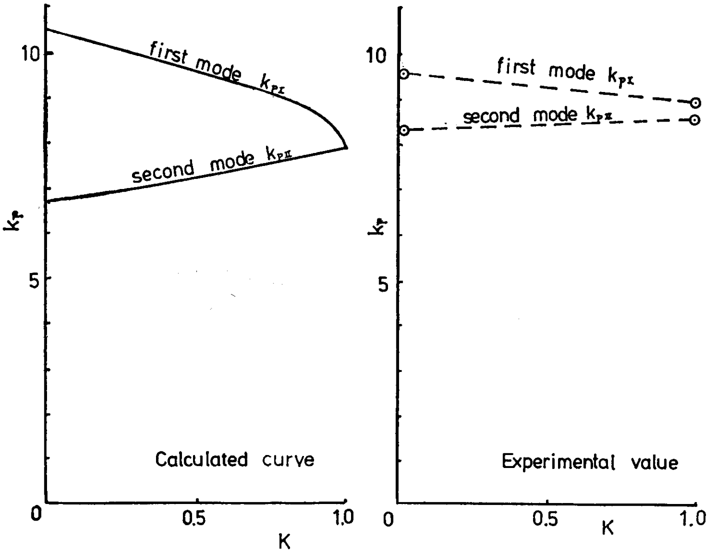

Fig. 5. Relation between k_p and K (k_p: nondimensional value which is proportional to mean collapse load P, suffixes I and II: values of first and second mode, K: coefficient of absorbed energy at the end by the plate bending)

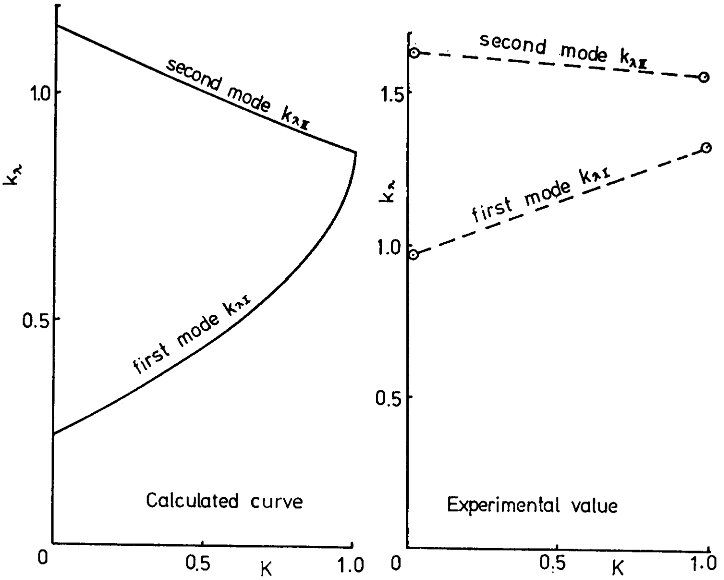

Fig. 6. Relation between k_λ and K (k_λ: nondimensional value which is proportional to displacement, suffixes I and II: values of first and second mode, K: coefficient of absorbed energy at the end by the plate bending)

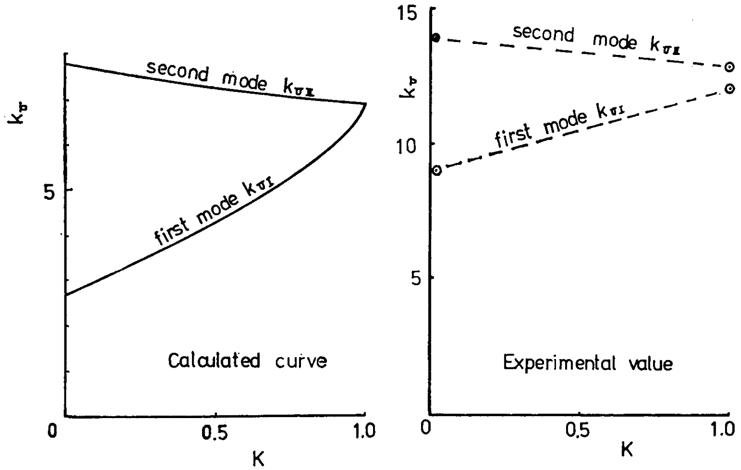

Fig. 7. Relation between k_U: and K (k_U: nondimensional value which is proportional to absorbed energy U, suffixes I and II: values of first and second mode, K: coefficient of absorbed energy at the end by the plate bending)

§ 4. Linear relation between dynamic collapse load and logarithmic impact velocity

Strain rate $\dot{\varepsilon}$ can be defined as ε_1/T, where ε_1 is the membrane strain of the pipe spread out in the one collapse mode and T is the duration time of one mode collapse with the constant velocity v_0. Membrane strain ε_1 and duration time T can be denoted as follows, $\varepsilon_1 \propto h/D$, $T \propto h/v_0$. Hence, $\dot{\varepsilon}=\varepsilon_1/T \propto (h/D)/(h/v_0)=v_0/D$. Figure 8 shows the relation between mean collapse load and above mentioned value v_0/D which is in proportion to strain rate $\dot{\varepsilon}$. An abscissa of this figure is denoted on a log scale. In this figure, for the results by the dropping hammer tester, initial impact velocities were multiplied by 0.8 for the compensation of speed changes(8). For the low speed tests by the Amsler tester, compensation is unnecessary. This figure shows the linear relation between the mean collapse load and the logarithmic strain rate. Because of the logarithmic scale, the impact collapse load can be deduced even in the high speed range. When the impact velocity is 20 km/hr, the dynamic collapse load is about 1.25 times as large as the static load, and is about 1.3 times when the velocity is 80 km/hr.

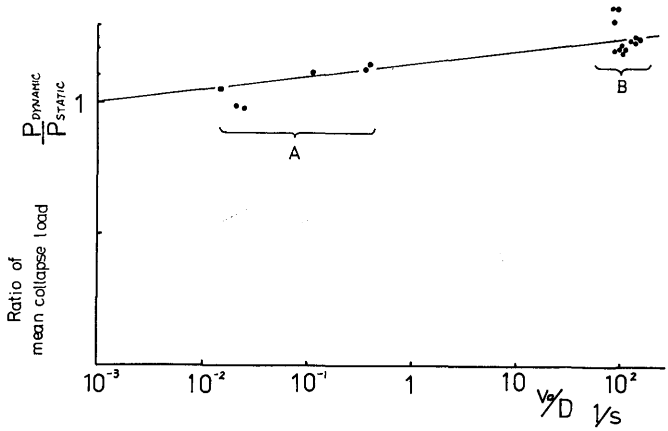

Fig. 8. Relation between ratio of mean collapse lead $P_{dynamic}/P_{static}$ and v_0/D (v_0: mean crash velocity, D: diameter of pipe, A—low speed test by the Amsler tester, B—high speed test by the dropping hammer tester)

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REFERENCES

(1) MIURA, KAWAMURA (1968): An Analysis of a Deformation Mechanics in Head-on Collision, *Journal of the Society of Automotive Engineers of Japan Inc.* (*in Japanese*), 22, No. 10, pp. 927-931.

(2) TANI, FUNABASHI (1976 Autumn): Energy Absorption by Plastic Deformation of Car Body Members, *Preprinting of the Society of Automotive Engineers of Japan Inc.* (*in Japanese*), pp. 645-654.

(3) MISAKA, YOSHIMOTO (1967): Formularization of Mean Resistance to Deformation of Plane Carbon Steels at Elevated Temperature, *Journal of Japan Society for Technology of Plasticity* (*in Japanese*), 8, No. 79, pp. 414-422.