Calculation of cylinder buckling

1) Be sure to calculate the cylinder buckling.

2) In the case of using a hydraulic cylinder, the stress and buckling must be considered depending on the cylinder stroke.
The strength in the case that the piston rod is regarded as a long column, the buckling strength, cannot be enhanced by adopting highly tension-proof steel or heat treatment. The only way to improve the buckling strength of a cylinder is to widen the piston rod dia., and therefore, the selection of the piston rod is the very important point.
The buckling chart shown in the next page, based on the Euler's equation that is applicable to an upright long column, indicates the maximum safe L values against the piston rod dia. when the cylinder is used with the compressive load that is most frequently applied.

3) When buckling occurs to a cylinder, the cylinder rod may be bent, causing malfunctions or serious accidents.

Calculation method of cylinder buckling (use of buckling chart)

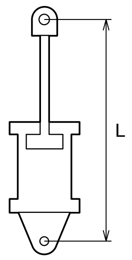
1. Find the L value (distance between the cylinder mounting position and load mounting position) with a cylinder fully extended.
2. Select any buckling chart depending on the mounting style, and find the maximum working load.

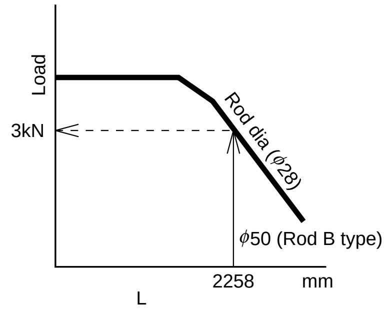
< Exercise >

Find the maximum working load for the 210C-1, ϕ50, rod B (rod dia. ϕ28), in case that the stroke is 1000 mm, CA type with the rod end eye.

< Answer >

1. Find the L value with the cylinder fully extended. From the dimensional drawings in this catalogue, the L value can be calculated by the formula below.
L = 242 + 80 + 1000 + 1000 = 2322 mm
2. From the buckling chart of the both ends pin joints, the load can be found as below.
W = 3 kN (≒ 306 kgf)



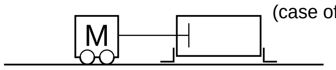


Notes on piston rod buckling

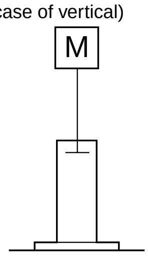
Prior to the calculation of the piston rod buckling, consider the cylinder stopping method. The stopping methods of a cylinder include the cylinder stopping method, in which a cylinder is stopped at the stroke end, and the external stopping method, in which a cylinder is stopped with the external stopper. The definition of load differs depending on the selection of the stopping method as shown below.

- Definition of a load when the cylinder stopping method is selected

In the case of ❷
(case of horizontal)



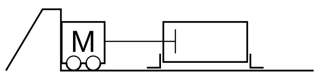
In the case of ❶
(case of vertical)

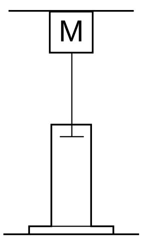


The state of stopping at the cylinder stroke end as shown in the figure.
For the load required for the buckling calculation, apply the formula below.

In the case of ❶ : load = M·g
In the case of ❷ : load = μ M·g
μ : frictional coefficient of load
g : gravity acceleration 9.8 m/s²
M : load weight (kg)

- Definition of a load when the cylinder stopping method is selected





The state of halfway stopping with the external stopper as shown in the figure.
The load required for the buckling calculation in this case is not the M, but the cylinder theoretical output (Relief set pressure MPa × Piston area mm²).

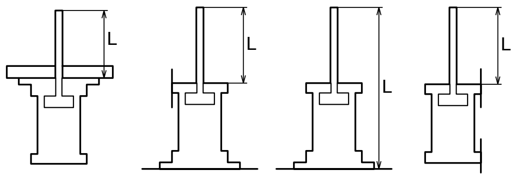
Rod diameter list

Unit: mm

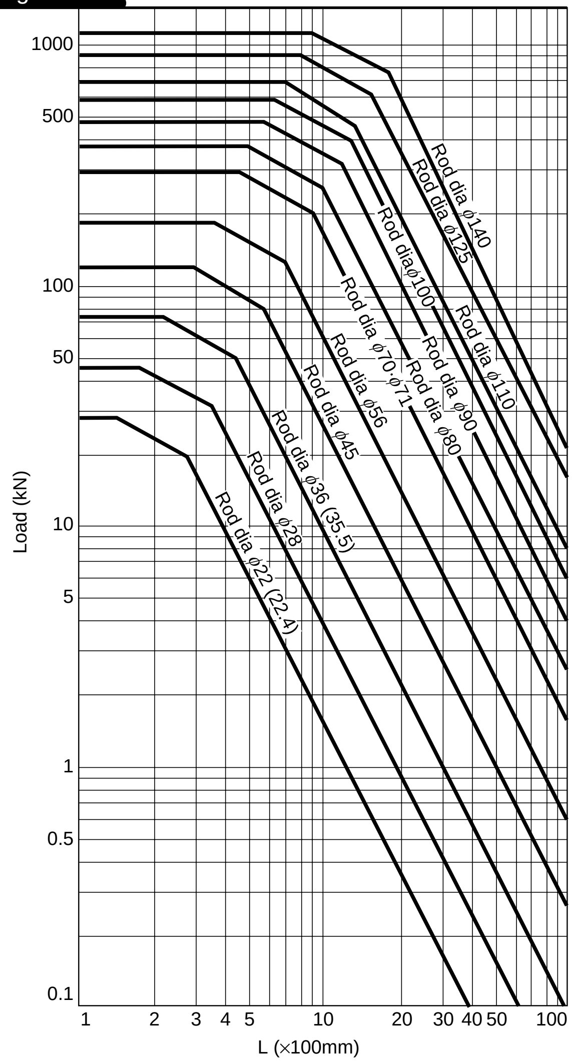
Series name \ Cylinder bore	ϕ40	ϕ50	ϕ63	ϕ80	ϕ100	ϕ125	ϕ140	ϕ150	ϕ160	ϕ180	ϕ200	ϕ224	ϕ250
210C-1 Rod B	ϕ22	ϕ28	ϕ36	ϕ45	ϕ56	ϕ70	ϕ80	–	ϕ90	ϕ100	ϕ110	ϕ125	ϕ140
210C-1 Rod A	ϕ28	ϕ36	ϕ45	ϕ56	ϕ70	ϕ90	ϕ100	–	ϕ110	–	–	–	–

Buckling chart by cylinder mounting style

Fixed cylinder, rod end free

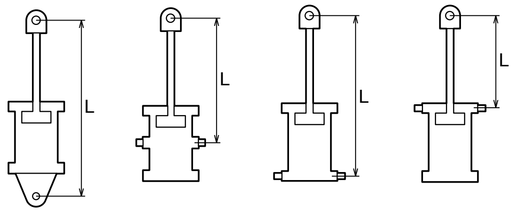


Buckling chart

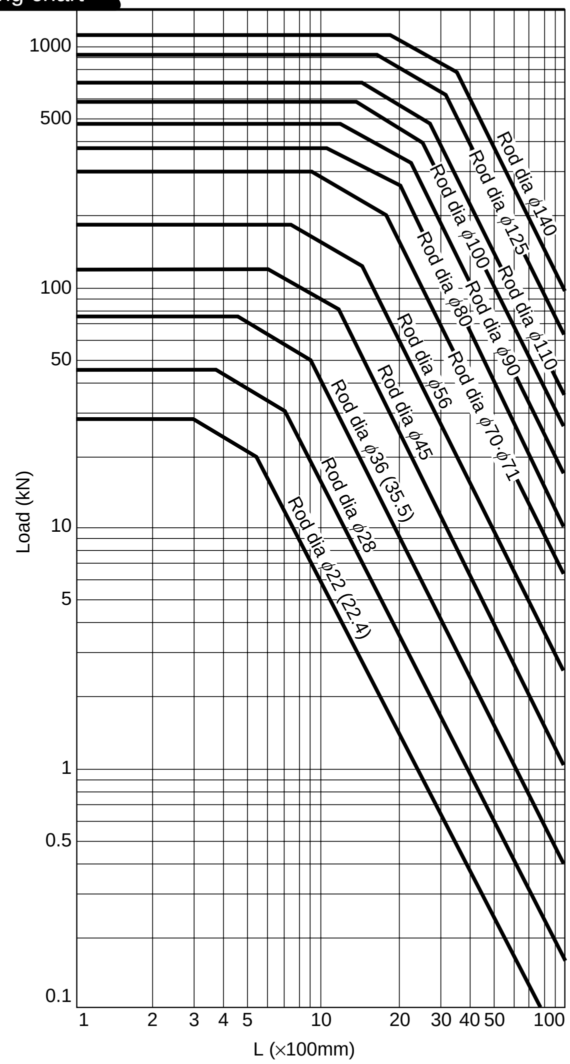


Buckling chart by cylinder mounting style

Both ends pin joints

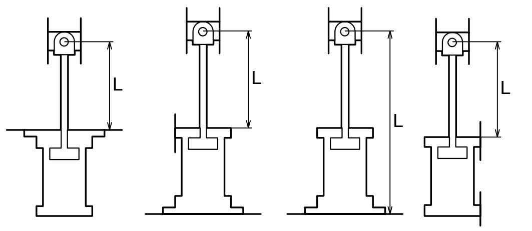


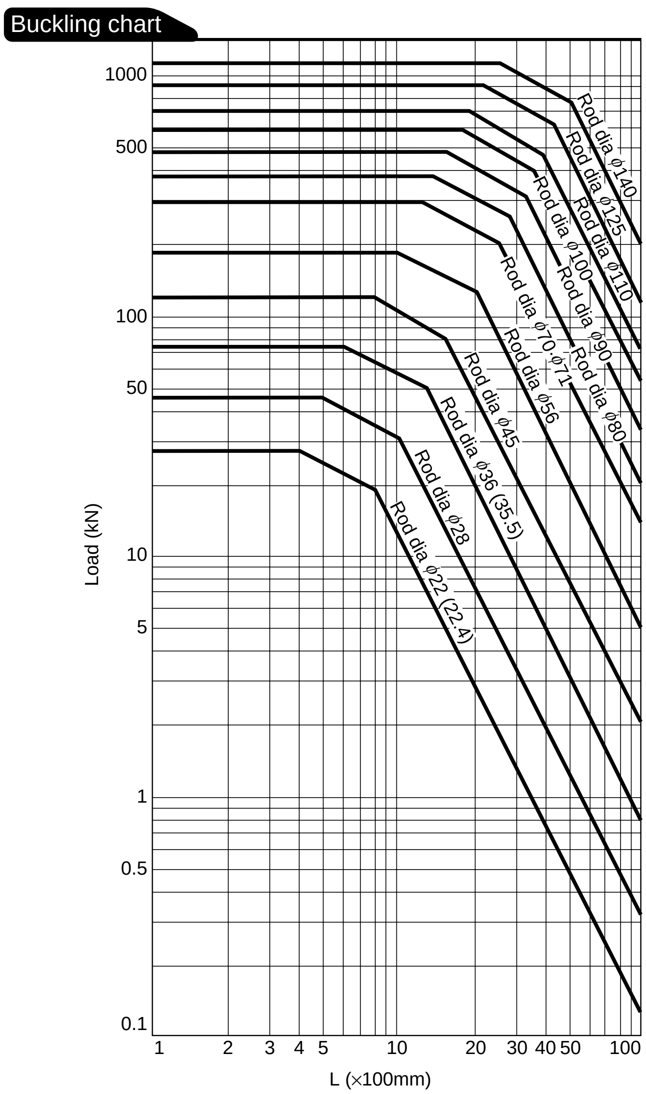
Buckling chart



Buckling chart by cylinder mounting style

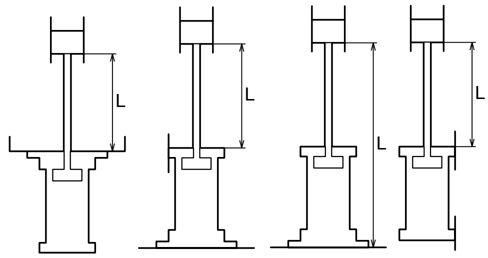
Fixed cylinder, rod end pin joint

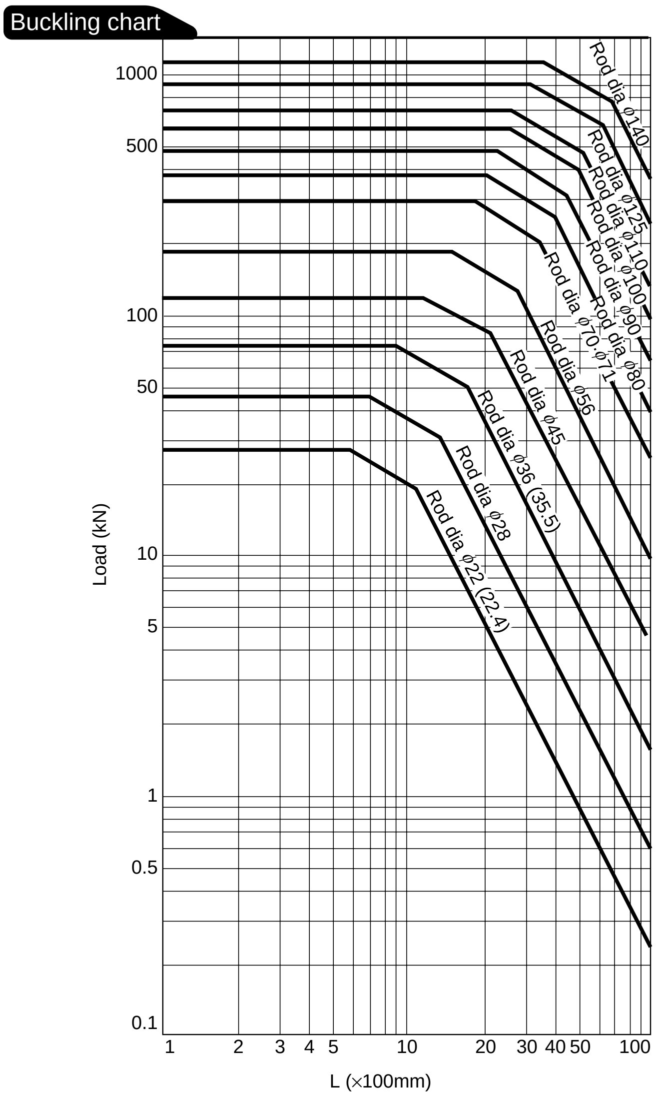




Buckling chart by cylinder mounting style

Fixed cylinder, rod end guide





Maximum energy absorbed of cylinder cushion

The conditions of absorbed energy allowable for the cylinder cushion can be obtained from the formula below.

Inertia energy of load at the inrush into cushion E_1
+
Energy generated by the external force applied to the cylinder at the inrush into cushion E_2
≦
Maximum energy absorbed of the cylinder cushion E_t

The procedures to find each item above are shown below.

Find the inertia energy of load at the inrush into cushion, E_1.

In the case of linear movement:

$E_1 = MV^2/2$ (J) M : load weight (kg)

V : load speed at the inrush into cushion (m/s)

In the case of rotation movement:

$E_1 = I\omega^2/2$ (J) I : inertia moment of load (kg • m²)

ω : angular velocity of load at the inrush into cushion (rads)

Notes: If the cylinder speed is less than 0.08 m/s (80 mm/s), the cushioning effect is weakened.
Even if the cylinder speed is less than 0.08 m/s (80 mm/s), suppose it is 0.08 m/s to find the E_1.
In the case of rotation movement, even when the cylinder speed is 0.08 m/s or lower, similarly suppose it is 0.08 m/s, and calculate the angular velocity ω to find the E_1.

↓

Find the energy generated by the external force applied to the cylinder at the inrush into cushion, E_2.

The forces acting in the direction of the cylinder axis at the inrush into cushion are shown below.

- The force applied to the cylinder by the gravity of load
- The force applied by other cylinders
- The force applied to the cylinder by springs

Find the external force F, which is applied to the cylinder at the inrush into cushion, and the energy E_2 by using the "Chart of conversion of external force into energy at the inrush into cushion".
In case that such an external force is not applied, the following condition is satisfied: $E_2 = 0$.
For the selection of cushion, suppose that the frictional resistance of load is 0.

↓

Find the maximum energy absorbed of the cylinder cushion, E_t.
Find it with the corresponding chart of the "Maximum energy absorbed".
The maximum absorbed enegy indicated on the graph can be applied for both directions.(forward/backward)

↓

Ensure that $E_1 + E_2$ is same as the maximum energy absorbed E_t, or smaller.
If the following condition is satisfied, the cylinder is applicable: $E_1 + E_2 \leqq E_t$.
If the following condition is satisfied, the cylinder is inapplicable: $E_1 + E_2 > E_t$.
In such a case, perform the steps below, and then, select again.

- Decrease the inertia force of load.
- Decrease the external force applied to the cylinder.
- Lower the set pressure.
- Widen the cylinder bore.
- Install a shock absorber.

When installing a shock absorber, refer to the "TAIYO Shock absorber general catalogue".
DO NOT use the cylinder cushion together with a shock absorber.
Otherwise, the inertia force of load may be applied to either of them due to the difference of cushioning characteristics.

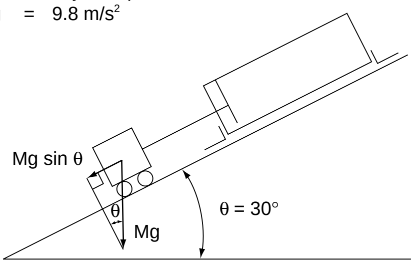
⚠ CAUTION

Be sure to use cylinders within the range of the maximum energy absorbed of the cylinder cushion.
Otherwise, the cylinder or the peripheral devices may be damaged, leading to serious accidents.

Example of calculation for selection

< Example 1 >

Cylinder	210C-1 rod B φ63
Set pressure	P_1 = 10 MPa
Load weight	M = 900 kg
Load speed	V = 0.3 m/s (the speed at the inrush into cushion is 300 mm/s)
Load moving direction	Downward θ = 30° (there is no external force applied to the cylinder other than gravity)
Working direction	Forward (the direction of the piston rod ejected from the cylinder)
Gravitational acceleration	g = 9.8 m/s²

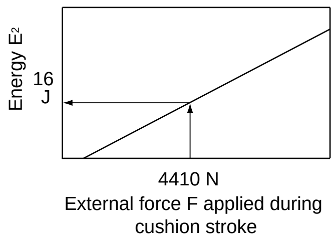


< Answer >

1. Find the inertia energy of load at the inrush into cushion, E_1.
   Inertia energy in the case of linear movement, E_1
   $E_1 = MV^2/2 = 900 \times 0.3^2/2 = 40.5$J

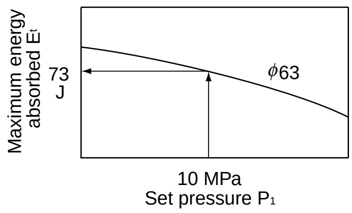
2. Find the E_2, energy generated by the external force F, applied to the cylinder at the inrush into cushion.
   2.1 Find the external force F, applied in the direction of the cylinder axis at the inrush into cushion.
   F = Mgsin θ = 900 × 9.8 × sin30° = 4410N

   2.2 Convert the external force F, found in the step 2.1, into the energy E_2. In the "Chart of conversion of external force into energy at the inrush into cushion of 100H-2", find the cross point of the straight line from the point of 2450 N on the lateral axis F and the slant line shown in the chart. Then, draw a straight line from the cross point on the slant line parallel with the lateral axis until it reaches the longitudinal axis of the chart. The cross point 7.5 J, indicates the energy applied by the external force.



   $E_2 = 16$J

3. Find the maximum energy absorbed of the cylinder, E_t.
   In the right chart, find the cross point of the straight line from the point of 010 MPa on the lateral axis, the set pressure of the "Maximum energy absorbed of cushion" of the 100H-2 and the curve of φ63. Then, draw a straight line from the cross point on the curve parallel with the lateral axis until it reaches the longitudinal axis of the chart. The cross point, 62 J, indicates the maximum energy absorbed.



   $E_t = 73$J

4. Ensure that $E_1 + E_2$ is same as the maximum energy absorbed E_t, or smaller.
   $E_1 + E_2 = 40.5 + 16 = 56.5$J
   where, $E_t = 73$J
   Therefore, the following condition is satisfied: $E_1 + E_2 \leqq E_t$.
   As a result, the cylinder is applicable.

< Reference >

In case that the load moving direction is horizontal and there is no external force applied ($E_2 = 0$), from the set pressure, first find the maximum energy absorbed, E_t. Then, the allowable load weight and allowable load speed can be found.

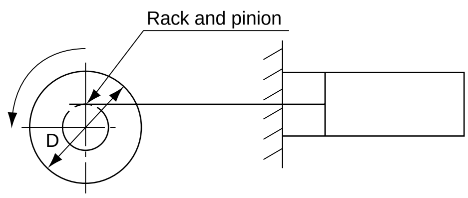
To find the allowable load weight, M : $M = 2E_t/V^2$

To find the allowable load speed, V : $V = \sqrt{2E_t/M}$

< Example 2 >

Cylinder	210C-1 rod B ϕ63
Set pressure	P_1 = 10 MPa
Load weight	M = 900 kg
Load dia.	D = 0.7 m (Uniform disk)
Angular velocity of load	ω = 1.5 rad/s (angular speed at the inrush into cushion)
Load moving direction	Horizontal (without external force applied to the cylinder)
Working direction	Forward (the direction of the piston rod ejected from the cylinder)

The weight of the rack and pinion is so light that it can be ignored.



< Answer >

1. Find the inertia energy of a load at the inrush into cushion, E_1.
   1.1 Find the inertia moment of a load, I.

   From the inertia moment calculation table, the I can be calculated as below.
   $I = MD^2/8 = 900 \times 0.7^2/8 = 55.1(kg \cdot m^2)$

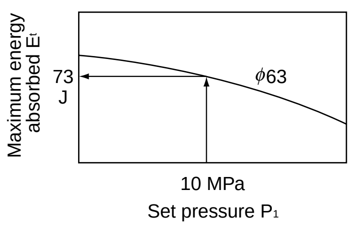
   1.2 Find the inertia energy of a load, E_1.
   $E_1 = I\omega^2/2 = 55.1 \times 1.5^2/2 = 62.0J$

2. Find the energy generated by the external force applied to the cylinder at the inrush into cushion, E_2.

   $E_2 = 0$, since there is no external force generated from the gravity of a load.

3. Find the maximum energy absorbed of the cylinder, E_t.
   In the right chart, find the cross point of the straight line from the point of 8 MPa on the lateral axis, the supply pressure of the "maximum energy absorbed of cushion" of the 210C-1 and the curve of ϕ63 bore. Then, draw a straight line from the cross point on the curve parallel with the lateral axis until it reaches the longitudinal axis of the chart. The cross point 40 J, indicates the maximum energy absorbed.

   $E_t = 73J$



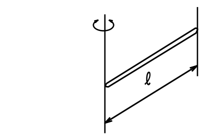
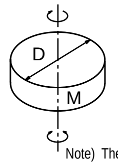
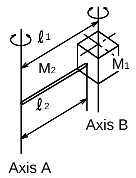
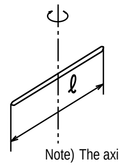
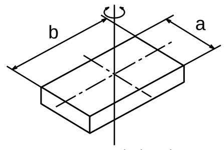
4. Ensure that $E_1 + E_2$ is same as the maximum energy absorbed, Et, or smaller.

   $E_1 + E_2 = 62.0 + 0 = 62.0$ J
   where, $E_t = 73J$
   Therefore, the following condition is satisfied: $E_1 + E_2 \leqq E_t$.
   As a result, the cylinder is applicable.

Note: Even if the cylinder speed is less than 0.08 m/s (80 mm/s), suppose it is 0.08 m/s, and find the angular velocity for calculation.

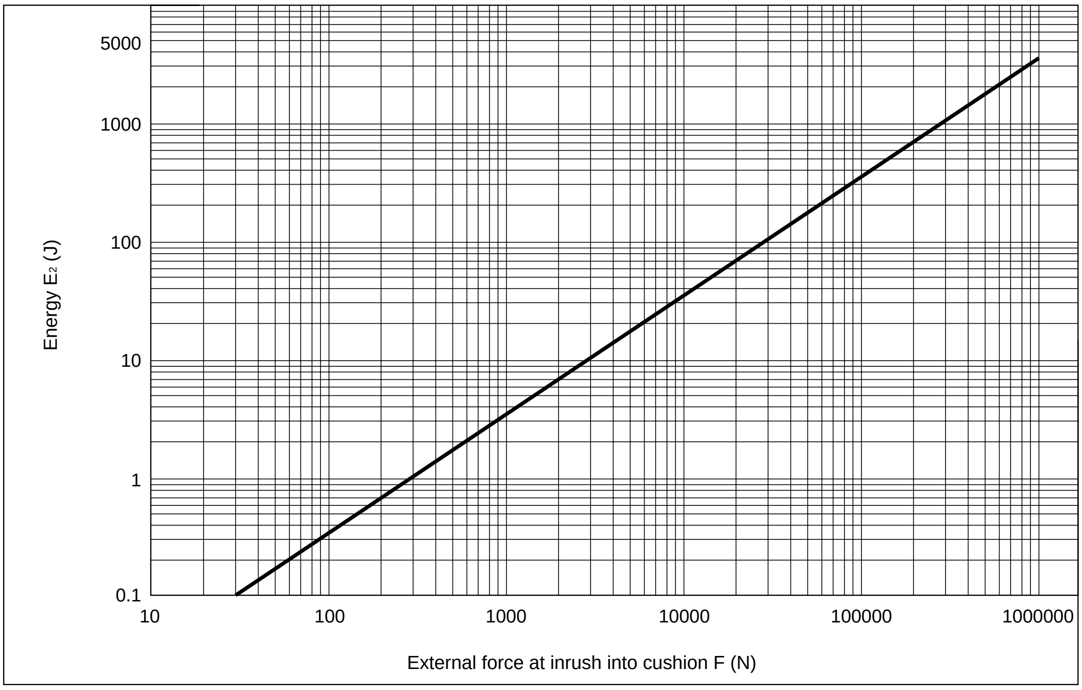
< Reference >
In case of the rotation movement, of which load moving direction is horizontal, without an external force ($E_2 = 0$), from the set pressure, first find the maximum energy absorbed, E_t. Then, the allowable inertia moment and allowable load angular velocity can be found.
To find the allowable load inertia moment, $I = 2E_t/\omega^2$
To find the allowable load angular velocity, $\omega = \sqrt{2E_t/I}$

Inertia moment calculation table

Outline	I: Inertia moment
● In the case of the axis at rod end 	$I = \frac{M\ell^2}{3}$
● In the case of a cylinder (including a disk)  Note) The axis passes through the center of gravity.	$I = \frac{MD^2}{8}$
● In the case of an arm (rotated around the axis A)  M_1: Weight of a weight M_2: Weight of an arm ℓ_1: Distance from the axis A to the center of a weight ℓ_2: Arm length	$I = M_1\ell_1^2 + I_1 + \frac{M_2\ell_2^2}{3}$ I_1: The inertia moment of a weight when the axis passing through the center of the gravity of the weight (axis B) is the center.
● In the case of the axis in the middle of rod  Note) The axis passes through the center of gravity.	$I = \frac{M\ell^2}{12}$
● In the case of a rectangular parallelepiped  Note) The axis passes through the center of gravity.	$I = \frac{M}{12}(a^2+b^2)$

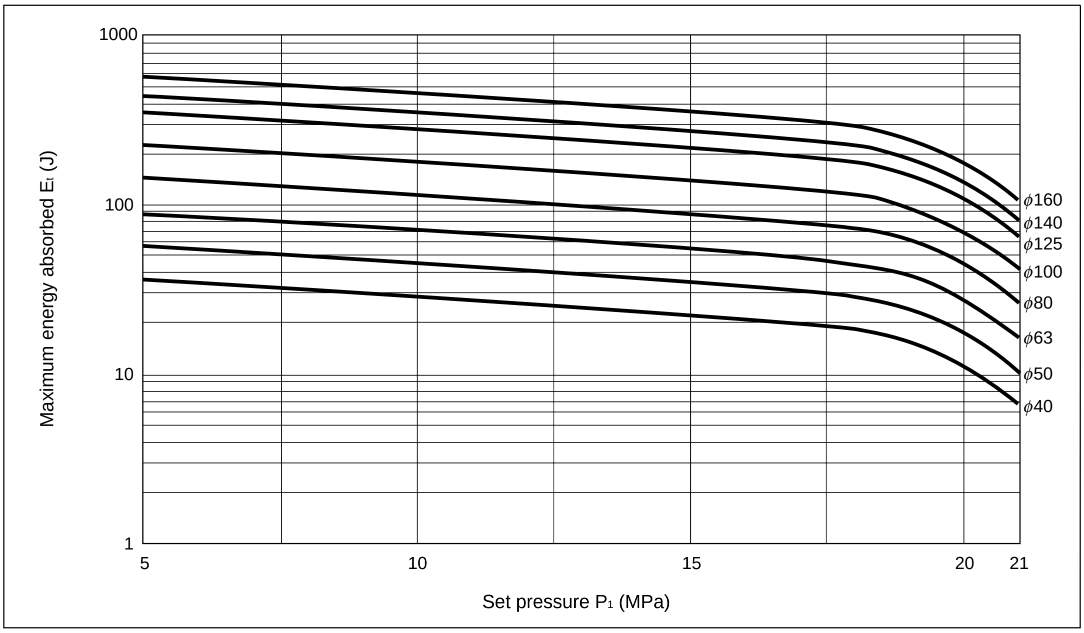
I (I_1): Inertia moment kg・m²
M (M_1, M_2): Weight kg
ℓ, a, b: Length m
D: Diameter m

Chart of conversion of external force into energy at inrush into cushion of 210C-1



210C-1 Rod B Maximum energy absorbed

ϕ40 - ϕ160



210C-1 Rod A Maximum energy absorbed

ϕ40 - ϕ160