Partner for Performance

RINGFEDER

SAP2000®

Application of RINGFEDER® Friction Springs

Instructions and Design Example

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RINGFEDER®
Earthquake Protection

Whether as cross bracing to maximize ultimate loads, as base isolation for decoupling from the foundation, or for shear walls: RINGFEDER® Friction Springs can be applied in buildings and other critical infrastructure as highly effective, maintenance- and wear-free protection system against earthquake damage. Compared to alternatives, e.g., hydraulic dampers, they provide numerous superior advantages.

Advantages of Dampers with RINGFEDER® Friction Springs

1. **Longevity** – Dampers with Friction Springs are designed to endure many load cycles and remain reusable. If one of the rings of a Friction Spring breaks inside a damper, it will lose some spring travel and the stiffness will increase slightly, but it will continue to function.

2. **Damping** – Using RINGFEDER® Standard Grease F-S1, 2/3 of the induced energy will be absorbed. If less damping is required, a customized solution can be used, reducing the damping to 1/3 of the induced energy. This is a simple solution to purposefully modify the characteristics of the damper.

3. **Fire and High Temperature** – Friction Springs are manufactured from special spring steel and lubricated with grease. In the event of fire, rubber products and viscous dampers are destroyed, but Friction Springs will withstand. Only re-greasing is required afterwards and the damper can be used further.

4. **Self-Centering** – Thanks to the custom-made design of dampers with Friction Springs, the optimum restoring force is always achieved for the particular application. This can be realized, for example, by using a different grease, increasing the outer diameter, or changing the taper angle.

5. **Environmental Sustainability** – Dampers with Friction Springs withstand seismic events. They are engineered to endure many load cycles while maintaining their beneficial functionality and performance. Friction Springs are maintenance-free.

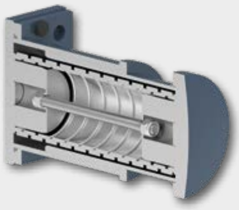
6. **Velocity** – Friction Springs work independently from loading rates and, unlike hydraulic dampers, react in the same way to very slow or very fast occurrences.

7. **Installation Space** – For a given diameter, Friction Springs provide the largest spring forces compared to other spring types.

Industrial Dampers

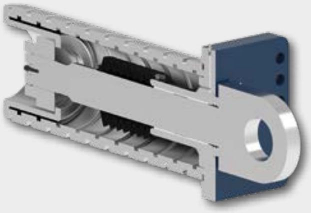
Friction Springs as application-specific damper versions (examples)

Buffer



Push-Pull Unit

Draw Gear



Friction Springs

Complete spring columns consisting of precisely machined inner and outer rings

Design Example with SAP2000®

Seismic Design of Buildings and Structures: Pre-Dimensioning Example of RINGFEDER® Friction Springs Used as Stiffening Elements for Cross-Bracing

Objectives of the Pre-Dimensioning:

- Insure the operational level of the seismic design
- Elastic structure behavior, no damage
- Economic and resource-saving design: increased damping, reduced internal forces for economical construction
- Consideration of wind loads to ensure operational safety of the friction springs

Estimation Formula:

Effective Stiffness $\mathbf{ke} \approx \frac{F_{max}}{ds}$

Effective Damping $\mathbf{ce} \approx \frac{\xi\, ke\, T}{\pi}$

with **ξ = 17 up to 33 % [1]**
T relevant natural period

Design Procedure:

1. Determination of the deformation capacity / target deformation of the building
2. Conclude the natural period from the response spectrum by using the target deformation
3. Iterative determination of the effective stiffness of friction springs in SAP2000®
4. Determination of the wind loads to define the required pre-tensioning
5. Dimensioning of the friction springs
6. Response spectrum analysis or time history analysis

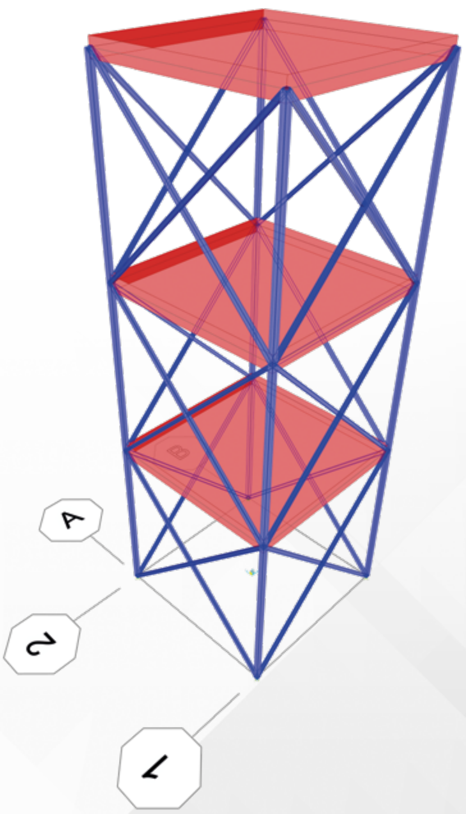
1. Determination of the deformation capacity / target deformation of the building

The deformation capacity of the building for the design earthquake has to be defined first. This is done on the basis of the specific requirements made on the building.

Here: Analogous to damage limitation acc. to EN 1998-1 (4.31)

$$d = \frac{0.005\ h}{v} = \frac{0.005 \times 9\ m}{0.5} = 0.09\ m$$

The horizontal target deformation due to the design earthquake is to be limited to *d = 0.09 m* at the top floor, where the building height is *h = 9 m*.



SAP2000® Model

2. Conclude the natural period from the response spectrum by using the target deformation

In this step, the first natural period T_1 of the building designed with friction springs is determined. To account for the target displacement in the response spectrum, the system is transformed into an equivalent single degree of freedom system.

Here: according to EC 1998-1 Annex B

$$d_{EMS} = \frac{d}{1.57} = 0.057\ \mathrm{m}$$

Note: *For simplification, the factor 1.57 can be used for systems with a constant mass and stiffness distribution.*

The S_d spectrum is now determined from the site-specific S_a spectrum:

$$S_d = S_a \left(\frac{T}{2\,\pi}\right)^2$$

If the decisive degree of stiffening is provided by friction springs, the positive influence of damping should also be considered. The damping value can be determined as discussed in reference [1].

Here: Damping is assumed to be 17 %.

$$\xi = 17\ \%$$

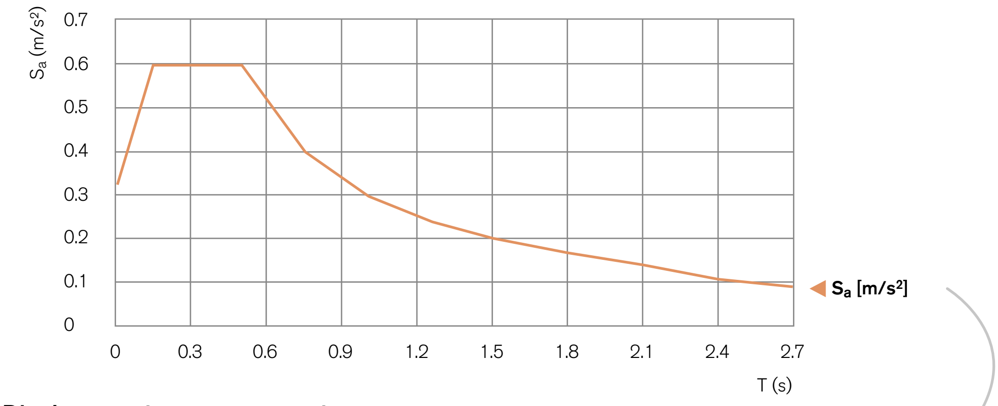
$$S_{d,red} = S_d \sqrt{\frac{10}{5+\xi}}$$

The natural period T_1 is determined by setting the target deformation d_{EMS} as the displacement response $S_{d,red}$. The natural period is derived as follow:

$$T_1 = 1.1\ \mathrm{s}$$

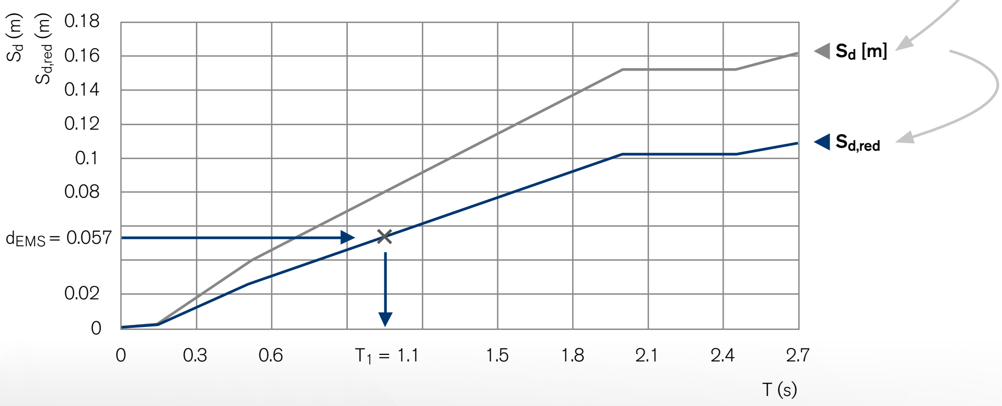
[1] Helm, L., Sadegh-Azar, H., Jahnel, L. and Jandrey, H., 2022. Innovative application of ring springs for seismic design. BAUTECHNIK, 99(1), pp.31-40. https://doi.org/10.1002/bate.202100075

Acceleration response spectrum



$$S_d = S_a \left(\frac{T}{2\,\pi}\right)^2$$

Displacement response spectrum



$$S_{d,red} = S_d \sqrt{\frac{10}{5+\xi}}$$

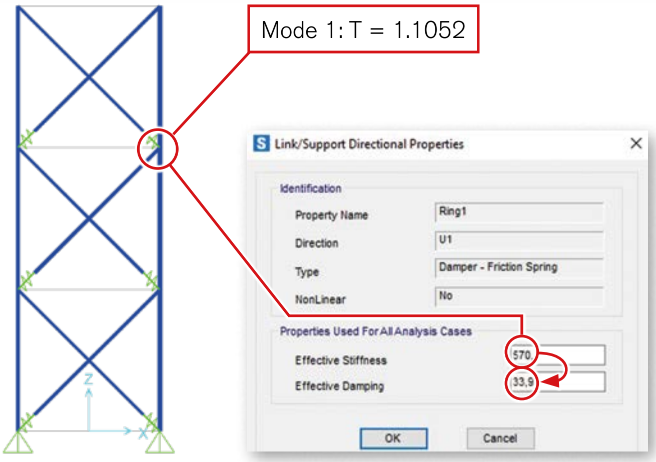
3. Iterative determination of the effective stiffness of friction springs in the SAP2000® Model

In SAP2000®, friction springs are denoted as "Link Element: Damper Friction Spring". The effective stiffness *ke* is adjusted until the first natural period matches $T_1 = 1.1\ s$. In the example below, the same stiffness was selected for all levels because of the symmetrical structure.

$$ke = 570\ \text{kN/m}$$

Determination of the effective damping:

$$ce = \frac{\xi\, ke\, T}{\pi} = \frac{0.17 \times 570 \times 1.1}{\pi} = 33.9\ \text{kNs/m}$$



Mode 1: T = 1.1052

Identification

Property Name: Ring1

Direction: U1

Type: Damper - Friction Spring

NonLinear: No

Properties Used For All Analysis Cases

Effective Stiffness: 570

Effective Damping: 33,9

The SAP2000® model is then analysed with the response spectrum method. The elastic response spectrum is used as the seismic action.

The maximum force required for the friction springs is determined as the minimum required section force in the most critical bracing element. This is derived from SAP2000®:

$$F_1 = 12.9\ \text{kN}$$

The associated deformation is also required:

$$u_1 = 0.0226\ \text{m}$$

The horizontal deformation of the top floor is:

$$d_{IST} = 0.0713\ \text{m} < 0.09\ \text{m} = d$$

The deformation d_{IST} calculated by SAP2000® is smaller than the horizontal target deformation *d* determined in step 1.

Note: *For a better overview, the friction springs are uniformed over the height of the building in this example.*

4. Calculation of the wind loads to define the required preload

The objective of this calculation is to make sure that the friction springs are not excessively activated by wind loads. This ensures the service life of the friction springs. For this reason, the preload of the friction springs is determined according to the characteristic wind loads with a low return period.

A return period of two years is recommended here (conversion acc. to EN 1991-1-4 (4.2)).

The characteristic section force in the bracing element for the design wind loads is known from the structural analysis of the building:

$$F_W = 5.07\ \text{kN}$$

Conversion for a return period of two years:

$$c_{prob} = \left(\frac{1 - 0.2\ \ln\left(-\ln\left(1-0.5\right)\right)}{1 - 0.2\ \ln\left(-\ln\left(0.98\right)\right)}\right)^{0.5} = 0.776$$

The wind loads define the minimum necessary preload:

$$F_{W,prob} = F_W\, c_{prob} = 5.07\ \text{kN} \times 0.776 = 3.93\ \text{kN}$$

5. Dimensioning of friction springs

The suitable friction spring is selected on basis of maximum force, spring stroke and preload.

Selected friction spring	03200; 40 elements; 30 % preload	
End Force $F_{max} > F_1$	14 kN	F_1 = 12.9 kN
Preload Force $F_v > F_{w,\,prob}$	4.2 kN	$F_{W,prob}$ = 3.93 kN
Stroke ds ≈ u_1	0.0224 m	u_1 = 0.0226 m

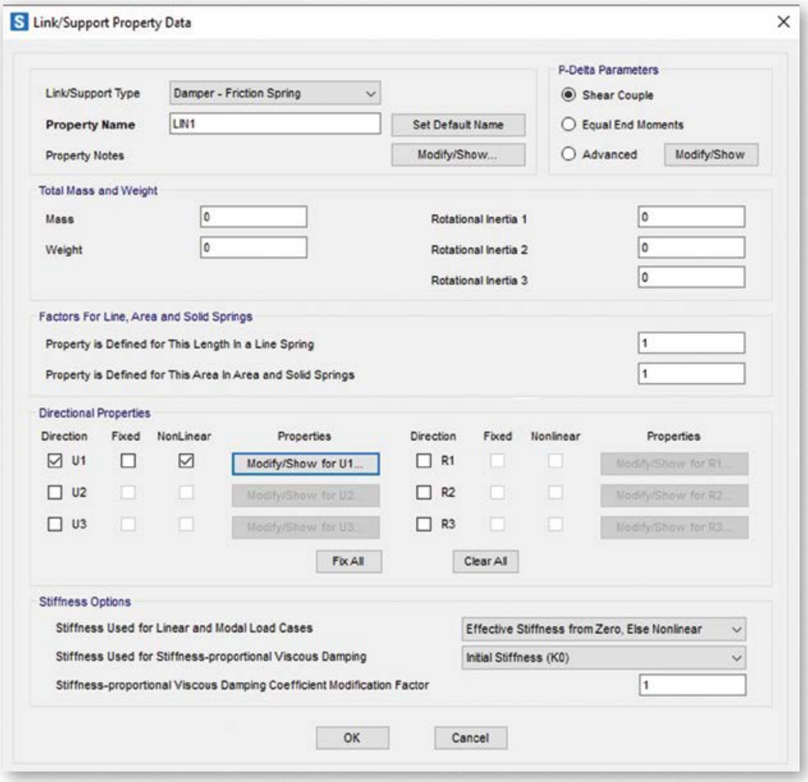
In case of discrepancies between the selected properties and the calculated values, it is advisable to recalculate the response spectrum method, incorporating the revised effective stiffnesses and damping factors.

6. Response spectrum or time history analysis

For complex or unsymmetrical systems, it is always recommended to perform the more precise non-linear time history analysis after the design. The exact force-deformation curve can be determined for a non-linear calculation in SAP2000® on the basis of the friction spring properties.

Structural Modelling in SAP2000® & ETABS®

- Friction springs are an integral part of SAP2000® and ETABS®
- Easy selection as “Link Element: Damper Friction Spring”
- The hysteresis is precisely considered in a non-linear calculation.



Link/Support Property Data

Link/Support Type: Damper - Friction Spring
Property Name: LIN1
Property Notes

P-Delta Parameters
● Shear Couple
○ Equal End Moments
○ Advanced

Total Mass and Weight
Mass: 0
Weight: 0
Rotational Inertia 1: 0
Rotational Inertia 2: 0
Rotational Inertia 3: 0

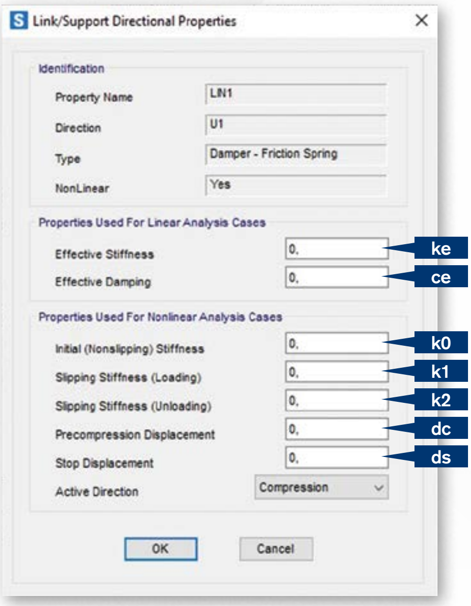
Factors For Line, Area and Solid Springs
Property is Defined for This Length In a Line Spring: 1
Property is Defined for This Area In Area and Solid Springs: 1

Directional Properties

Direction	Fixed	NonLinear	Properties	Direction	Fixed	Nonlinear	Properties
☑ U1	☐	☑	Modify/Show for U1...	☐ R1	☐	☐	Modify/Show for R1...
☐ U2	☐	☐	Modify/Show for U2...	☐ R2	☐	☐	Modify/Show for R2...
☐ U3	☐	☐	Modify/Show for U3...	☐ R3	☐	☐	Modify/Show for R3...

Stiffness Options
Stiffness Used for Linear and Modal Load Cases: Effective Stiffness from Zero, Else Nonlinear
Stiffness Used for Stiffness-proportional Viscous Damping: Initial Stiffness (K0)
Stiffness-proportional Viscous Damping Coefficient Modification Factor: 1

Link/Support Property Data



Link/Support Directional Properties

Identification
Property Name: LIN1
Direction: U1
Type: Damper - Friction Spring
NonLinear: Yes

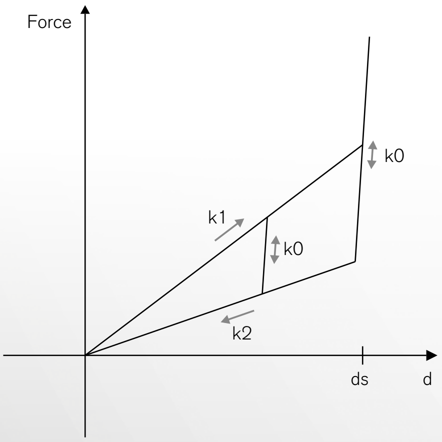
Properties Used For Linear Analysis Cases
Effective Stiffness: 0.
Effective Damping: 0.

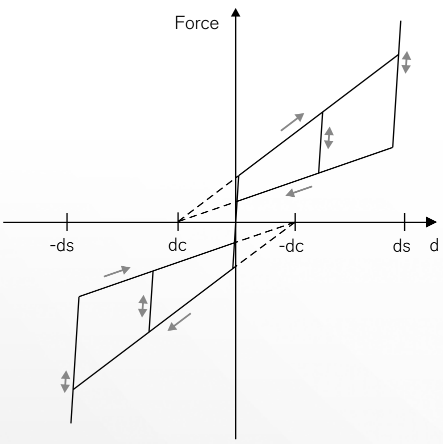
Properties Used For Nonlinear Analysis Cases
Initial (Nonslipping) Stiffness: 0.
Slipping Stiffness (Loading): 0.
Slipping Stiffness (Unloading): 0.
Precompression Displacement: 0.
Stop Displacement: 0.
Active Direction: Compression

Link/Support Directional Properties

- All six degrees of freedom can be defined, although only u_1 is usually required.
- Compression, tension, or both directions are available.

Properties for Linear Analyses *



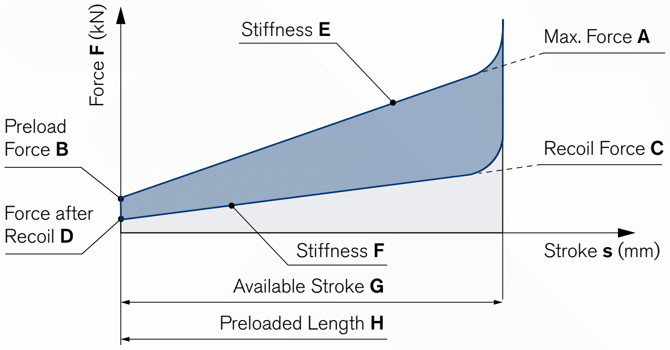


* For the simplification of a linear calculation, e.g., a modal analysis or response spectrum analysis. A non-linear calculation is recommended for complex systems.

Design Parameters for Friction Springs

The friction springs can be combined individually. The maximum force defines the type, and the spring travel is determined by the number of the elements. Typically, the hysteretic damping $(1 - \frac{k_2}{k_1})$ is 66 %. In addition, the pre-tensioning value has to be determined.

Type →	Max. Force **A**, 5 -1800 kN
Hysteretic Damping →	**D**, 66% is standard
Elements →	Stroke s_{tot}
Pretensioning →	P_{ret}, 10 -50 %



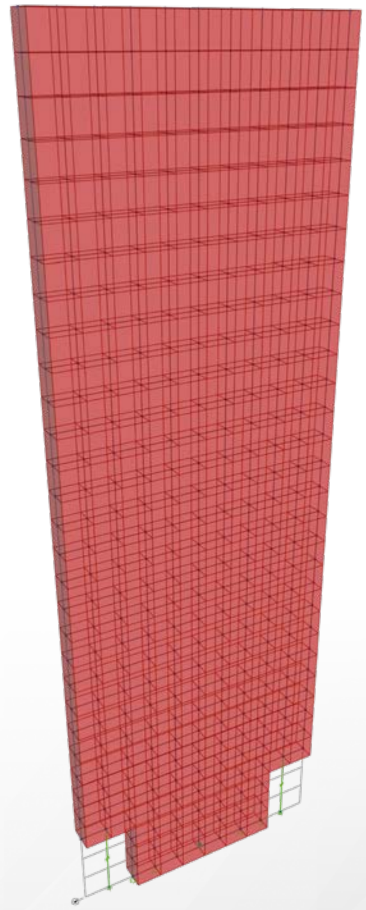
Force-stroke diagram

SAP2000®/ETABS® input is determined from the following parameters:

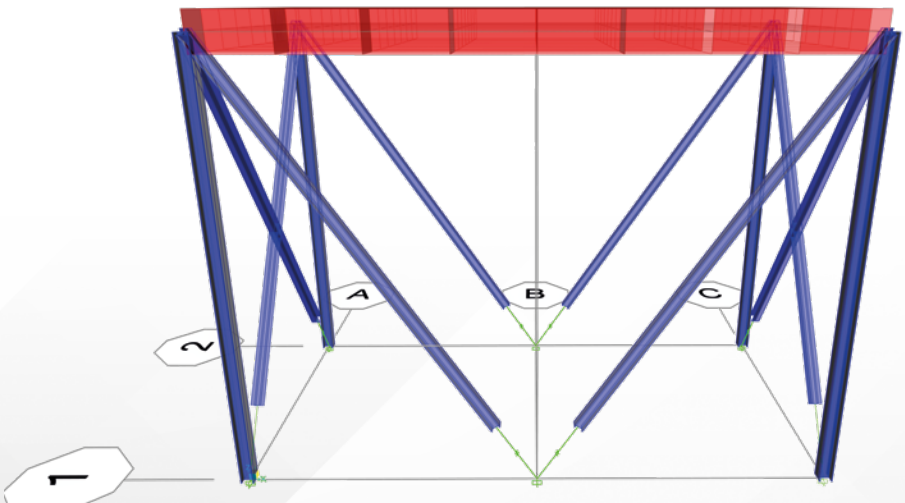
Slipping stiffness (Loading)	$k1 = \frac{A}{s_{tot}}$
Slipping Stiffness (Unloading)	$k2 = k1\,(1-D)$
Precompression displacement	$dc = s_{tot}\,P_{ret}$
Stop displacement	$ds = s_{tot} - dc = s_{tot}\,(1 - P_{ret})$

Initial (Nonslipping) Stiffness k0

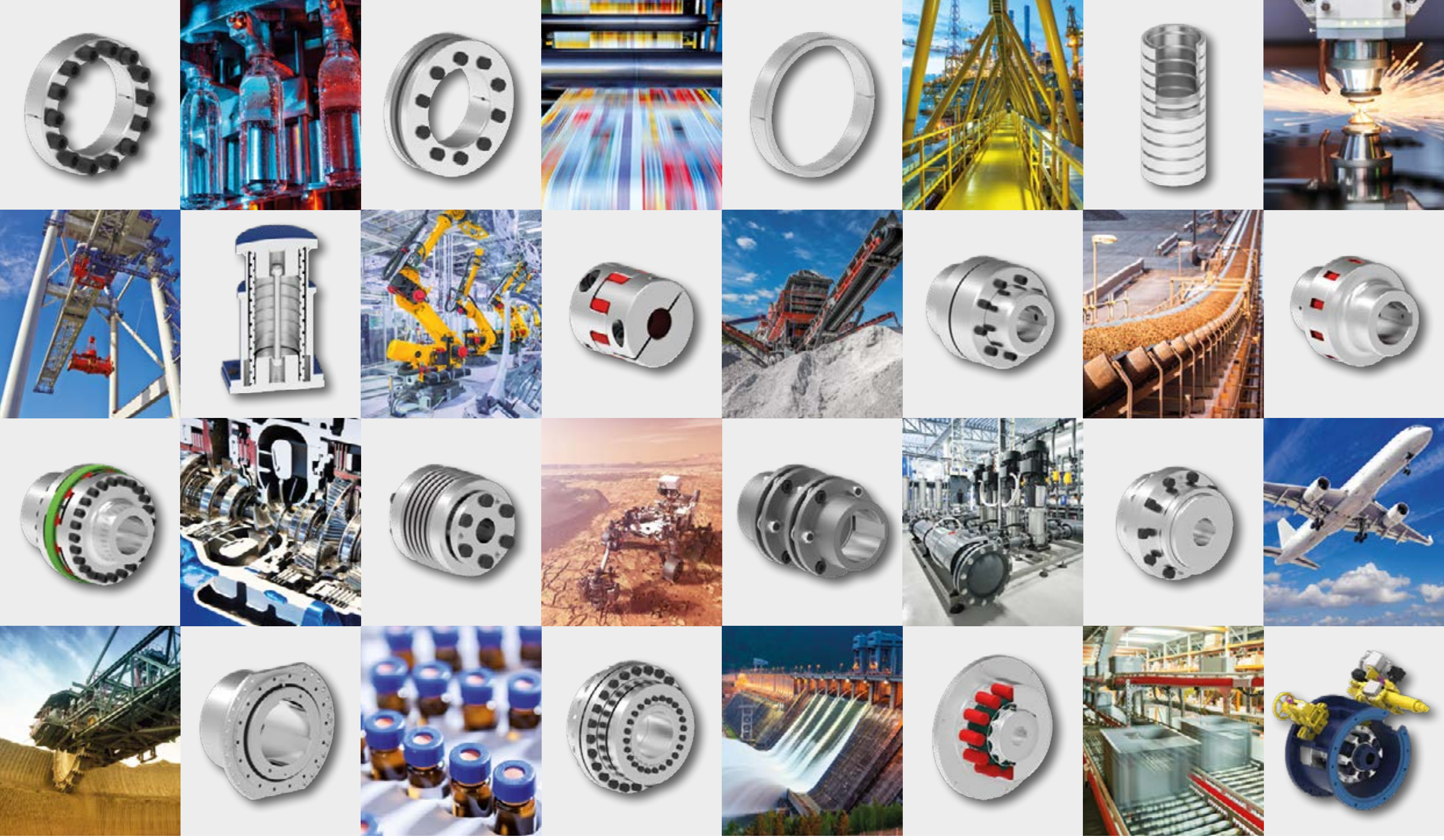
- Elastic stiffness before the preload is exceeded and the friction spring is activated
- Results from the connection/housing, for example
- The following condition should be fulfilled: *k0>>k1>k2>0*
- If *k0>>k1* is fulfilled, this parameter does not have a large influence on the results and a high stiffness can be conservatively assumed.
- If *k0>>k1* is not fulfilled, a closer review will be necessary.



SAP2000® Modeling: Shear wall



SAP2000® Modeling: Cross-Bracing



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