11CCEE

The 11th Canadian Conference on Earthquake Engineering

Canadian Association for Earthquake Engineering

DESIGN APPROACH FOR FRICTION SPRING DAMPERS IN STEEL FRAMED BUILDINGS. EXPERIENCES FROM CHRISTCHURCH / NZ

Lars JAHNEL
Application Engineer, RINGFEDER® Power Transmission, Germany
lars.jahnel@ringfeder.com

Edward M. COLE
Engineering Manager, RINGFEDER® Power Transmission USA Corporation, Westwood NJ, USA
edward.cole @ringfeder.com

ABSTRACT: The February 2011 Christchurch/New Zealand earthquake was a powerful natural event that severely damaged New Zealand's second-largest city. Of course, not all of the damage could have been avoided, but with friction springs, you have a greater possibility that your building will survive an earthquake like the ones in 2010/11 and still be habitable. There already are buildings in New Zealand, which are equipped with friction springs, for example Te Puni Village Student Accommodation, 24 Taranaki Street, One Market Lane (all in Wellington) and Tait Communication Campus (Christchurch). Te Puni Village was already completed when the earthquake struck on July 21st 2013, measuring 6.5 on the Moment Magnitude Scale (MMS) and the following aftershock measuring 5.8 on the MMS. The building withstood the earthquake without considerable damage. Depending on the configuration of the friction spring, up to 2/3 of the introduced energy will be absorbed. Friction springs can be used by themselves as base isolation or together with other protecting systems such as sliding hinge joints (SHJ) or lead rubber bearings (LRB). The friction spring damper is integrated in the SAP2000® software for the structural analysis and design of buildings.

1. INTRODUCTION

The philosophy regarding damages to buildings or industrial facilities during an earthquake has changed over the years. In the past, it was not important whether or not a building crumbles. The main function for a building during a seismic event was to protect the people who work or live in it. No consideration was given to its condition after. Nowadays, affected governments have even less capacity financially than in the past to rebuild their cities after an event. Following this, emergency centers need to be setup and a mostly functioning infrastructure is required. Economic and ecological reasons are now playing an important role in the design of new buildings that are still usable after a big seismic event. An imposing example of this is the rebuild of Christchurch, where the cost has been estimated at around NZ$ 40 billion (source: NZ Treasury). That and advances in seismic engineering have led to a “Damage Avoidance Design” philosophy whereby a structure is designed to withstand a major seismic event with minimal and repairable damage. This typically involves incorporating mechanisms in the structure that can control loads and sustain large deformations without causing damage. Structural damage needs to be planned for in design, controlled and limited, to ensure a building can remain useable after a large earthquake. Friction springs are one solution for controlling seismic damage in taller steel framed buildings. We believe this technology means it is now economically viable to achieve this objective.

2. DESIGN FEATURES

Friction springs are employed in the mechanical engineering sector when high kinetic energies must be absorbed and damped or when springs of relatively compact dimensions are required for high forces.

2.1. Basic design of a friction spring

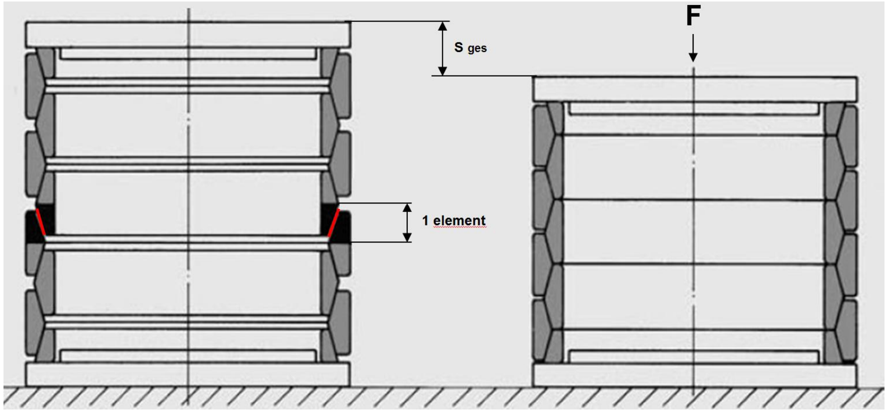


Figure 1 – RINGFEDER® friction spring

Friction springs consist of closed outer and inner rings with tapered contact surfaces. A spring element is understood to be one single mating taper surface, i.e. half one inner and half one outer ring. For example, the spring shown in Figure 1 consists of 4 outer rings, 3 inner rings and 2 half inner rings that means the spring has 8 elements. When the spring column is axially loaded the tapered surfaces overlap causing the outer rings to expand and the inner rings to contract in diameter. The outer and inner rings are made of special spring steel. Application of high loads causes elastic deformation to the rings. The total spring travel of a friction spring results from the number of elements whereas the spring force does not change with the number of elements. In contrast to other spring types, the peripheral stresses are distributed almost uniformly over the cross-sectional area; each element of a friction spring is hence utilised uniformly as regards to volume so that the weight of the spring is less than that of other types of spring.

2.2. Long life

Friction springs are designed to last through many cycles and are reusable. If one of the rings in a friction spring assembly breaks, the spring will still work and become slightly stiffer. The end force and the dampening remain unaffected.

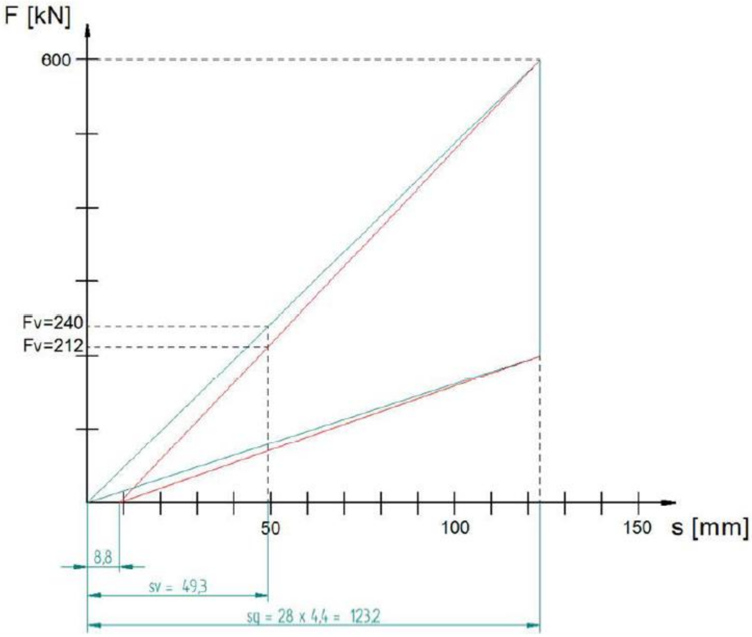


Figure 2 – Effect on the spring if one ring fails.

2.3. Lubrication

Before dispatch, the sliding surfaces of the rings are lubricated by special grease (lifetime lubrication).

2.4. Fire and high temperatures

Ring springs are made of special spring steel and coated with grease. In case of a fire, rubber products, hydraulic or fluid elastomeric dampers will be destroyed, but friction springs will endure the fire. As long as the tempering temperature of the steel will not exceeded, they only need to be re-greased.

2.5. Speed

The force travel diagram is applicable under all operating conditions. The rate at which the load is applied is of almost no significance. Ring springs react faster to applied forces than any other spring type.

2.6. Dampening

The special feature of the ring spring is the powerful dampening of about 66% of the energy introduced, the remaining 34% (return force) are needed to bring the spring back in its original position. This value is reached by using the standard grease F-S1. Oscillations and shocks hence are attenuated very quickly. If the damping spring is installed so as to act in both directions (impact and traction), Energy depletion occurs twice during an oscillation process. The energy E_O introduced decreases with increasing number of oscillations z in accordance with the following equation:

$$\frac{E_Z}{E_O} = (1-D)^{2Z} * 100\,[\%] \tag{1}$$

This function is plotted in Figure 2 for various percentage damping values. In ring springs in which D = 66% the energy introduced had fallen to 1.3% of the initial value after only two oscillation! Resonance phenomena are therefore completely suppressed.

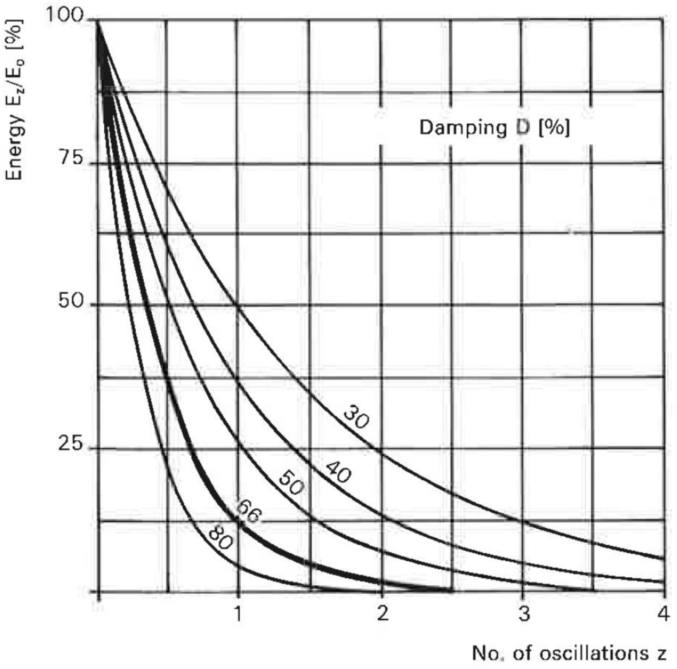


Figure 3 - Decrease in the energy Ez (referred to the initial value E0) as a function of the numbers of oscillations z for different dampening values.

If the characteristic of a friction spring has to be changed, there are three different possibilities to do this:

- The friction coefficient can be influenced by using another grease.
- The angle of the tapered surfaces can be changed.
- The thickness of the rings can be changed.

For example, in certain seismic designs it is necessary to reduce the dampening and to increase the force when the spring is unloaded to help to push the building back to its vertical position.

2.7. Operational characteristics

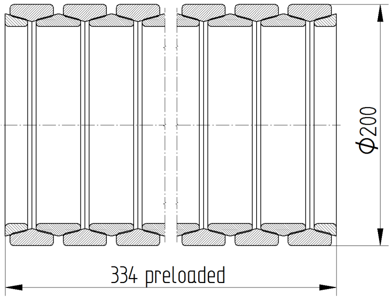


Figure 3 – Preloaded spring

Figure 3 represents the diagram of a friction spring type 20000, which is a typical one for earthquake applications. It consists of 8 outer rings, 7 inner rings and 2 half inner rings. It is preloaded with 200 kN to a length of 334 mm. With these values, it has a maximum stroke of 38 mm and a capacity of 13400 Joules. The requirement, for example, is to absorb a maximum energy of 6000 Joules.

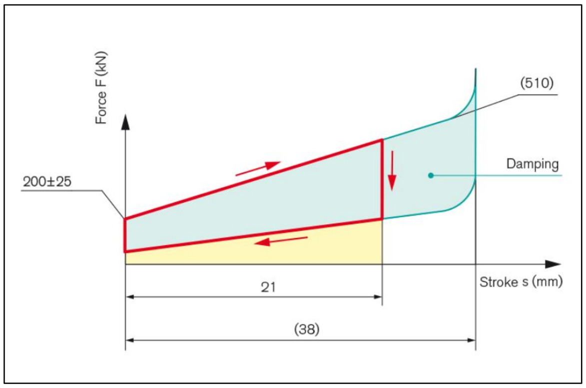


Figure 4 – First impact

When the ring spring receives an impact energy, it compresses by 21 mm and absorbs 6000 Joules from which 4000 Joules respectively = 66% are converted to heat. After the compression, the friction spring discharges back by the same 21 mm due to a reaction force and there are 2000 Joules which have to be absorbed.

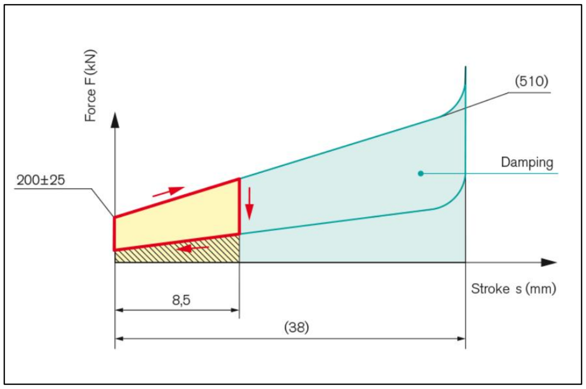


Figure 5 - Second impact

Figure 5 shows that the impacting body strikes again on the ring spring with the remaining 2000 Joule and compresses it by 8.5 mm. After the compression, the buffer springs back by the same 8.5 mm due to the reaction force.

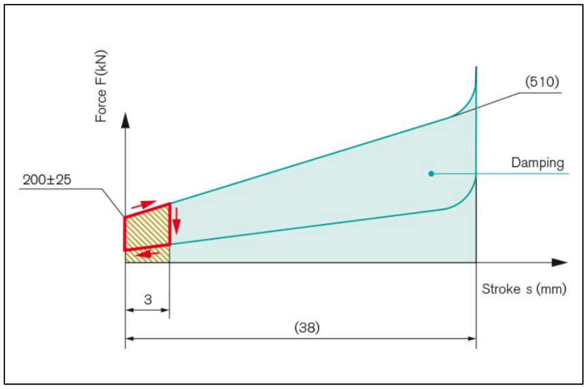


Figure 6 - Third impact (not necessarily)

Based on the fact that the friction not only occurs between the rings of the ring spring but in the whole system, the complete 6000 Joules are now absorbed and the system comes to rest. Figure 6 shows a low theoretical 3rd oscillation.

2.8. Return force.

The best return force will be determined for every application and for every specific design in cooperation with the structural engineers and their requirements of the supporting structure. Every spring that leaves our facility is tested twice with a load of 140% and the diagram is recorded to guarantee that the values meet the customers’ requirements.

2.9. Re-usability

Friction springs can be re-used after a seismic event. They are designed to withstand many cycles and remain stable. They are maintenance free. For example, the company Krupp uses jaw crushers that are equipped with friction springs. These work since 50 years without maintenance. Railway buffers with friction springs have a lifetime of 30 to 40 years without maintenance.

2.10. Speed

Friction springs react faster to applied forces than any other spring type.

2.11. Temperature

The diagram is independent from temperature between -20°C to +60°C. If required, the temperature range can be increased from -73°C up to +200°C. Additionally there is no influence of loading rate or velocity to the function.

3. Application examples

3.1. Base isolation

Ring springs can be used as damping elements for themselves. A good example of this is the base isolation of Tait Communication Campus in New Zealand.

An excavation pit is dug, tubes are piled into the ground. The depth depends on the point from where you reach solid ground.

The bottom of the pit is condensed, the tubes cut off ~ 4” above the surface. Then the tubes are filled with concrete and reinforcement.

The basic steel construction and a framework for the concrete is designed.

The pit is filled with concrete. From this support base, the ground floor is built up.

The friction springs are integrated into the steel frame underneath the floor.

After this is done, the floor is completely closed.

Figure 7 - Possible course of action for base isolation

The figures 7 show one of the possible procedures while using the base isolation method (here New Zealand / Tait Communication Campus). The friction spring damper has different tasks. It adds flexibility to the structure and allows the building to rock. It helps re-centering the structure and dissipates energy. Depending on requirements and dimensioning is one or the other characteristic more pronounced.

3.3. Sliding hinge joints

The Sliding Hinge Joint (SHJ) is a beam-column connection that is able to undergo large inelastic rotations with minimal damage [Clifton 2005]. This is achieved through sliding in Asymmetric Friction Connections (AFCs) to allow joint rotation. The SHJ has been used in practice, with many benefits over welded connections which include decoupling of joint strength and stiffness, confining inelastic demand to the bolts which are easily replaced following an earthquake, improving dynamic re-centering ability and reducing construction costs. The SHJ however undergoes a loss of elastic strength and stiffness once forced into the sliding state [Khoo et al 2013]. As the next stage of the SHJ development, the self-centering version of the SHJ (SCSHJ) was proposed, which incorporates friction springs to reduce joint elastic strength and stiffness losses, and reduce frame residual drifts to within construction tolerances following an earthquake [Khoo et al., 2012a].
In the Self-Centering Sliding Hinge Joint (SCSHJ) the beam is connected to the column through the top flange plate which acts as the point of rotation. AFCs are installed in the bottom flange and web bolt groups. The properties of the joint can be altered by varying the percentage of moment capacity contributed by the ring springs. The joints can thus be categorized into the standard SHJ, where moment capacity is developed only by AFCs, the friction spring Joint (RSJ) where the moment capacity is developed only by ring springs and the SCSHJ where the moment capacity is a combination of AFC and ring springs. The SCSHJ was studied and analyzed on a 10-storey frame. Frames with a percentage of total joint moment capacity (PRS) of 25% had residual drifts within 0, 2 %, showing its viability in developing frame dynamic re-centering characteristics [Khoo et al 2013].

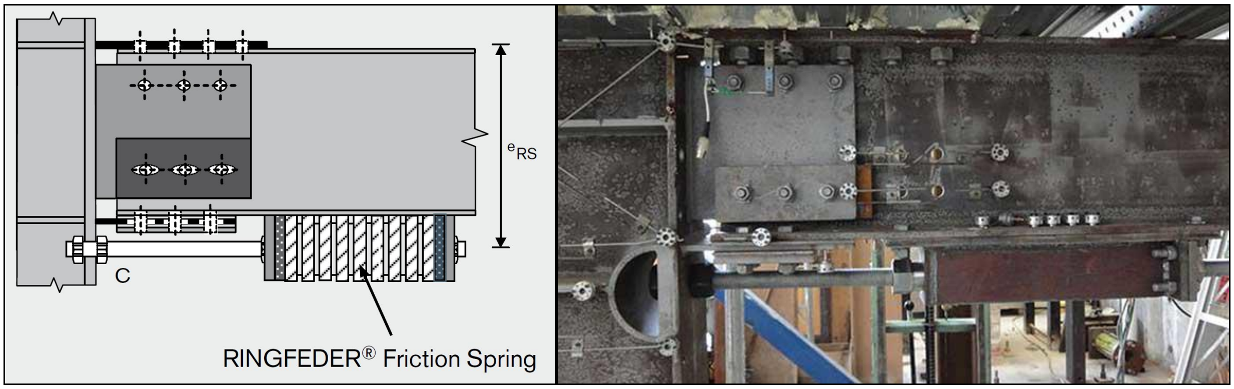


Figure 8 – Self centering sliding hinge joints

3.4. Rocking shear walls

Rocking structures avoid structural damage by shifting the burden of energy dissipation to non-critical, replaceable structural elements, and by preventing weak story failure Damage that would result in severe injury, and also damage that would prevent future serviceability of the structure, can be addressed by allowing structures to move, relative to their foundations. By enabling structures to be serviceable after a seismic event, rocking systems are a highly sustainable approach to structural design in earthquake-prone regions. There are different possibilities to integrate friction springs in rocking shear walls [Rocking –Wall].

3.4.1. Timber constructions (design concept)

Rocking shear walls in timber constructions are providing ductility to the system. Additionally they are equipped with fuses, which work as energy dissipators by using the tensile strength of steel rods to dampen the system. After an event, the steel rods have to be replaced. Instead of these steel rods, push-pull friction spring units (Figure 9, right side) that work as a double acting system can easily be integrated into the construction. They don’t have to be replaced after an event.

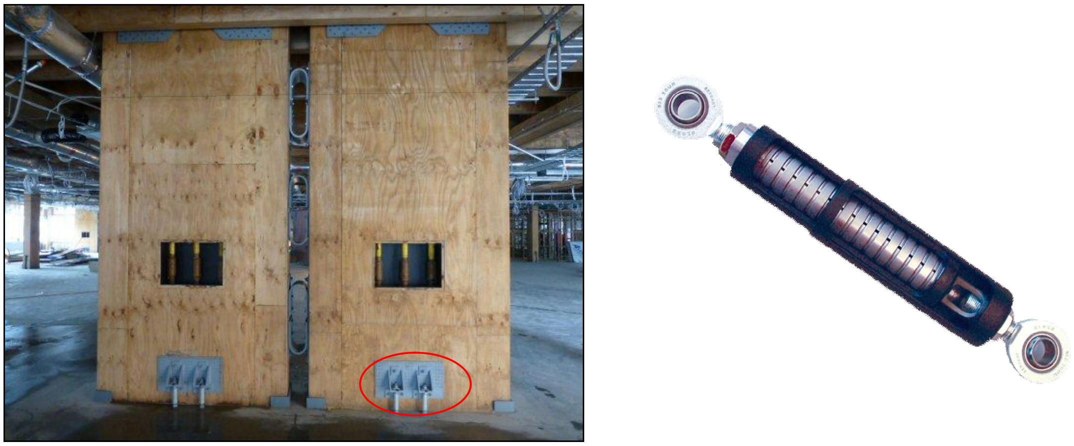


Figure 9 - Left side: Cross Laminated Timber (CLT) rocking shear walls, right side: push pull unit

3.4.2. Steel frames (design concept)

The rocking wall system in Figure 10 utilises an elastic tension field action to resist the shear force, a rocking pivot to reduce the impact of uplifting and maintain the stability of the structure, and energy dissipation devices installed at the bottom of the columns to dissipate energy and provide re-centering of the wall. The lateral forces are resolved into shear force and axial force. The shear force form diagonal tension fields in web plates to be distributed to the nearest boundary frames. These forces are anchored to the end posts of the topmost and bottommost beam and then transferred through the rocking pivot into the foundation system. The axial forces are carried by columns to the foundation system through the friction springs. These springs are designed to remain elastically rigid up to a defined column axial force. When the applied force is more than that axial force, the devices will dissipate considerable energy during the rocking and will provide the ability to re-center after earthquakes [Djojo et al 2014].

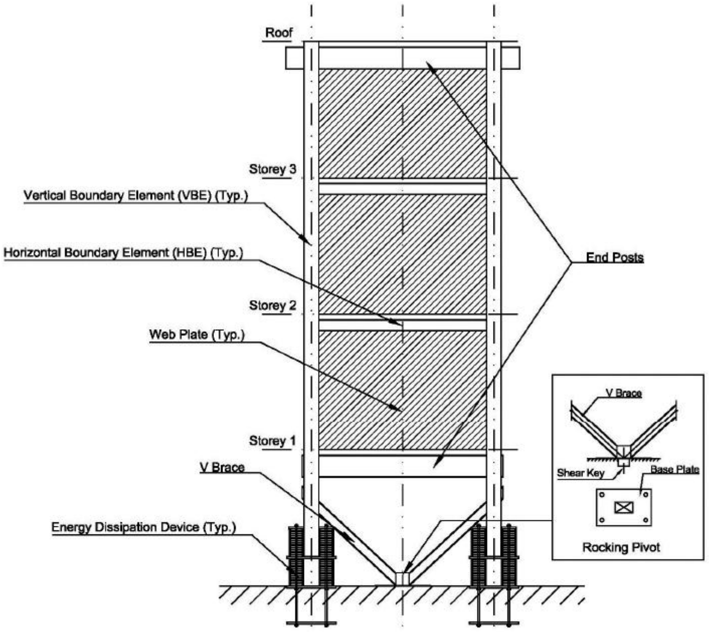
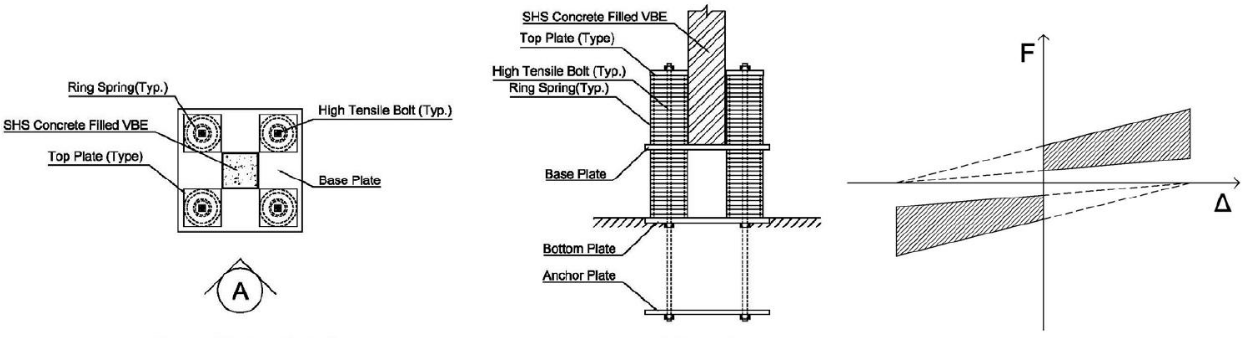


Figure 10 - Rocking wall

The rocking wall requires double acting preloaded springs to dissipate energy and provide self-centering when a column moves upward and downward. To facilitate this action, two stacks of friction springs are assembled at top and bottom of a base plate in series arrangement with a high tensile grade AISI 4140 threaded rod fastened through a baseplate connection to the foundation as shown in Figure 11.



Base Plate Detail

View A

Hysteresis Curve

Figure 11 - Proposed system of double acting friction springs

These stacks remain rigid under gravity loads, SLS (serviceability limit state) earthquakes, and ULS (ultimate limit state) wind forces. Each stack operates individually to dissipate energy when the structure rocks under ULS earthquakes. The top stack or bottom stack are compressed when the column move upward or downward respectively. The threaded rod is designed to begin yielding when the ring springs are locked up. The ring spring is pre-stressed to 50% of the capacity to allow this ring spring to move upward and downward equally and dissipate energy with another 50% of capacity [Djojo et al 2014].

3.4.3. Capacitor bank platforms and electrical switch gears

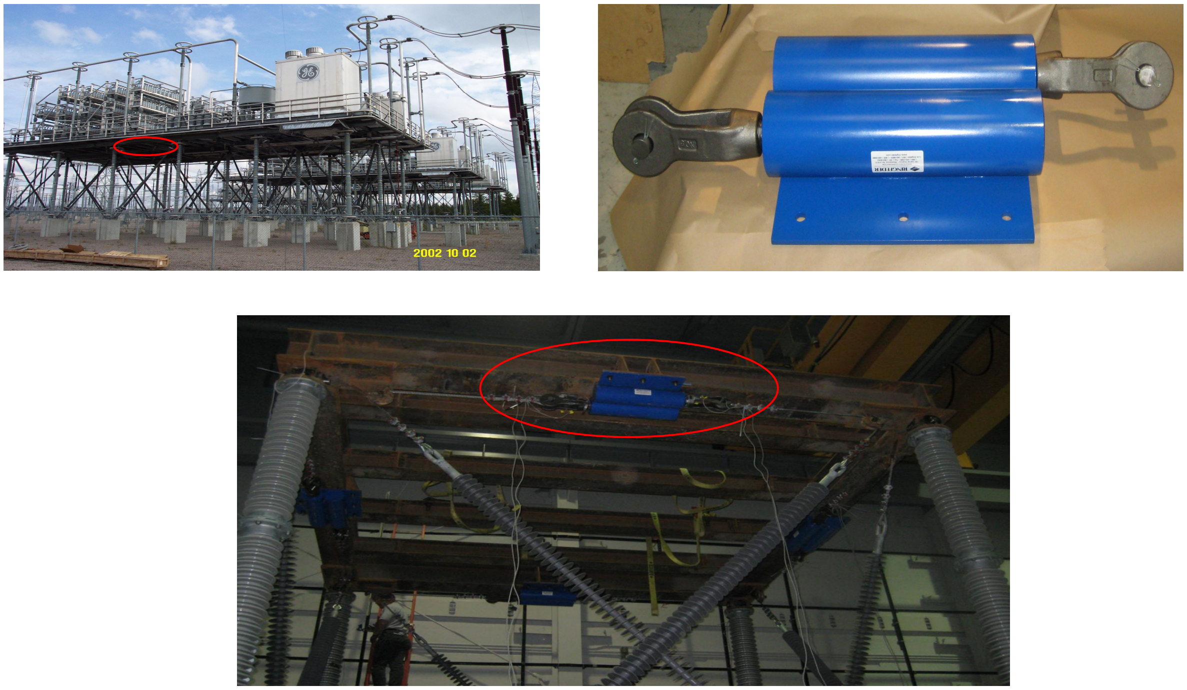


Figure 12 - Bracing of the cross members of a capacitor bank platform for more flexibility

As shown in Figure 12 the cross members of a capacitor bank platform are braced by the help of ring springs. This adds more flexibility to the system and allows the platform to rock. The design of the buffer was a specification of the customer. Figure 13 shows a push-pull unit which allows the switch gear to swing. Here also you get more flexibility in the application.

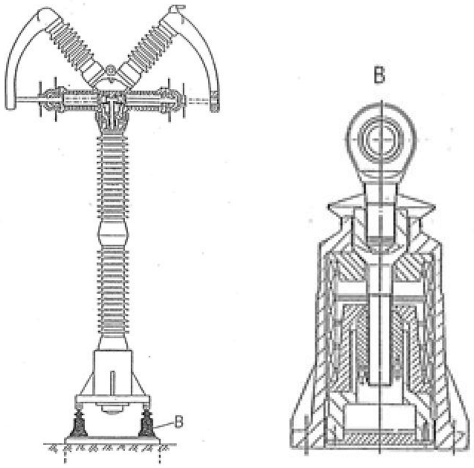
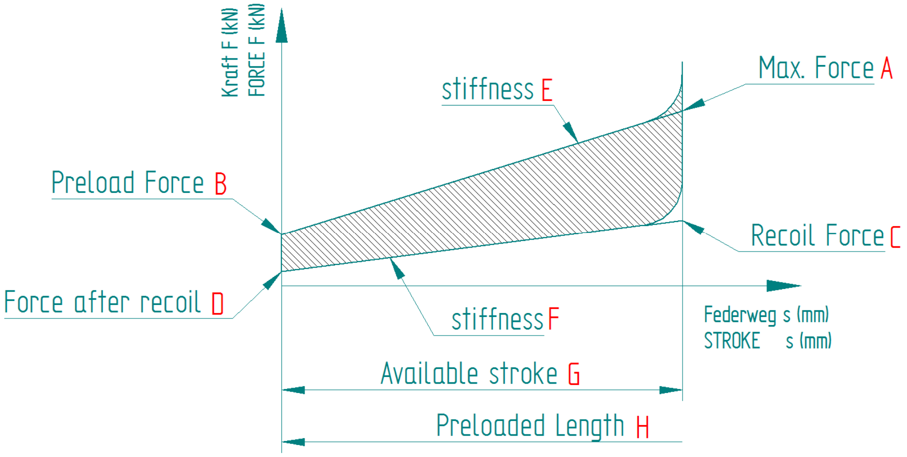


Figure 13 - Push-pull unit used for an electrical switch gear

4. Software Integration

The friction spring damper is integrated in the SAP2000® software for the structural analysis and design of buildings. A table with the necessary data of the standard sizes of friction springs from outer diameter

18mm up to 400mm is deposited in the software. In this table the engineer has to fill in the values for the percentage of damping, number of elements and percentage of pretension which is required for his application. Thereupon the necessary data of every spring size will be displayed, that is needed to fill in the values in SAP2000 (e.g. effective stiffness during the loading cycle, effective damping, displacement etc.). So the engineer is able to choose the right friction spring size for his application.



5. Conclusion

This paper has provided some background information about the use of friction springs for earthquake protection. This is only a brief overview of the capabilities that friction springs can offer. While structural engineers try to find the right system for ongoing projects, they will notice that they are limited using only one system. The combination of friction springs and other systems, for example rubber lead dampers, is possible and useful.

6. Acknowledgements

The authors wish to thank Dr G Charles Clifton and the Department of Civil and Environmental Engineering at the University of Auckland for the research regarding the use of friction springs for earthquake protection.

7. References

DJOJO, G. S., CLIFTON, G. C., HENRY, R. S., “Rocking steel shear walls with energy dissipation devices”, 2014 NZSEE Conference, March 2014.

KHOO, H.-H., CLIFTON, G. C., BUTTERWORTH, J., MACRAE, G., “Experimemtal study of full scale self centering sliding hinge joint connections with friction springs”, Journal of Earthquake Engineering, 17:7, 927-997.

CLIFTON, G. C., “Semi-rigid joints for moment-resisting steel framed seismic-resisting systems”, 2005 Ph.D. thesis , Dept. of Civil and Environmental Engineering, University of Auckland, Auckland.

KHOO, H.-H., CLIFTON, C., BUTTERWORTH, J., MACRAE, G., GLEDHILL, S. M., and SIDWELL, G. K. [2012a] “Development of the self-centering sliding hinge joint with ring springs, Journal of Constructional Steel Research 78(2012), 201-211.

www.rocking-wall.com/rocking_structures.htm 20.03.2015
http://www.treasury.govt.nz/budget/2013/speech/06.htm