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Earthquake laboratory tests on balconies with thermal break elements (Schöck Isokorb®)

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ABSTRACT: Earthquakes do not only affect the main supporting framework of the building, but also the secondary constructions such as balconies. Balconies in Europe are commonly separated from slab by using thermal break elements, like the Schöck Isokorb®. These are placed between the inner and outer slab in the line of the insulation layer (façade) to prevent thermal bridging.

The goal of study is to investigate the behavior of thermal break elements under seismic effects. Therefore a balcony-plate connection has been produced with the scale 1:1 and is artificially aged. After fatigue loadings representing a service life of 80 years, the slab construction was exposed to an earthquake simulation through intermittent loadings. For this purpose the connection was cycled vertically and horizontally with seismic loadings.

The tests were carried out based on a truss system with tension bars, shear bars made of welded steel- and stainless steel bars and pressure bearings made of ultra-high-strength concrete (UHPC). The system was analyzed with and without additional crossed horizontal bars to measure the differences in stiffness, deformation and maximum force absorption and to determine the optimum component assembly for the seismic load case for thermal break elements.

1 INTRODUCTION

External free cantilevered slabs are the most common constructions method for balconies in Switzerland and nearly each balcony is connected with thermal break elements to avoid any risk of condensation and mold formation, which can lead to a health hazard. The simultaneous introduction of new energy efficiency standards with continuously increasing requirements and majored seismic requirements has lead constructors to develop innovative solutions. These solutions have to both ensure structural integrity but also have to ensure, that the cross-section of the bearing components is as small as possible to prevent heat losses.

Balconies do not have any impact on the vibration behavior of the building structure in the case of an earthquake, they are not primary seismic members which ensure the stiffening of the structure. If the supporting structure is not affected by the failure of a balcony, then they are by definition also not secondary seismic members and balconies without special protection requirements could be considered as non-structural elements. However, the usual balcony should not endanger people even in an earthquake event, so an appropriate load-bearing capacity is recommended. For subordinate structures, according to the standard, the verification for "non-structural members" can be used, which means that they are not allowed to collapse due to seismic loadings and they have to carry their own weight after a seismic load case.

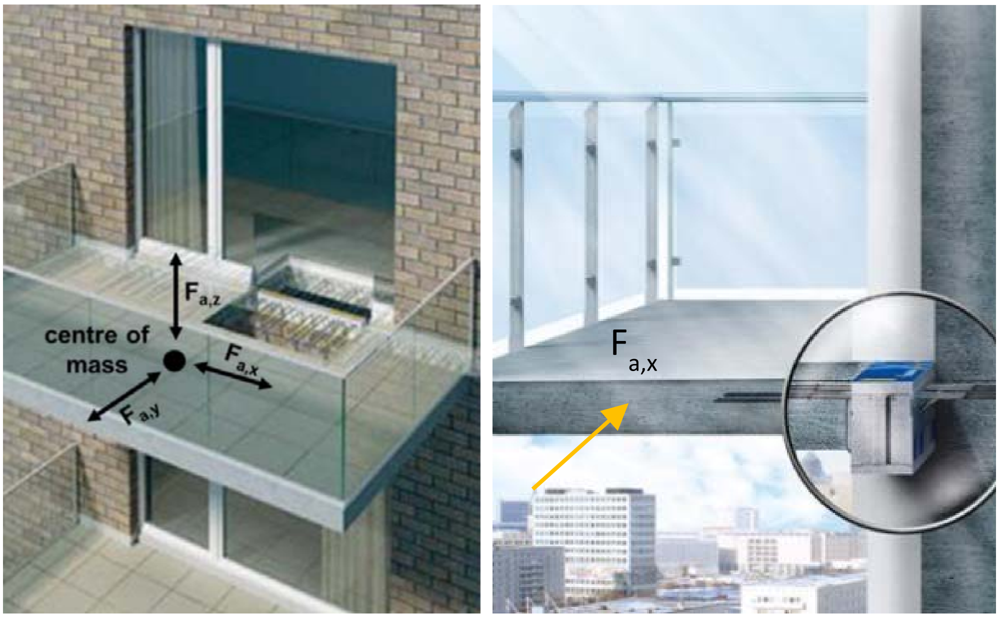

Figure 1. Thermal break element in balcony slab with possible seismic forces

According to EN 1998 section 4.3.5 the load F_a (ULS) acting on a non-structural member can be calculated as shown:

$$F_a = \frac{S_a \cdot W_a}{q_a}$$

with

F_a	horizontal equivalent static load (horizontal seismic force), acting at the center of mass of the structural member in both horizontal directions
S_a	seismic coefficient applicable to structural members
q_a	behaviour factor of the structural member

The seismic coefficient S_a may be calculated using the following expression:

$$S_a = \frac{a_g}{g} \cdot S \cdot \left[\frac{3 \cdot (1 + Z/H)}{1 + (1 - T_a/T_1)^2} - 0.5\right]$$

with

a_g	design ground acceleration
g	acceleration of gravity
S	soil factor
z	height of the non-structural element above the level of application of the seismic action
H	building height measured from the level of application of the seismic action
T_i	natural period of the building
T_a	natural period of the non-structural element

In the period of the non-structural element the consideration of the thermal break elements is fundamental, because they can be modelled as a one degree of freedom system.

$$T_a = 2\pi \cdot \sqrt{\frac{M}{K}}$$

with

M	mass of the structural member
K	stiffness of the connection

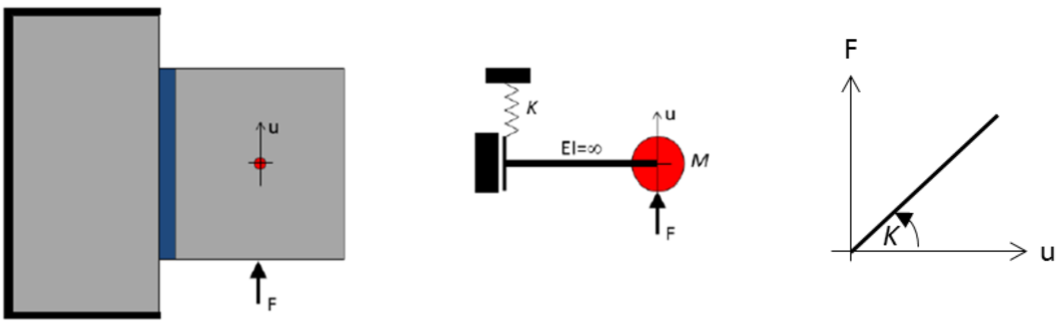

Figure 2. Model for the calculation of the natural period of a non-structural element

In the following sections the before by 3D finite element (FE) calculated stiffness K, based on Schöck Isokorb®, will be verified in experimental testing at EMPA laboratory in a 1:1 scale.

2 EXPERIMENTAL SETUP OF THE CANTILEVER PLATECONSTRUCTION

The test specimen consisted of two plates, the inner slab and the cantilever slab connected by thermal break elements (2x Isokorb type K80M-CV35-V8-H280 and 1x Isokorb earthquake module type EQM-H280) with a connection width of 2.1 m and a plate thickness of 28 cm. The cantilever length was 1.7 m, but a cantilever length of 2.9 m was simulated for the test by additional loads by 3x steel weights (with approx. 60x60x80cm³ and 62.1kN).

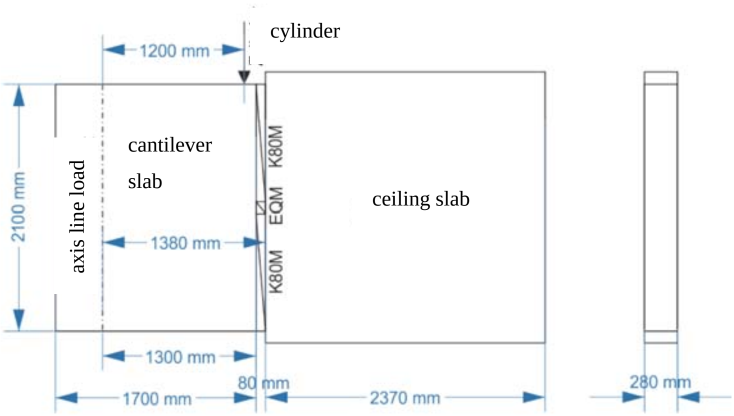

Figure 3. Geometry test body

An overview of the experimental setup is shown in Figures 4 and 5. The ceiling was fixed with steel beams (supports) on the floor of the construction hall. The variable displacement was transferred by a hydraulic cylinder (LOG 50.660, maximum force 630 kN, maximum stroke 250 mm), which has been adjusted according to the excitation direction in horizontal (phase 1 and 3) or vertical (phase 2) directions. (Both cases are shown in the figure at the same time.)

For horizontal excitation, the hydraulic cylinder is supported by a reaction bracket. This keeps the ceiling plate fixed at the same time by the horizontal support so that only the cantilever plate is free to move as far as possible. In the vertical direction, the hydraulic cylinder is held by a framework.

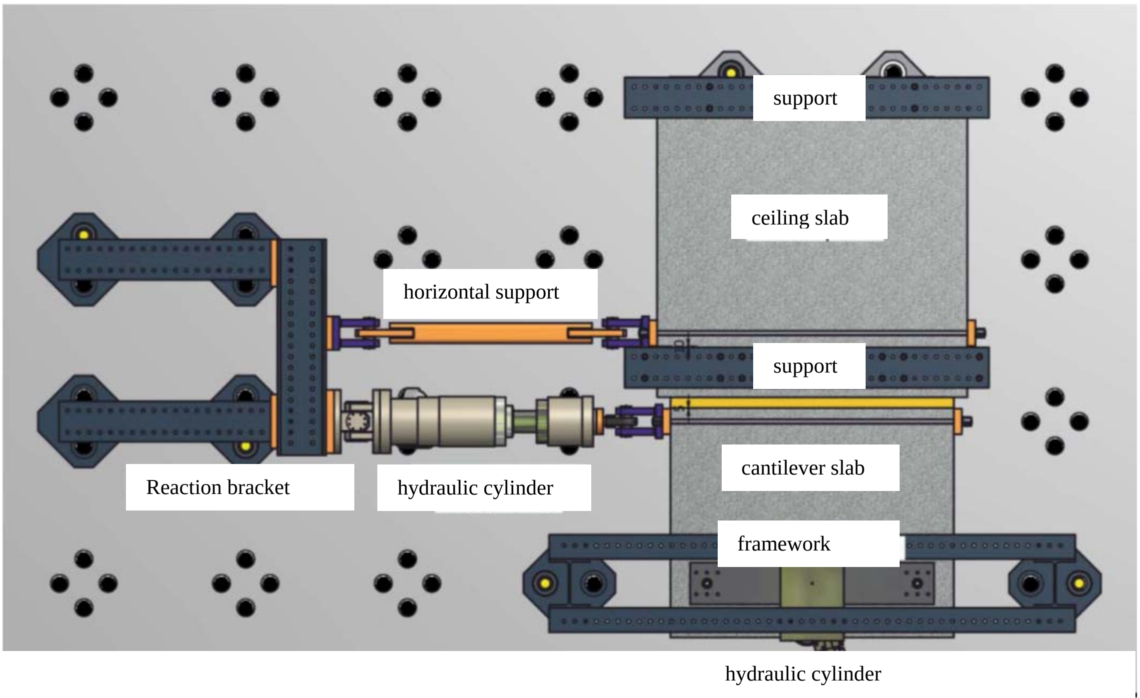

Figure 4. Top view arrangement of test setup

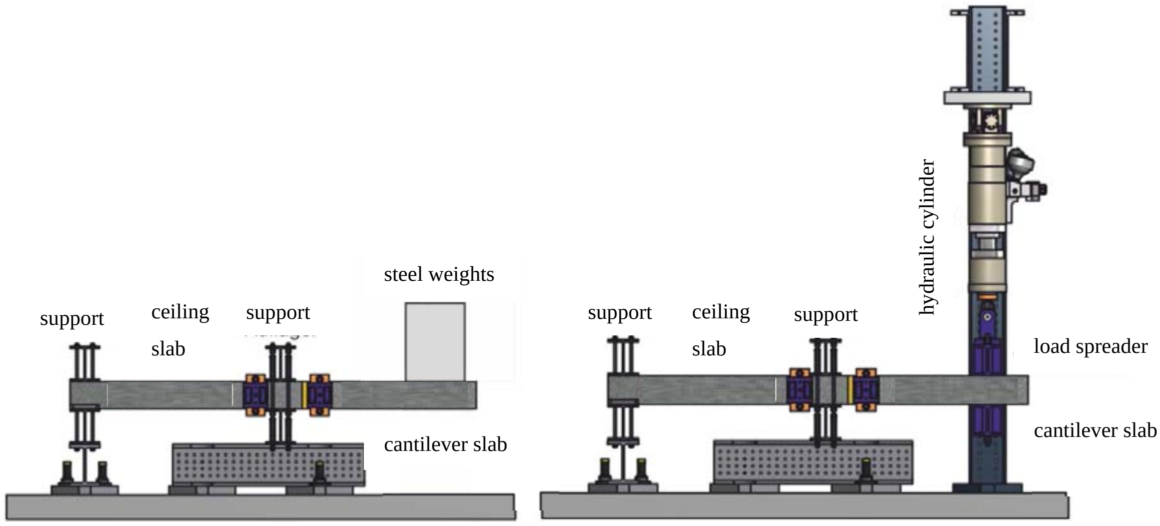

Figure 5. Sections arrangement of test setup (horizontal and vertical)

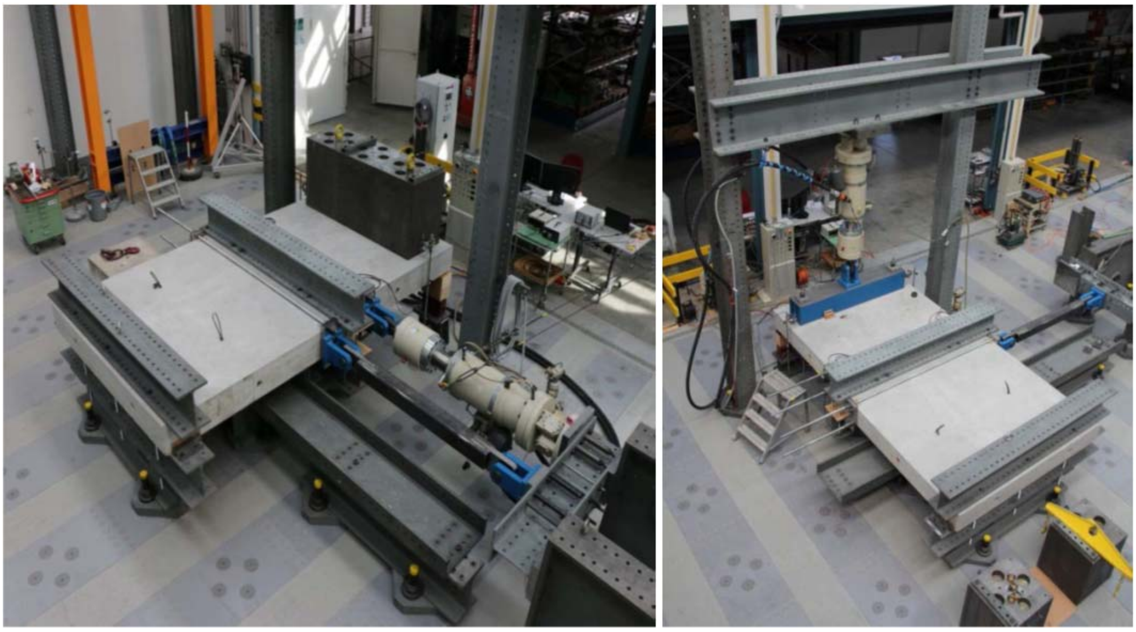

Figure 6. Pictures arrangement of test setup (horizontal and vertical)

3 THERMAL AND SEISMIC TESTS ON THERMAL BRAKE ELEMENTS

The tests at the EMPA are intended to supplement the results of the existing scientific studies (approval attempts for Italy) in order to obtain a test result which is as close as possible to a typical application in Switzerland (large cantilever lengths, balcony length and ceiling thickness as well as high life expectancy).
Normally thermal break elements transmit only negative moments and positive shear forces, but in a seismic load case additional horizontal forces should be investigated. Relative displacements within the connection can lead to horizontal forces and deformations on the thermal break elements can lead to constraints and furthermore a collision of the building parts must be prevented.

<u>Load assumptions for seismic test:</u>

Self-weight cantilever slab	= 0.28 m × 25 kN/m^3	= 7 kN/ m²
Dead load (covering 8 cm)	= 0.08 m x 24 kN/m^3	= 2 kN/m²
Life load (30% for seismic case)	= 0.3 × 3 kN/m²	= 0.9 kN//m²
Edge load (balustrade)	= 0.8x0.2 m x 25 kN/m^3	= 4 kN/m

The test includes three phases, first, the fatigue of the connection by horizontal cycles, which simulated the temperature elongation for a lifetime of 80 years, they have been derived from the directive EAD 050001-00-0301 (draft) with factor for cycles 1,6 for the increase from 50 to 80 years life time. Second, after the artificial aging, with vertical cycles, this simulated the seismic influence on the connection. Third and last with separated earthquake module EQM. The variable displacements were applied with hydraulic cylinders and measured by laser devices.

Table 1. Test program

Phase 1: Fatigue from temperature		
1a) natural frequencies before fatigue		
1b) Fatigue from temperature: forced horizontal displacement for a maximum joint distance of 13.0 m and a building life time of 80 years.		
Step	number of cycles	Relative path
1	1'600 à 0.32-0.34 Hz	+/-1.14 mm (ΔT = 40°C)
2	160 à 0.23-0.24 Hz	+/-2.00 mm (ΔT = 70°C)
3	3’200 à 0.27-0.31 Hz	+/-1.71 mm (ΔT = 60°C)
4	30’400 à 0.65-0.68 Hz	+/-1.14 mm (ΔT = 40°C)
1c) natural frequencies after fatigue		
Phase 2: Vertical earthquake: forced vertical displacement without steel weights. Zero position as before removing the steel-weights		
	umber of cycles	Displacement
	5	+/-5 mm
	5	+/-10 mm
	5	+/-15 mm
Phase 3: Horizontal load resistance with divided EQM module and vertical loads from phase 1		
3a) Hysteresis: 5 cycles with forced displacement of +/- 4 mm		
3b) Breaking test		

Before and after the fatigue loadings, the horizontal and vertical natural frequencies were determined in order to identify any damage to the cantilever plate construction. The seismic cycles were selected according to a previous Italian approval attempt and applied in addition to the static deflection, the vertical loads were limited for safety reasons to 1.4 times of the planed maximum bending moment, but remained with 168,2kN slightly below this value. Thereafter additional horizontal cycles were applied before the horizontal displacement was increased to failure to determine the end stiffness.

4 NUMERICAL RESULTS

4.1 Natural frequencies (phase 1a and 1c)

Before the fatigue cycles, the natural frequency of the cantilever slab was determined in the direction along the cantilever slab connection to 12.75 Hz, after the fatigue cycles to 12.56 Hz. In the case of vertical excitation, a natural frequency of 7.25 Hz was measured before the fatigue cycles and after the fatigue cycles to 7.19 Hz.

4.2 Measured values from the fatigue cycles (phase 1b)

4.2.1 Step 1: 1.600 cycles +/- 1.14 mm

At beginning of this cycle a load change of +/- 190 kN was measured with a displacement of +/-1.14mm. After 1600 cycles, the load change was still about +/- 140 kN. The vertical deformations of the plate head increase by 1.2 mm during step1.

4.2.2 Step 2: 160 cycles +/- 2.00 mm

At beginning of this cycle a load change of +/- 205 kN was measured with a displacement of +/-2.00mm. After 160 cycles, the load change was still about +/- 182 kN. The vertical deformations of the plate head increase by further 0.5 mm during step 2 to about 1.7 mm at the end of step 2.

4.2.3 Step 3: 3.200 cycles +/- 1.71 mm

At beginning of this cycle a load change of +/- 160 kN was measured with a displacement of +/-1.71mm. After 3.200 cycles, the load change was still about +/- 105 kN. The vertical deformations of the plate head increase by further 0.4 mm during step 2 to about 2.1 mm at the end of step 3.

4.2.4 Step 4: 30.400 cycles +/- 1.14 mm

During of this cycle constant load change of +/- 70 kN was measured with a displacement of +/-1.140mm. The vertical deformations of the plate head stay by 2.1 mm at the end of step 4.

4.3 Measured values during phase 2

In phase 2 vertical displacements of +/- 5 +/- 10 and +/- 15 mm were imposed in 5 cycles each. At the start of the experiment with a 5 mm deflection a stiffness of 14.66 kN / mm was measured, at the test end with 15 mm deflection a stiffness of 12.27 kN / mm. The stiffness loss is thus about 16%. The remaining displacement after completion of the load cycles is 7.2 mm

4.4 Measured values during phase 3

In phase 3, were first 5 load cycles with forced horizontal displacements of +/- 4mm applied, thereafter the test body was loaded monotonically horizontally until it breaks. The horizontal load resistance was reached with 187.5 kN at a displacement of 15 mm. The vertical load-bearing resistance was also sufficient at the end of the test to support the applied permanent loads with vertical shifts of around 30 mm.

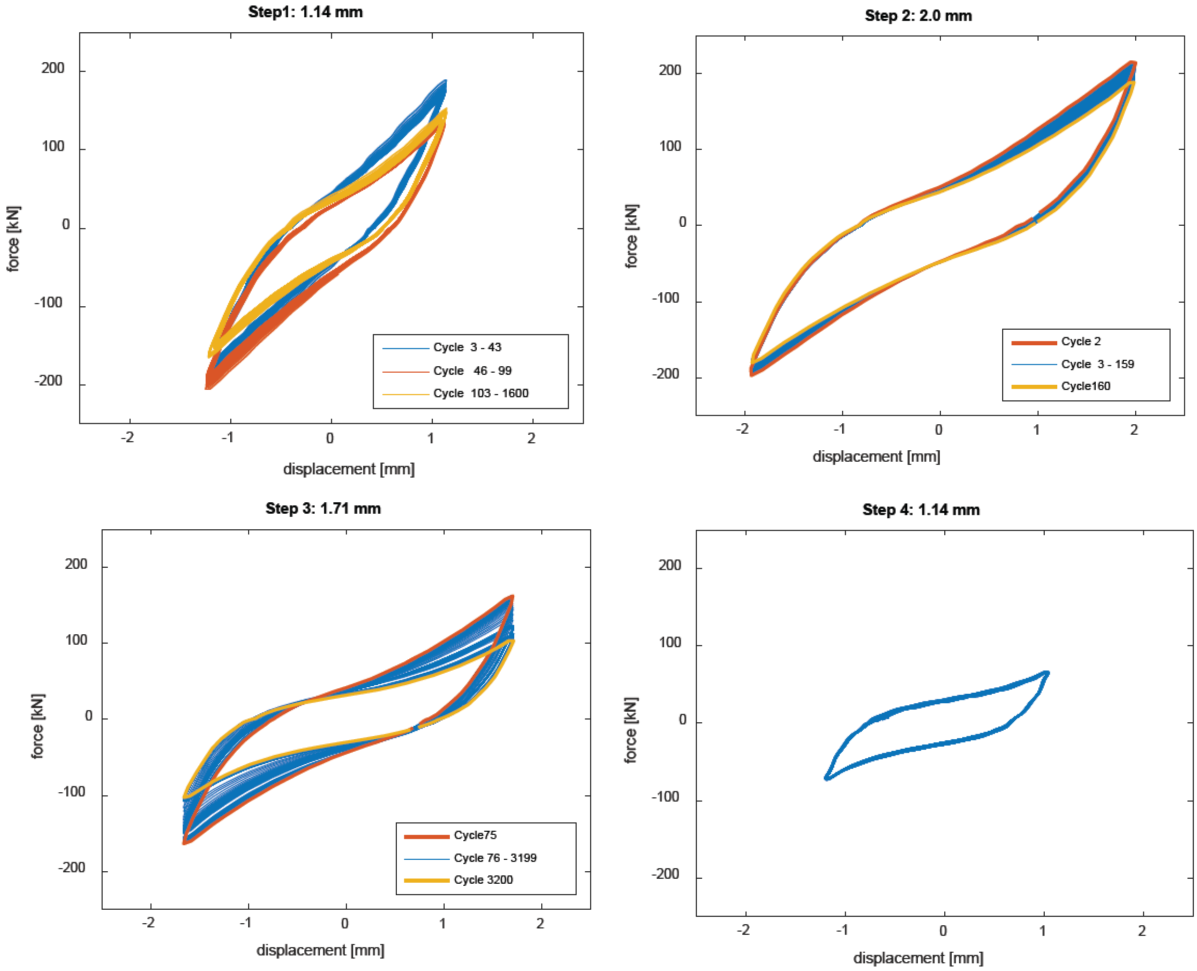

Figure 7. Fatigue cycles (Step 1-4: Hysteresis)

5 CONCLUSIONS

The Schöck Isokorb® thermal break elements have very good-natured characteristics regarding their behavior under seismic loadings:

The horizontal stiffness and the horizontal load-bearing capacity of the tested cantilever slab connections, even without the earthquake module Isokorb type EQM are highly and remain high unaffected even in the case of forced deformations at a very large deformation range. Even far beyond the achievement of the maximum horizontal resistance, the vertical bearing capacity of the tested thermal break elements are at least high enough to absorb the value determined by standard vertical loads to prevent a fall of the connected balcony.

6 REFERENCES

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