

MEMO 62
TSS / RVK
SEISMIC PROPOSAL

Dato: 15.04.2014
Siste rev.: 19.05.2016
Dok. nr.: K3-11/62E

Sign.: PJ/SB
Sign.:
Kontr.: ES

PLANNING

SEISMIC PROPOSAL

1. Basic design philosophy

In seismic design the ductility of a structure is a central concept, defined as follows:

Ductility is the ability to deform beyond the elastic limit without losing strength or function.

In seismic events the actions will vary dynamically, primarily with equal magnitude in opposite directions. To maintain strength and function during a seismic event, three conditions must be satisfied:

- The materials must have sufficient deformation capability.
- The components (joints, beams, columns, slabs, diaphragms and shear walls) must be able to absorb large repetitive deformations, strains or curvatures.
- The load carrying structure must be composed of the ductile components to form a deformation mechanism.

2. Ductility classes

The European standard on seismic design [EN 1998-1:2004, Design of structures for earthquake resistance. Part 1: General rules, seismic actions and rules for buildings. (EC8), reference] defines three ductility classes:

- Ductility Class Low (DCL).
- Ductility Class Medium (DCM).
- Ductility Class High (DCH).

3. Relationship between design calculations and ductility classes.

In DCL the design can be carried out according to the usual standards used for calculation of capacities. EC8 is used only to determine the actions from the earthquake.

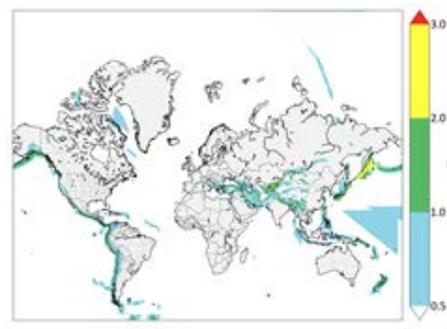
In DCM a ductile deformation mechanism must be identified. The mechanism is normally secured by using an “overstrength” factor for areas of the structure where plastic hinges may make the deformation mechanism unstable. The design procedure will lead to seismic actions smaller in DCM than in DCL. EC8 has detailed requirements to the calculation procedure and execution at the site.

Designing in DCH is carried out as in DCM, the difference being that there are stricter and more detailed requirements to the calculation procedure and execution at the site.

4. Earthquake definitions

Building codes around the world are classifying the earthquake areas depending on the earthquake intensity in g (gravity). Normally we hear about intensities according to the Richter scale. Below we have made an approximate comparison between the two measuring methods.

0,47g ->	4,0-6,0	Richter
0,73g ->	5,0-7,0	Richter
1,33g ->	6,0-7,5	Richter
2,00g ->	above 7	Richter
3,00g ->	above 7,5	Richter



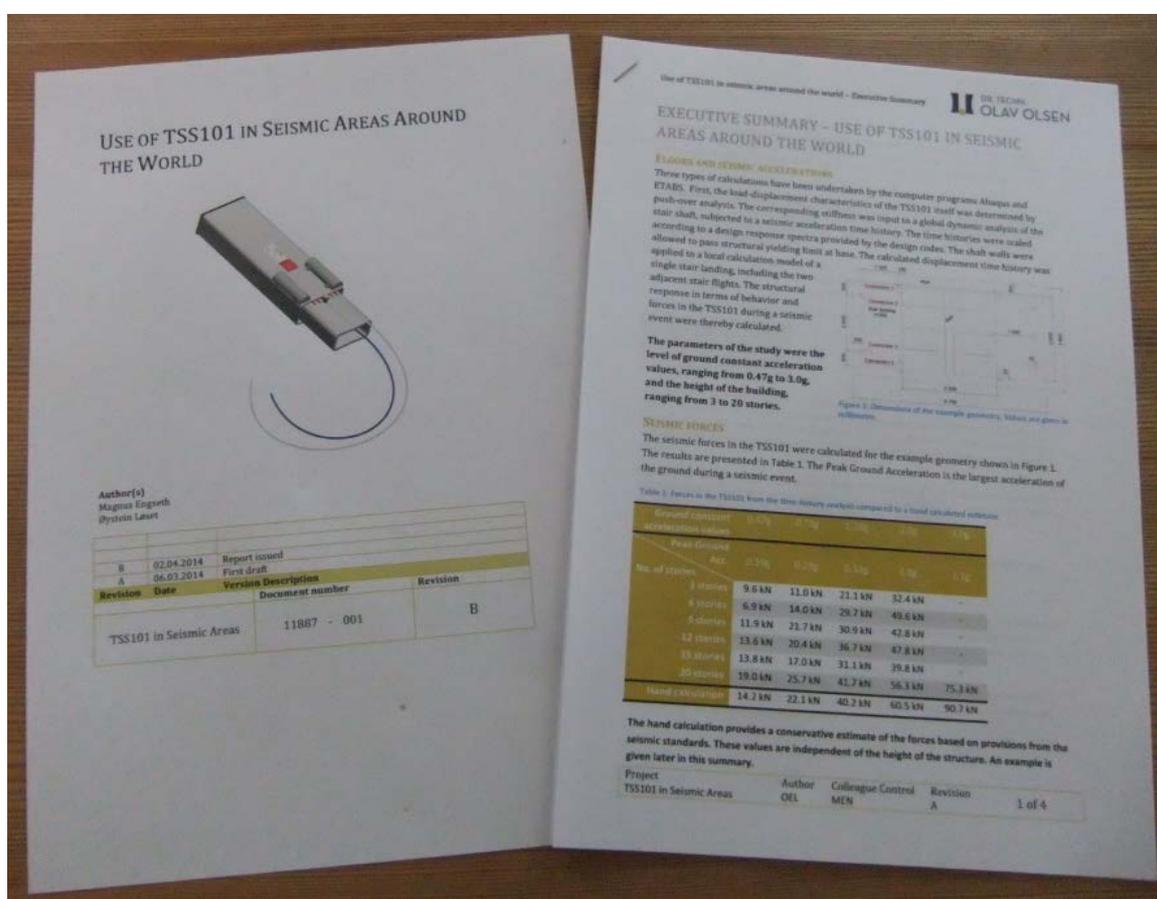
5. Testing and analysis

In 2013-2014 we hired the well reputed consulting company Dr. Techn. Olav Olsen to make a comprehensive study of the TSS connections for stairways exposed to earthquake conditions. The aim of this study was to identify the relevant requirements in the governing seismic design codes in USA, Europe, New Zealand and China. The performance of the TSS101 during an earthquake was then analyzed and compared to the demands set forth in the standards.

A number of different analyses were run to ensure that the TSS101 satisfies these demands. A pushover analysis of the connection itself was carried out to reveal the strength, stiffness and ductility properties of the connection. These results were then used to model the TSS101 as a set of linear springs. These springs were used as a simplification of the TSS101 in a global model.

A parameter study was carried out, where the height of the structure and the strength of the earthquake was varied. Two recorded time-histories were taken from a database of strong motion earthquakes and scaled to fit the design spectrums of the different earthquake intensities. The height varied from 3 to 20 stories and the constant part of the design response spectrum varied from 0.47g to 3.0g. The response of the global model was calculated for all the sets of parameters.

The results from the testing and analyses are recorded in two reports dated 02.04.2014 (*Main report – 40 pages, Executive Summary – 4 pages*),



6. Key conclusions

1. Invisible connections efficiently reduce the energy transfer. *“Forces in the landing will be reduced during seismic actions compared to full in-situ cast concrete constructions”*.
2. Forces to our TSS 101 are far below their capacity on all simulation tests on earthquakes up to 3g, **independent of the height** of the structure.- **utilizing a standard connection detail.**

3. *“Analysis shows that TSS101 demonstrates a behavior which puts it within the scope of the seismic design standards. It fulfills the requirements that allow the engineer to dimension the staircase without the need for special analyses. “*
4. The standard reinforcement provided by the manufacturer is sufficient to carry the earthquake forces.
5. Calculations show that the forces can be further reduced by using special rubber solutions connections between the landing and the wall.

7. Capacity control of RVK or TSS units.

The maximum forces acting on the TSS101 during a seismic event can be estimated by simple hand calculations. These hand calculations are based on Newton's second law, which says that the force equals mass multiplied with acceleration. The maximum acceleration at each floor (PFA) is calculated by magnifying the PGA with a factor. This factor is given by the seismic design codes.

$$PFA = PGA \cdot C(z, H) \geq PGA$$

Where:

PFA = Peak Floor Acceleration at level z in structure

PGA = Peak Ground Acceleration

C = Floor magnification factor

z = Floor height

H = Roof height

The New Zealand Standard gives the most conservative factor, so this is used in the following example, controlling the capacity of a TSS 101 unit.

The mass of stair flight and landing affecting the TSS101 unit considered can be calculated by visual geometrical division, provided the sum of subdivided mass equals the total mass.

Section 8.3 in NZS 1170.5:2004 prescribes a magnification value of 3.0.

Connection 1 and 4 in **Feil! Fant ikke referansebildet.** (see below) carry most of the mass, and therefore experience the highest seismic loads.

Each of these connections carry one half of the landing and one half of the stair. The mass of the structure is:

$$M = 2500 \text{ kg/m}^3 \cdot \left(\frac{3 \text{ m} \cdot 1.5 \text{ m} \cdot 0.265 \text{ m}}{2} + \frac{3.3 \text{ m} \cdot 1.45 \text{ m} \cdot 0.175 \text{ m}}{2} \right) = 2537 \text{ kg}$$

We assume that the stairs need to carry 500 kg/m^2 . In the Accidental Limit State (ALS) table 4.1 of NZS 1170.0:2002 provide a combination factor for live load of 0.6. I.e. the stair needs to carry 300 kg/m^2 during a seismic event. The mass from live load acting on one of the connections is therefore:

$$m = 300 \text{ kg/m}^2 \cdot \left(\frac{3 \text{ m} \cdot 1.5 \text{ m}}{2} + \frac{3.3 \text{ m} \cdot 1.45 \text{ m}}{2} \right) = 1393 \text{ kg}$$

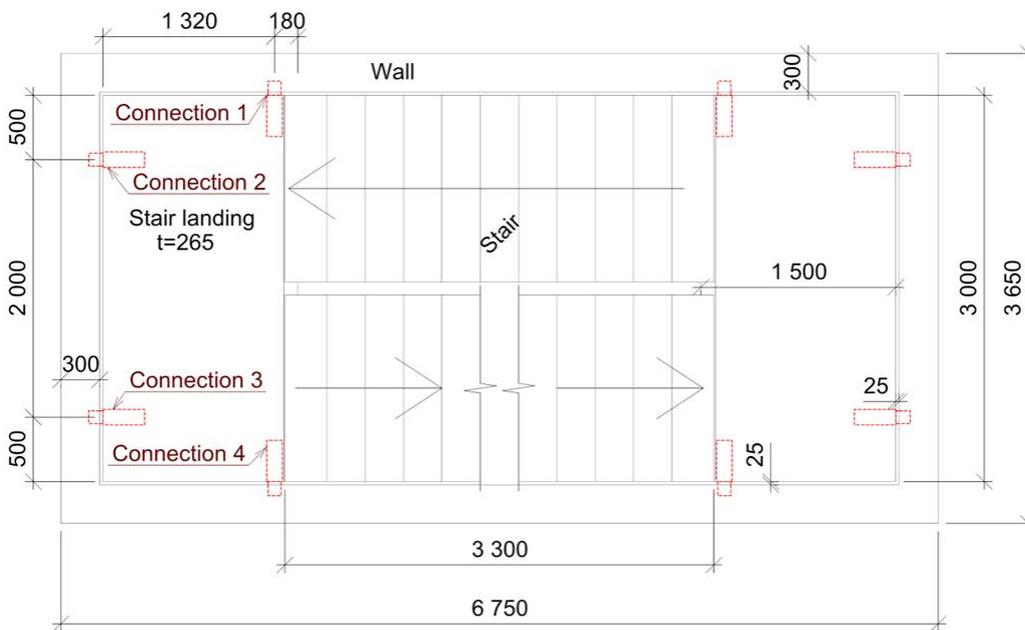


Figure 1.

We calculate the forces in the TSS101 for a quake with PGA equal to 1.2g. Given the floor magnification factor above, the PFA is:

$$PFA = 3.0 \cdot 1.2g = 3.6g$$

Now we have everything we need to calculate the horizontal force in the TSS101.

$$F_{max} = (M + m) \cdot PFA = (2537 \text{ kg} + 1393 \text{ kg}) \cdot 3.6 \cdot 9.81 \text{ m/s}^2 = 139 \text{ kN}$$

In the NZ standard the floor magnification factor varies linearly between 1.0 and 3.0 from the ground and up to 20% of the building's height. From there on and up the magnification is constant and equal to 3.0. The factor in the Eurocode varies linearly from 1.0 to 2.5 from the ground to the roof. The US standard actually provides a reduction factor between 0.5 and 1.0. This is in contradiction with results from this study.

Correspondingly to the capacity of TSS101, which is 213kN, this gives a moderate utilization of 64 % for a very large earthquake.

Using the calculation method above, we might be able to calculate the capacity utilization of;

- Any type of RVK or TSS unit
- Any type or shape of landing or stairway.
- From various code requirements.

If the capacity utilization from such an analysis is too high, we have options!

Invisible Connections AS has developed various possibilities for energy damping utilizing rubber. In the following pages we have shown some idea;

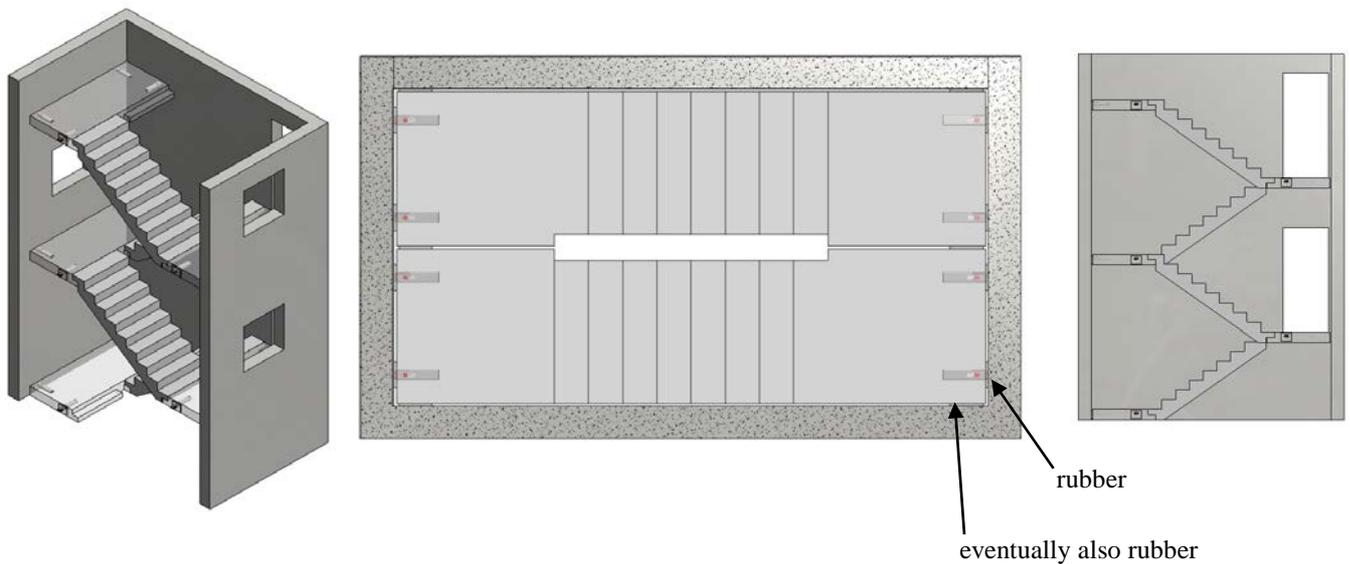


Figure 2.

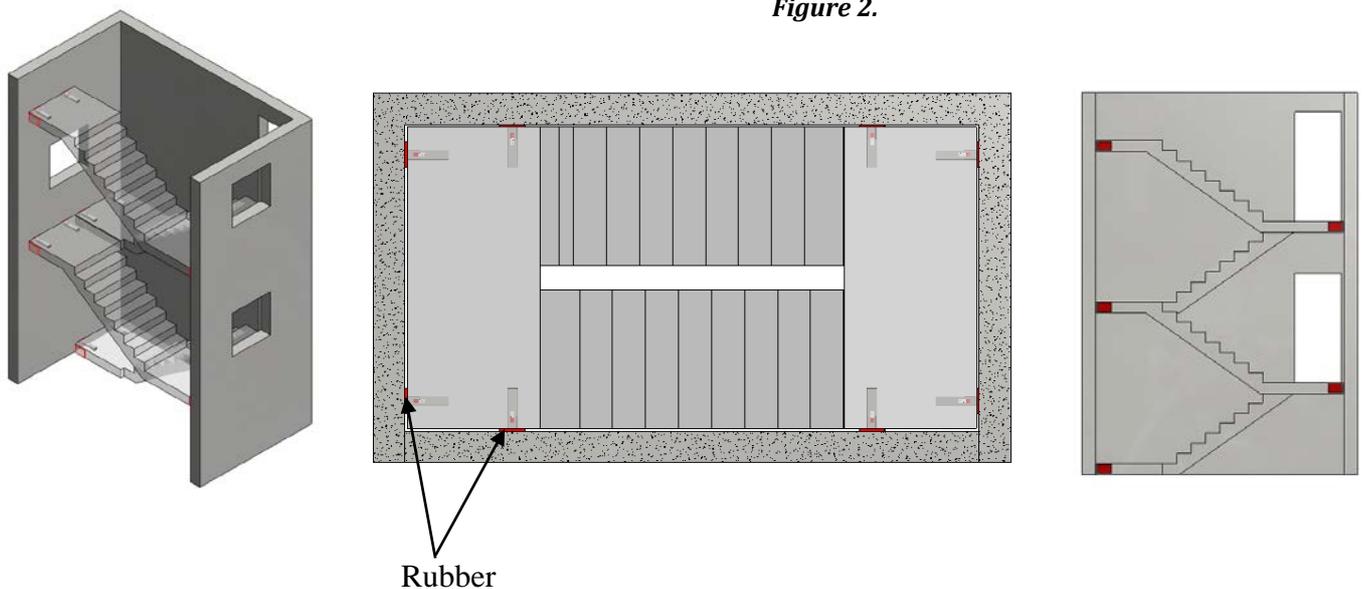
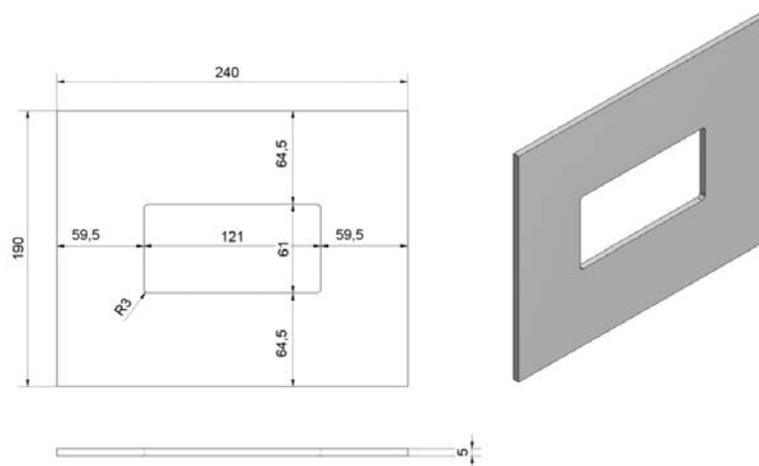


Figure 3.

By using rubber damping the energy transformation might be reduced, - depending on hardness of rubber, rubber thickness, rubber area and the shaping of the rubber.

Example:

Vertical rubber flange Memo 41 for TSS101 can be used to transfer seismic forces. The rubber flange can then take forces from the stairs as shown in Figure 3



The rubber flange is 60 shore and at approx.

With 30% compression can it transmit/attenuate approx. 4N/mm².

The rubber flange have an square at 38219 mm².

And the calculation: $38219 \cdot 4N = 152876 N \Rightarrow 153 \text{ kN}$