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MEMO 71 iC SOLUTION FOR EARTHQUAKE AND STAIRS IN BUILDINGS -SPREADSHEET DESIGN	Date: 08.02.2021 Last rev.: 08.03.2021 Doc. no.:	Sign.: SSS Sign.: SSS Control: MEN IC Contr: SB

iC SOLUTION FOR EARTHQUAKE AND STAIRS IN BUILDINGS - SPREADSHEET

DYNAMIC FORCES

The dynamic system is simplified due to the sliding solution at the bottom of the stair, preventing constraining forces. During an earthquake, one landing, together with the connected stair, will follow the displacement and acceleration of the wall, at the level of the landing connections.

To accelerate the landing and stair, the connections between the landing and wall will (in sum) experience a horizontal force that equals the product of mass and acceleration, F=M·a. Where:

M = Mass of stair + Mass of landing + Mass of live load.

a = design peak acceleration at the relevant floor level (PFA).

EC8 /6/ provides a simplified way of calculating the peak floor acceleration (PFA) based on the peak ground acceleration. Typically, PFA is found as 1-2,5 times the PGA. Irregular and complex structures may require more sophisticated evaluations to find a more precise value.

As illustrated in Figure 1, the external force required to accelerate the stair and landing in positive x-direction will come into the landing as direct pressure (C_1) through the grouting around the connections at the rear of the landing. The force required to accelerate the stair and landing in negative x-direction will be applied as transverse shear forces (H_1) in the connections at the front of the landing. It is assumed that connections do not carry tension loads and that the compressive stiffness is much higher than the shear stiffness.

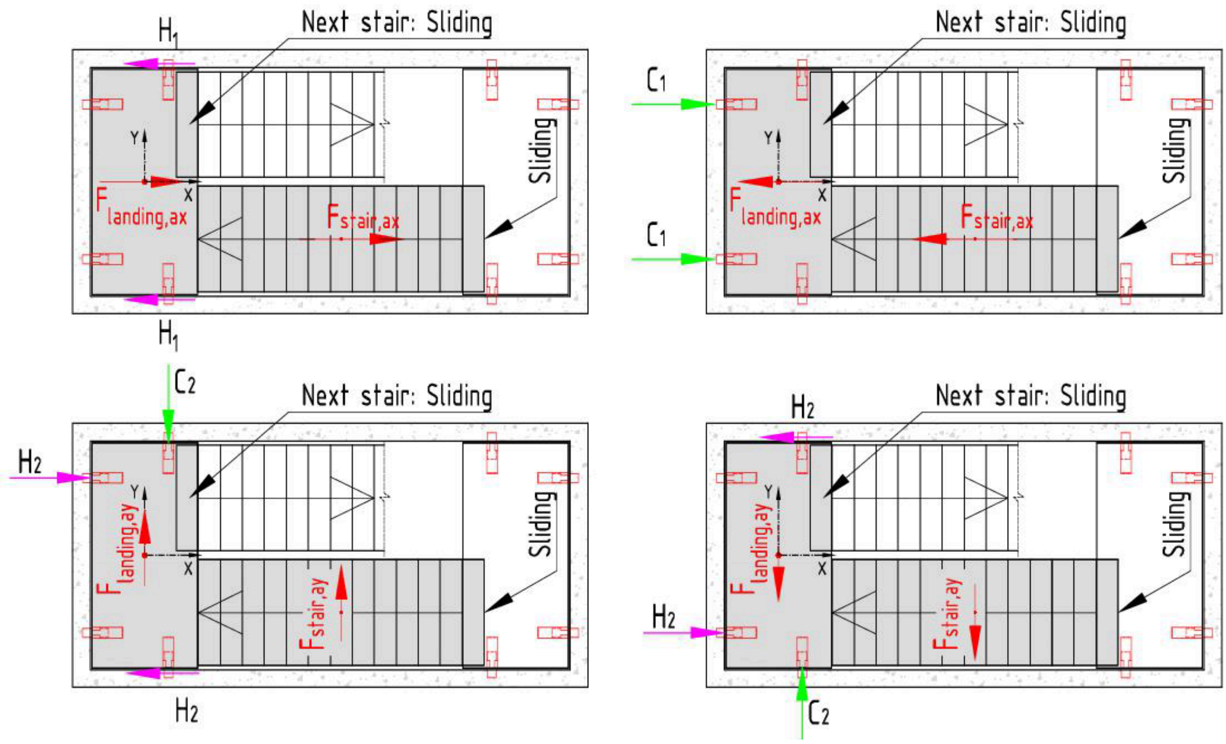

Figure 1: Principal transfer of forces between landing and wall – acceleration parallel and perpendicular to stair.

The horizontal force required to accelerate the stair and landing in positive y-direction will come into the landing as direct pressure(C_2) through the grouting around the front connection. Rotation caused by the eccentricity to the mass centres of the stair and landing is prevented by a force couple in x-direction (H_2). When the direction of the acceleration changes, the forces are mirrored, as illustrated.

Dr.techn. Olav Olsen has developed a spreadsheet where the seismic load on the different connections can be found when PFA is known. The spreadsheet can be downloaded from iC's homepage.

A user guide for the spreadsheet is found in the following chapter, together with a simplified method for calculation of PFA.

DESIGN BASIS - EARTHQUAKE

NB: This Chapter collects information from several Eurocodes. Effort has been made to verify that the values are referred correctly, but errors may occur. Many parameters are to be decided in accordance with National appendixes. In these cases, values according to the Norwegian national appendixes are given. Final design shall always be done in accordance with values and methods taken directly from the current version of the Eurocode, and applicable National appendixes.

MATERIAL SAFETY FACTOR

Table 1 summarizes the material safety factors for different limit states.

CONCRETE:			**Reference**
Limit state	γ_c	γ_s	EC2 /4/ EC8 /6/
Ordinary ULS	1,5	1,15	
Seismic DCL	1,2	1,0	
Seismic DCM	1,5	1,15	
STEEL:			**Reference**
Limit state		γ_s (γ_M)	EC3 /5/ EC8 /6/
Ordinary ULS	*General*	1,05	
	Tension	1,25	
Seismic DCL	*General*	1,05	
	Tension	1,25	
Seismic DCM	*General*	1,1	
	Tension	1,25	

Table 1: Material safety factors.

MASSES AND LOAD COMBINATIONS

<u>Masses - earthquake forces:</u>

According to EC8 /6/, clause. 3.2.4 (2), the inertia forces shall be calculated using a mass representing an approximate permanent situation.

$$\sum G_{k,j} + \sum \psi_{E,i} \cdot Q_{k,i}$$

Where: $G_{k,j} = characteristic\ value\ dead\ load$

$Q_{k,i} = characteristic\ value\ live\ load$

$\psi_{E,i} = \varphi \cdot \psi_{2,i}$, clause. 4.2.4

$\varphi = 1.0$ according to EC8 /6/, Table NA 4.2.

$\psi_{2,i}$ according EC0 /2/, Table NA. A1.1.

The same value for the permanent and live masses shall be included when calculating the earthquake forces as when calculating the separate load reactions.

Combination of actions:

Earthquake is an accidental load. The forces from the earthquake shall be combined according to EC0 /2/, Table NA.A1.3, see Table 2 below:

Permanent loads	Earthquake load	Dominating variabel load	Other variabel loads
1,0	1,0	0,0-0,8 (ψ_2)	0,0-0,8 (ψ_2)

Table 2: Combination of actions, EC0 /2/.

Live load in buildings is related to the use of the building. Load factor ψ_2 for approximate permanent situation is given in EC0 /2/, Table NA. A1.1.

USE OF IC's EARTHQUAKE SPREADSHEET

I) INPUT PART:

The spreadsheet is based on the original spreadsheet for calculation of static loads on the landing connections. The input part of the spreadsheet is illustrated in Figure 2.

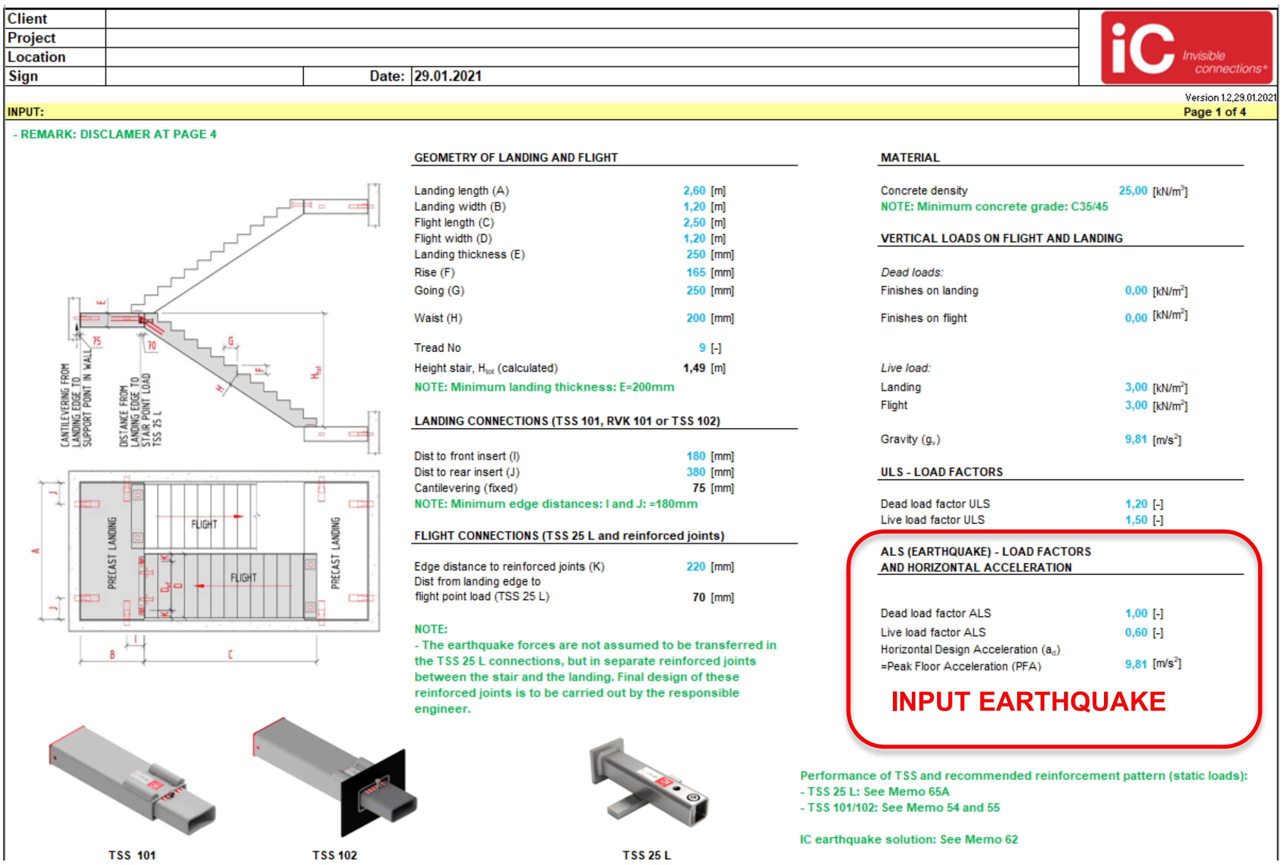

Figure 2: Input part of IC spreadsheet.

To calculate the load on the connections, three new input parameters are defined:

1) Dead load factor ALS:

This parameter sets the part of the defined dead load masses that becomes included when calculating the earthquake forces on the connections.

2) Live load factor ALS:

This parameter sets the part of the defined live load masses that becomes included when calculating the earthquake forces on the connections. «Live load factor ALS»= ψ_2

3) Horizontal design acceleration = Peak floor acceleration (PFA):
Horizontal design acceleration in the building at the actual level of the connection between the landing and the wall. (Maximum occurring horizontal acceleration including amplifications factors due to soil conditions and magnification factor due to building height).

The peak floor acceleration is assumed to work in an arbitrary direction, and the spreadsheet calculates the maximum forces in the landing and stair connections for three separate situations:

- PFA works parallel to stair, see Figure 1
- PFA works perpendicular to stair, see Figure 1
- PFA works in direction α_{max} to the stair, where α_{max} represents the angle yielding maximum axial force (N_{MAX}) in the joints between the stair and the landing. N_{MAX} and α_{max} is calculated in the spreadsheet.

In some cases, PFA can be calculated in accordance with simplified equations. Section 4.3.5.2 in EC8 treats the verification of non-structural elements. According to /1/ one can argue that the stair and landings are non-structural elements, and Eurocode provides a way of calculating the floor acceleration based on the peak ground acceleration:

$$S_a = \alpha S \cdot \left[\frac{3\left(1+\frac{z}{H}\right)}{1+\left(1-{}^{T_a}/_{T_1}\right)^2} - 0{,}5 \right] \geq \alpha S$$

Reformulated this can be written:

$$PFA = PGA \cdot \left[\frac{3\left(1+\frac{z}{H}\right)}{1+\left(1-{}^{T_a}/_{T_1}\right)^2} - 0{,}5 \right] \geq PGA$$

Where:

PGA = Peak ground acceleration at the fundament of the building, included amplification due to soil condition. Where:
z = Floor height
H = Roof height
T_a = Fundamental period of part
T_1 = Fundamental period of structure

Assuming the fundamental period of the stair is much less than that of the structure (T_a/T_1=0), the expression simplifies and the magnification factor at the top story becomes 2.5. This is illustrated in Figure 3.

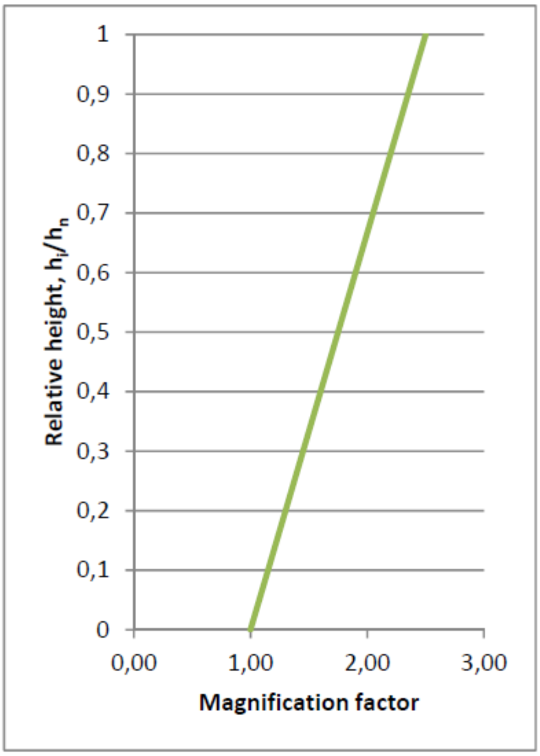

Figure 3: Floor height coefficient according to EC8, assuming T_a<<T_1.

II) OUTPUT PART:

Results for inserts in landing.

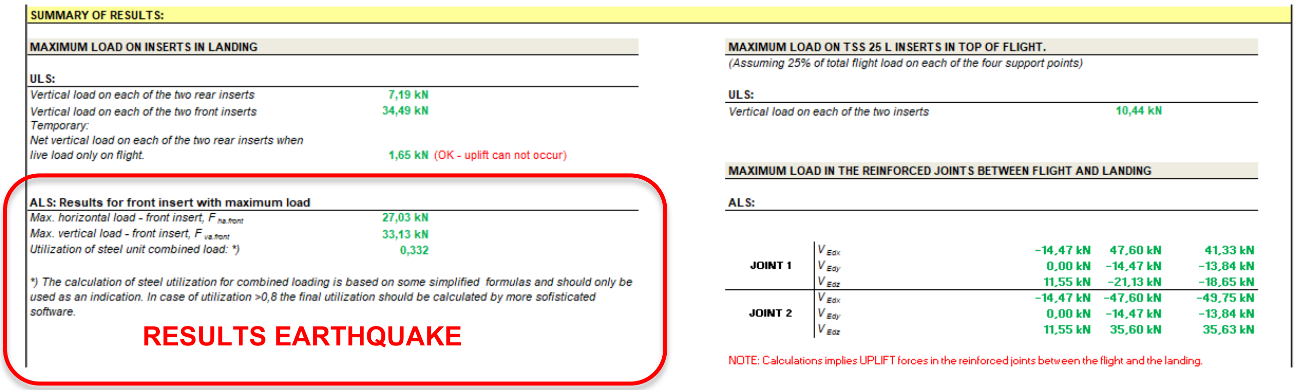

Figure 4: Results for inserts in landing.

The load on the inserts in the landing can be found on the left side in the result part of the spreadsheet. At top, the forces for the ULS situation are given (static evaluation), while the forces in earthquake situation is given at the bottom. The maximum vertical load, together with the simultaneous working horizontal load, is given for the front inserts, as these are supposed to experience the worst load combination. A combined utilization factor for the inserts is also calculated according to EC3.

Results for joints in flight.

The load on the flight joints can be found on the right side in the result part of the spreadsheet. At top, the forces on the two TSS 25 L inserts are given in the ULS situation (static evaluation). At the bottom, the calculated forces occurring in the reinforced joints during the earthquake situation is listed.

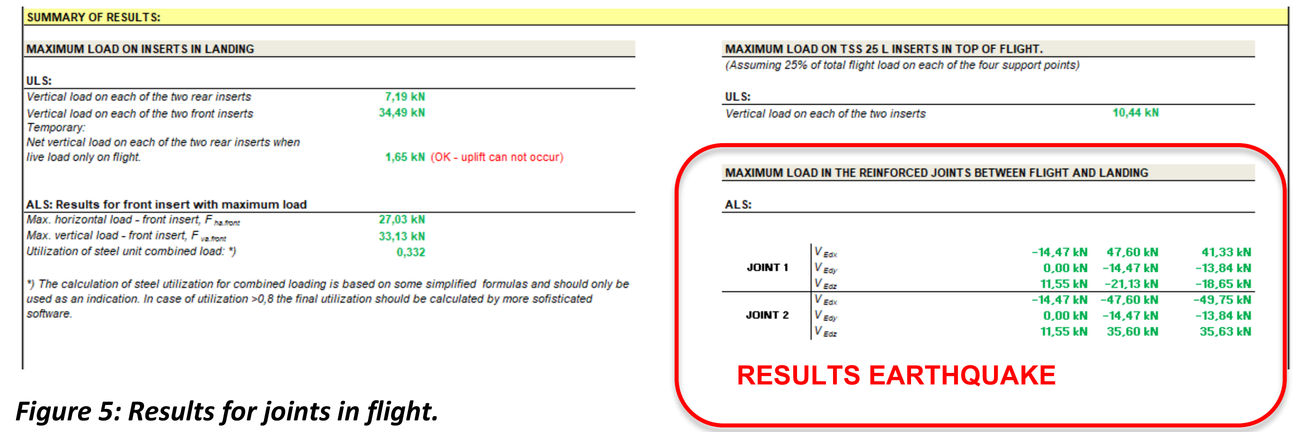

Figure 5: Results for joints in flight.

The forces are reported in accordance with the axis and sign convention in Figure 5.

- $V_{Ed,x}$: Horizontal force working in axial direction of the insert.
- $V_{Ed,y}$: Horizontal force working transverse to the direction of the insert.
- $V_{Ed,z}$: Vertical support force.

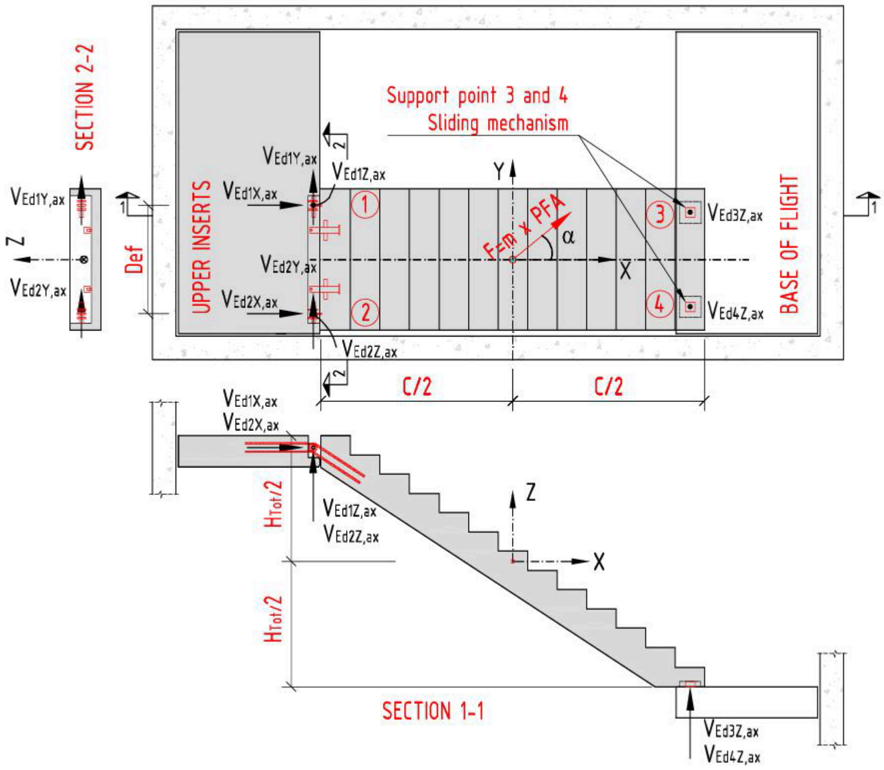

Figure 6: Definition of axis.

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EKSAMPEL

Assuming a building where the horizontal acceleration (PFA) at the relevant level is calculated as: 1g=9.81m/s^2. Assuming 60% live load during the earthquake.

Geometry. See also input part in spreadsheet, Figure 6:

- Floor height: approximate 3m
- Thickness landing: 250mm
- Width of stair and landing: 1200mm

Client			
Project			
Location			
Sign		Date:	29.01.2021

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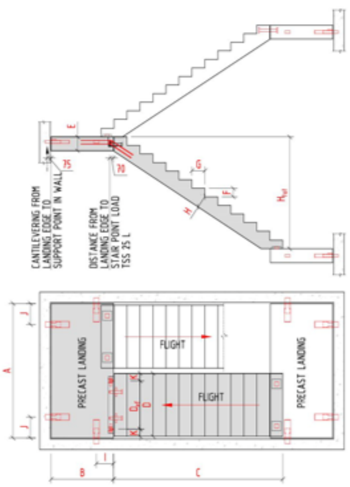


GEOMETRY OF LANDING AND FLIGHT

Landing length (A)	2,60	[m]
Landing width (B)	1,20	[m]
Flight length (C)	2,50	[m]
Flight width (D)	1,20	[m]
Landing thickness (E)	250	[mm]
Rise (F)	165	[mm]
Going (G)	250	[mm]
Waist (H)	200	[mm]
Tread No	9	[-]
Height stair, H_{tot} (calculated)	1,49	[m]

NOTE: Minimum landing thickness: E=200mm

LANDING CONNECTIONS (TSS 101, RVK 101 or TSS 102)

Dist to front insert (I)	180	[mm]
Dist to rear insert (J)	380	[mm]
Cantilevering (fixed)	75	[mm]

NOTE: Minimum edge distances: I and J: =180mm

FLIGHT CONNECTIONS (TSS 25 L and reinforced joints)

Edge distance to reinforced joints (K)	220	[mm]
Dist from landing edge to flight point load (TSS 25 L)	70	[mm]

NOTE:
- The earthquake forces are not assumed to be transferred in the TSS 25 L connections, but in separate reinforced joints between the stair and the landing. Final design of these reinforced joints is to be carried out by the responsible engineer.

MATERIAL

Concrete density	25,00	[kN/m³]

NOTE: Minimum concrete grade: C35/45

VERTICAL LOADS ON FLIGHT AND LANDING

Dead loads:		
Finishes on landing	0,00	[kN/m²]
Finishes on flight	0,00	[kN/m²]
Live load:		
Landing	3,00	[kN/m²]
Flight	3,00	[kN/m²]
Gravity (g_n)	9,81	[m/s²]

ULS - LOAD FACTORS

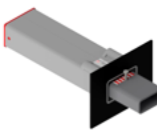
Dead load factor ULS	1,20	[-]
Live load factor ULS	1,50	[-]

ALS (EARTHQUAKE) - LOAD FACTORS AND HORIZONTAL ACCELERATION

Dead load factor ALS	1,00	[-]
Live load factor ALS	0,60	[-]
Horizontal Design Acceleration (a_d)	9,81	[m/s²]

NOTE:
- Horizontal Design Acceleration is the peak floor acceleration (PFA) in the building, at the level of the connection between the landing and the wall.

TSS 101



TSS 102

TSS 25 L

Performance of TSS and recommended reinforcement pattern (static lo
- TSS 25 L: See Memo 65A
- TSS 101/102: See Memo 54 and 55

IC earthquake solution: See Memo 62

SUMMARY OF RESULTS:

MAXIMUM LOAD ON INSERTS IN LANDING

ULS:

Vertical load on each of the two rear inserts	7,19 kN	
Vertical load on each of the two front inserts	34,49 kN	
Temporary:		
Net vertical load on each of the two rear inserts when live load only on flight.	1,65 kN	(OK - uplift can not occur)

ALS: Results for front insert with maximum load

Max. horizontal load - front insert, $F_{h,Steel}$	27,03 kN
Max. vertical load - front insert, $F_{v,Steel}$	33,13 kN
*Utilization of steel unit combined load: *)*	0,332

**) The calculation of steel utilization for combined loading is based on some simplified formulas and should only be used as an indication. In case of utilization > 0,8 the final utilization should be calculated by more sofisticated software.*

MAXIMUM LOAD ON TSS 25 L INSERTS IN TOP OF FLIGHT.

(Assuming 25% of total flight load on each of the four support points)

ULS:

Vertical load on each of the two inserts	10,44 kN

MAXIMUM LOAD IN THE REINFORCED JOINTS BETWEEN FLIGHT AND LAN

ALS:

JOINT 1	V'_{Ed}	-14,47 kN	47,60 kN	41,33 kN
	V'_{Ed}	0,00 kN	-14,47 kN	-13,84 kN
	V'_{Ed}	11,55 kN	-21,13 kN	-18,65 kN
JOINT 2	V'_{Ed}	-14,47 kN	-47,60 kN	-49,75 kN
	V'_{Ed}	0,00 kN	-14,47 kN	-13,84 kN
	V'_{Ed}	11,55 kN	35,60 kN	35,63 kN

NOTE: Calculations implies UPLIFT forces in the reinforced joints between the flight and the landing.

Figure 7: Example – results from spreadsheet.

Landing - wall connections:

The maximum forces on the landing connections are found as:

Maximum vertical force: $F_{va,front}$ = 33,13kN
Maximum horizontal force: $F_{ha,front}$ = 27,03kN

The utilization of the TSS 101 unit is low.

Stair – landing:

The stair and landing are cast separate. The maximum forces in the reinforced joints are found as:

Maximum tension: $V_{Ed,x}$ = 49,75kN ≈ 50kN
Maximum shear: $V_{Ed,y}$ = 14,47kN ≈ 15kN
Maximum vertical force: $V_{Ed,z}$ = 35,63kN ≈ 36kN

The forces in the stirrups are calculated according to the illustration in Figure 7 (simplification):

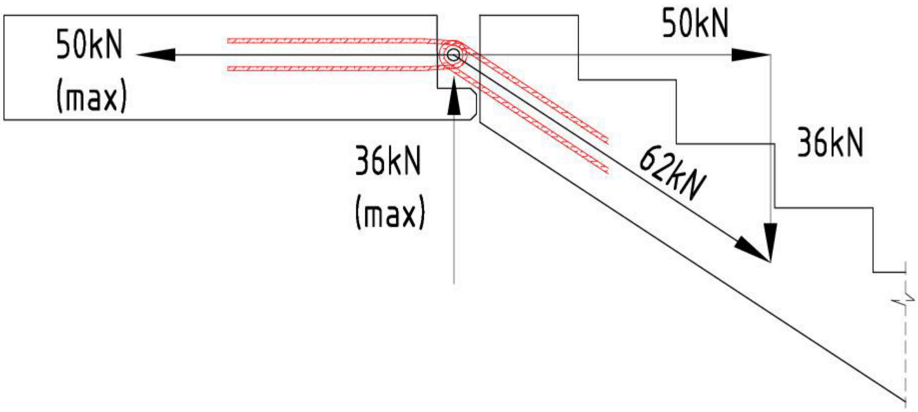


Figure 8: Forces in the joints between stair and landing.

Reinforcement in landing: $A_s = 50kN/500MPa = 100mm^2 \Rightarrow$ Select 2ø8 stirrups: A_s=200mm^2
Reinforcement in stair: $A_s = 62kN/500MPa = 124mm^2 \Rightarrow$ Select 1ø10 stirrup: A_s=157mm^2

E.g., Ø25 reinforcement bar as transverse “locking bolt” in the centre of the stirrups.

The example is not completely detailed. The project specific design must take care of all details in the force transfer and reinforcement detailing.

REFERENCES:

/1/ M. Engseth and Ø. Løset: «Use of TSS101 in Seismic Areas Around the World» Doc. No: 11887 - 001, rev B. 2014. Company: Dr.techn. Olav Olsen.

/2/ EN 1990 - (EC0). Basis of structural design.

/3/ EN 1991 - (EC1). Actions on structures.

/4/ EN 1992 - (EC2). Design of concrete structures.

/5/ EN 1993 - (EC3). Design of steel structures.

/6/ EN 1998 - (EC8). Design of structures for earthquake resistance.

REVISION HISTORY	
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08.02.2021	Preliminary edition
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