

HOLES AND NOTCHES

Thanks to high shear strength and tensile strength perpendicular to grain, holes and notches can be made on Kerto® LVL products. The holes can have round or rectangular shape. Design methods for holes are given in VTT certificate VTT-C-184/03.

Especially Kerto-Q with cross veneer structure is suitable for applications where holes for ventilation and drain pipes are needed.

SIZE AND LOCATION OF THE HOLES

In figure 1 and 2 are shown the general symbols to define the size and location of the holes.

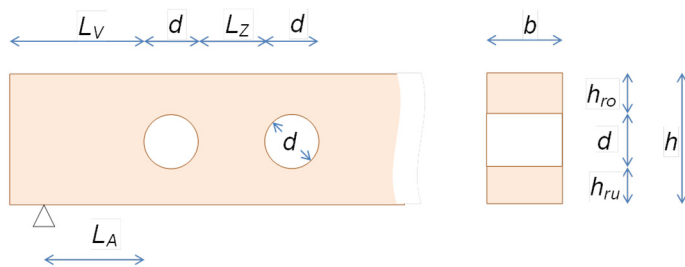


Figure 1. Definitions related to round holes.

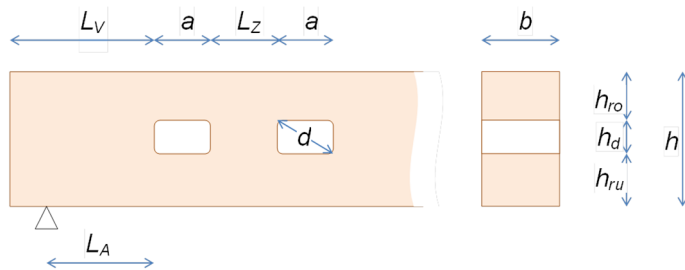


Figure 2. Definitions related to rectangular holes.

The design methods given in this document can be used when the following requirements 1 – 10 are fulfilled. Requirements are the same for both Kerto-S and Kerto-Q products.

General requirements for round and rectangular holes:

$$L_v \geq h \quad (1)$$

$$L_A \geq 0,5h \quad (2)$$

Additional requirements for round holes:

$$d \leq 0,7h \quad (3)$$

$$L_z \geq \max \begin{cases} 0,5h \\ 2,0d \end{cases} \quad (4)$$

In addition, when the centre of the hole is located on the neutral axis of the beam

$$h_{ro} \text{ and } h_{ru} \geq 0,15h \quad (5)$$

or when the centre of the hole is not located on the neutral axis of the beam

$$h_{ro} \text{ ja } h_{ru} \geq 0,25h \quad (6)$$

Additional requirements for rectangular holes:

$$a \leq 1,3h \quad (7)$$

$$h_d \leq 0,3h \quad (8)$$

$$h_{ro} \text{ and } h_{ru} \geq 0,35h \quad (9)$$

$$L_z \geq 1,5h \quad (10)$$

And the radius of curvature at each corner of the hole shall be minimum 15 mm.

DESIGN TABLES FOR HOLES

Table 1. Geometrical limitations for round holes in Kerto-S and Kerto-Q beams.

BEAM DEPTH	DISTANCE FROM THE BEAM END	DISTANCE FROM THE SUPPORT	CENTRE OF THE HOLE ON NEUTRAL AXIS		CENTRE OF THE HOLE NOT ON NEUTRAL AXIS	
			MAXIMUM DIAMETER OF THE HOLE	DISTANCE FROM THE EDGES OF THE BEAM	MAXIMUM DIAMETER OF THE HOLE	DISTANCE FROM THE EDGES OF THE BEAM
h [mm]	L_V min [mm]	L_A min [mm]	d [mm]	h_{ro} and h_{ru} min [mm]	d [mm]	h_{ro} and h_{ru} min [mm]
200	200	100	140	30	100	50
225	225	112,5	157,5	33,75	112,5	56,25
260	260	130	182	39	130	65
300	300	150	210	45	150	75
360	360	180	252	54	180	90
400	400	200	280	60	200	100
450	450	225	215	67,5	225	112,5
500	500	250	250	75	250	125
600	600	300	420	90	300	150

NOTE. In addition the distance between two holes $L_z = \max [0,5h; 2,0d]$

Table 1. Geometrical limitations for rectangular holes in Kerto-S and Kerto-Q beams.

BEAM DEPTH	DISTANCE FROM THE BEAM END	DISTANCE FROM THE SUPPORT	DISTANCE BETWEEN THE HOLES	MAXIMUM LENGTH OF THE HOLE	MAXIMUM HEIGHT OF THE HOLE	DISTANCE FROM THE EDGES OF THE BEAM
h [mm]	L_V min [mm]	L_A min [mm]	L_z min [mm]	a max [mm]	h_d max [mm]	h_{ro} and h_{ru} min [mm]
200	200	100	300	260	60	70
225	225	112,5	337,5	292,5	67,5	78,75
260	260	130	390	338	78	91
300	300	150	450	390	90	105
360	360	180	540	468	108	126
400	400	200	600	520	120	140
450	450	225	675	585	135	157,5
500	500	250	750	650	150	175
600	600	300	900	780	180	210

NOTE. The radius of curvature at corners of the hole shall be minimum 15 mm.

is given by

DESIGN OF KERTO-S BEAMS WITH HOLES

For both round and rectangular holes, the following design criterion shall be satisfied:

$$\sigma_{t,90,d} = \frac{F_{t,90,d}}{0,5bl_{t,90}} \leq 0,85k_{hole}k_{space}k_{t,90}f_{t,90,d} \quad (11)$$

where $\sigma_{t,90,d}$ and $f_{t,90,d}$ are the design values for tensile stress and tensile strength perpendicular to the grain. Length $l_{t,90}$ is calculated by

$$l_{t,90} = 0,35d + 0,5h \text{ round holes} \quad (12)$$

$$l_{t,90} = 0,5h_d + 0,5h \text{ rectangular holes} \quad (13)$$

Reduction factor $k_{t,90}$ for both round and rectangular holes

$$k_{t,90} = \min \left\{ \begin{array}{l} 1 \\ (450/h)^{0,5} \end{array} \right. \quad (14)$$

Beam depth h is given in millimeters.

Reduction factor k_{hole} is calculated as follows

$$k_{hole} = \min \left\{ \begin{array}{l} 1 \\ 1 - 1,5 \frac{d - 0,5h}{0,5h} \text{ round holes} \end{array} \right. \quad (15)$$

$$k_{hole} = 1 \text{ rectangular holes} \quad (16)$$

Reduction factor k_{space} is given by

$$k_{space} = \min \begin{cases} 1 \\ 1 - 0,8 \frac{h - L_z}{h} & \text{round holes} \\ 1 - 0,8 \frac{4d - L_z}{4d} \end{cases} \quad (17)$$

$$k_{space} = 1 \quad \text{rectangular holes} \quad (18)$$

The design tension load $F_{t,90,d}$ is calculated by

$$F_{t,90,d} = \frac{V_d h_d}{4h} \left(3 - \frac{h_d^2}{h^2} \right) + 0,008 \frac{M_d}{h_r} \quad (19)$$

where V_d is the design shear force and M_d is the design moment at the hole edge. For round holes $h_d = 0,7d$.

Distance h_r is given by

$$h_r = \min \begin{cases} h_{ro} + 0,15d \\ h_{ru} + 0,15d \end{cases} \quad \text{round holes} \quad (20)$$

$$h_r = \min \begin{cases} h_{ro} \\ h_{ru} \end{cases} \quad \text{rectangular holes} \quad (21)$$

In addition to the design criterion (11) the bending, shear, tensions and compression stresses of the beam shall be checked at the holes for cross-section reduced with the depth of the hole.

The design bending stress σ_d for holes of which centre is located at the neutral axis is given by

$$\sigma_{m,d} = \frac{M_d h}{2I_{red}} + \sigma_{add,d} \quad (22)$$

where M_d is the design moment calculated at the centre of the hole and I_{red} is calculated by

$$I_{red} = \frac{b}{12} (h^3 - d^3) \quad \text{round holes} \quad (23)$$

$$I_{red} = \frac{b}{12} (h^3 - h_d^3) \quad \text{rectangular holes} \quad (24)$$

For round holes bending stress $\sigma_{add,d} = 0$ and for rectangular holes it is given by

$$\sigma_{add,d} = \frac{M_{add,d}}{W_{ro}} = \frac{V_d a / 4}{bh_{ro}^2 / 6} = \frac{3V_d a}{2bh_{ro}^2} \quad (25)$$

Design tension and compression stresses $\sigma_{t,d}$ and $\sigma_{c,d}$ in the case that the hole is located at the neutral axis of the beam are given by

$$\sigma_{t,d} = \frac{F_{t,d}}{A_{red}} \quad (26)$$

$$\sigma_{c,d} = \frac{F_{c,d}}{A_{red}} \quad (27)$$

where $F_{t,d}$ and $F_{c,d}$ are the design tension forces at the centre of the hole and A_{red} is calculated by

$$A_{red} = b(h - d) \quad \text{round holes} \quad (28)$$

$$A_{red} = b(h - h_d) \quad \text{rectangular holes} \quad (29)$$

The design shear stress $\sigma_{v,d}$ for cases where the hole is located at the beam neutral axis ($h_{ro} = h_{ru}$) is given by

$$\sigma_{v,d} = 1,5 \frac{V_d}{A_{red}} \quad (30)$$

where V_d is the design shear force at the centre of the hole and A_{red} is calculated with equations 28 and 29.

DESIGN OF KERTO-Q BEAMS WITH HOLES

The same design method can be used for Kerto-Q beams with holes when the requirements 1-10 are fulfilled. In addition, the radius of curvature at the corners of the hole shall be at least 15 mm.

Due to the cross-plyed veneer structure, the tension strength perpendicular to grain of Kerto-Q is high enough to prevent the possible initial crack growth to propagate the failure and the design criterion for Kerto-Q beam with holes can't be presented by formula presenting the proceeding of the cracking. Instead the bending, tension, compression and shear stresses of the beam calculated for the reduced cross-section shall be verified at the location of the holes. The stresses are calculated as given in equations 22, 26, 27 and 30.

DESIGN OF NOTCHES

The stress concentrations at the notch shall be taken in to account by reduction factors. The effects of them can be disregarded in the following cases:

- Tension or compression parallel to the grain
- Bending with tension stresses at the notch, when the taper is not steeper than 1:10, that is $i \geq 10$, see figure 3a.
- Bending with compressive stresses at the notch, see figure 3b.

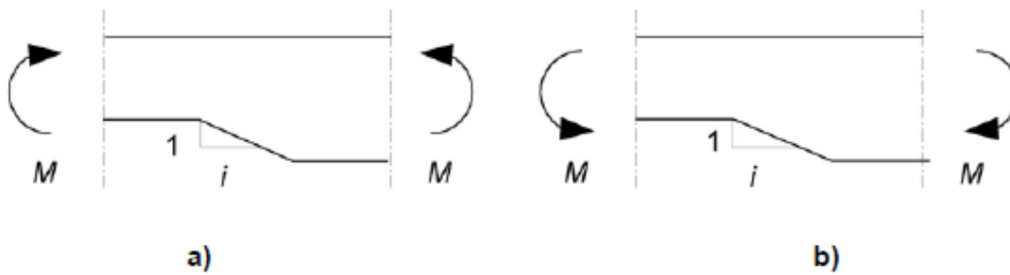


Figure 3. Bending at notch: a) tension stresses at the notch, b) compression stresses at the notch

BEAM WITH A NOTCH ON SUPPORT

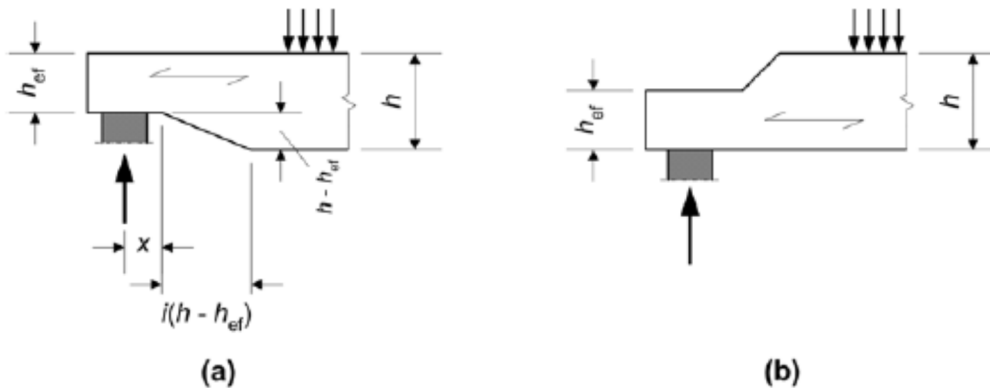


Figure 4. Notch on support, at the end of the beam

For beams with rectangular cross-sections, the shear stress at the notched support shall be calculated using the reduced depth h_{ef} (see figure 4),

$$\tau_d = \frac{1,5V}{b \cdot h_{ef}} \leq k_v \cdot f_{v,d} \quad (31)$$

where k_v is the reduction factor defined as follows:

Beams, notched at the opposite side to the support
(see figure 4b):

$$k_v = 1 \quad (32)$$

Beams, notched at the same side to the support
(see figure 4a):

$$k_v = \min \left\{ \frac{1}{k_n \left(1 + \frac{1,1i^{1,5}}{\sqrt{h}} \right)}, \frac{1}{\sqrt{h} \left(\sqrt{\alpha(1-\alpha)} + 0,8 \frac{x}{h} \sqrt{\frac{1}{\alpha} - \alpha^2} \right)} \right\} \quad (33)$$

where

- i is the notch inclination (see figure 4a)
- h is the beam depth (mm)
- x is the distance from line of action of the support reaction to the corner of the notch

$$\alpha = \frac{h_{ef}}{h} \quad (34)$$

$$k_n = \begin{cases} 6 & \text{Kerto-S} \\ 16 & \text{Kerto-Q} \end{cases} \quad (35)$$

On support, the design shear stress is calculated by:

$$f_{v,0,edge,d} = \frac{k_{mod} \cdot f_{v,0,edge,k}}{\gamma_M} \quad (36)$$

The shear stress capacities for Kerto products are

$$f_{v,0,edge,k} = 4,1 \text{ N/mm}^2 \quad \text{Kerto-S}$$

$$f_{v,0,edge,k} = 4,5 \text{ N/mm}^2 \quad \text{Kerto-Q}$$

Design shear force capacity V_k is given by:

$$V_k = \frac{k_v \cdot f_{v,0,edge,k} \cdot b \cdot h_{ef}}{1,5} \quad (37)$$

In tables 3 and 4 are given examples of the shear force capacities of notched Kerto-S and Kerto-Q beams.

Table 3. The shear force capacity V_k [kN] of Kerto-S beams with different notch depths and inclinations (figures 3 and 4). Distance from the support line to the edge of the notch (x) is 100 mm.

NOTCH DEPTH	Beam size (b x h)	50 mm		100 mm		b / 2	
		i = 0	i = 3	i = 0	i = 3	i = 0	i = 3
	V_k without notch						
51 x 200	27.9	11.3	15.9	5.7	8.1	5.7	8.1
45 x 260	32.0	15.3	20.7	8.8	11.9	6.6	8.9
45 x 300	36.9	18.9	25.2	11.4	15.2	7.5	10.0
51 x 300	41.8	21.5	28.5	13.0	17.2	8.5	11.3
45 x 360	44.3	24.6	32.0	15.4	20.1	8.8	11.5
51 x 400	55.8	32.3	41.5	20.6	26.5	10.9	14.1
57 x 450	70.1	42.3	53.7	27.4	34.8	13.5	17.1
75 x 500	102.5	63.8	80.2	41.9	52.6	19.3	24.2

Table 4. The shear force capacity V_k [kN] of Kerto-Q beams with different notch depths and inclinations (figures 3 and 4). Distance from the support line to the edge of the notch (x) is 100 mm.

NOTCH DEPTH	Beam size (b x h)	50 mm		100 mm		b / 2	
		i = 0	i = 3	i = 0	i = 3	i = 0	i = 3
	V_k without notch						
51 x 200	30.6	23.0	23.0	15.3	15.3	15.3	15.3
45 x 260	35.1	28.4	28.4	21.6	21.6	17.6	17.6
45 x 300	40.5	33.8	33.8	27.0	27.0	20.3	20.3
51 x 300	45.9	38.3	38.3	30.6	30.6	23.0	23.0
45 x 360	48.6	41.9	41.9	35.1	35.1	24.3	24.3
51 x 400	61.2	53.6	53.6	45.9	45.9	30.6	30.6
57 x 450	77.0	68.4	68.4	59.9	59.9	38.5	38.5
75 x 500	112.5	101.3	101.3	90.0	90.0	56.3	56.3

