HOLES AND NOTCHES

Kerto® LVL

The structure and strength properties of Kerto® LVL products offer a significant advantage to design beams with holes. Especially the crossveneer structure of Kerto LVL Q-panel acts as an reinforcement around the holes preventing cracking due to tension stresses perpendicular to the grain. The excellent resistance against cracking allows designing of large rectangular and round holes on Q-panel products.

Design methods for holes are provided in Eurofins Product Certificate (EUFI29-20000676-C) for Kerto LVL S-beam and Kerto LVL Q-panel products. The holes can have round or rectangular shape.

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.

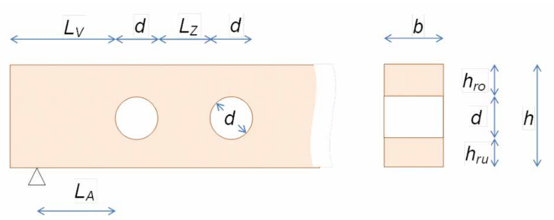

Figure 1. Definitions related to round holes.

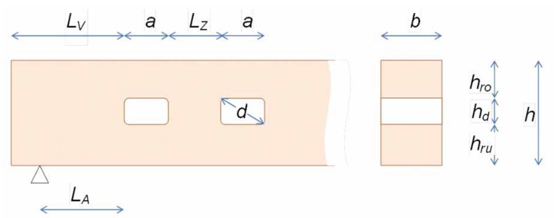

Figure 2. Definitions related to rectangular holes.

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 LVL S-beam and Kerto LVL Q-beam 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

$$h_{ro} \text{ and } h_{ru} \geq 0.25h \quad (6)$$

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 S-beam and Q-panel products.

			CENTRE OF THE HOLE ON NEUTRAL AXIS		CENTRE OF THE HOLE NOT ON NEUTRAL AXIS	
BEAM DEPTH	DISTANCE FROM THE BEAM END	DISTANCE FROM THE SUPPORT	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	315	67.5	225	112.5
500	500	250	350	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 2. Geometrical limitations for rectangular holes in S-beam and Q-panel products.

BEAM DEPTH	DISTANCE FROM THE BEAM END	DISTANCE FROM THE SUPPORT	DISTANCE BET-WEEN 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.

Design of Kerto LVL S-beams with holes

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

$$\sigma_{t,90,d} = \frac{F_{t,90,d}}{0.5bl_{t,90}} \leq 0.85k_{hole}\,k_{space}\,k_{t,90}\,f_{t,90,d} \qquad (11)$$

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

$$l_{t,90} = 0.35d + 0.5h \quad \text{round holes} \qquad (12)$$

$$l_{t,90} = 0.5h_d + 0.5h \quad \text{rectangular holes} \qquad (13)$$

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

$$k_{t,90} = \min \begin{cases} 1 \\ (450 / h)^{0,5} \end{cases} \qquad (14)$$

Beam depth h is given in millimeters.

Reduction factor k_{hole} is calculated as follows

$$k_{hole} = \min \begin{cases} 1 \\ 1 - 1,5\,\dfrac{d - 0.5h}{0.5h} \quad \text{round holes} \end{cases} \qquad (15)$$

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

Reduction factor k_{space} is given by

$$k_{space} = \min \begin{cases} 1 \\ 1 - 0.8 \dfrac{h - Lz}{h} & \text{round holes} \\ 1 - 0.8 \dfrac{4d - Lz}{4d} \end{cases} \quad (17)$$

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

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 $h_d = 0,7_d$.
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

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

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

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

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.

In case that the centre of a rectangular hole is located at the neutral axis ($h_{ro} = h_{ru}$) the design shear stress is given by

$$\sigma_{v,d} = k_\tau \frac{1.5 V_d}{A_{red}} \quad (31)$$

where V_d is the design shear force at the hole edge and k_τ is a factor to determine the maximum shear stress given by

$$k_\tau = 1.85 \left(1 + \frac{a}{h}\right) \left(\frac{h_d}{h}\right)^{0,2} \quad (32)$$

Design of Kerto LVL Q-panels with holes

The same design method can be used for Kerto LVL Q-panel 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 crosswise veneer structure, the tension strength perpendicular to grain of Q-panel is high enough to prevent the possible initial crack growth to propagate the failure and the design criterion for Q-panel 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 crosssection shall be verified at the location of the holes. The stresses are calculated as given in equations 22, 26, 27, 30 and 31.

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 ≥ 10, see figure 3a.
- Bending with compressive stresses at the notch, see figure 3b.

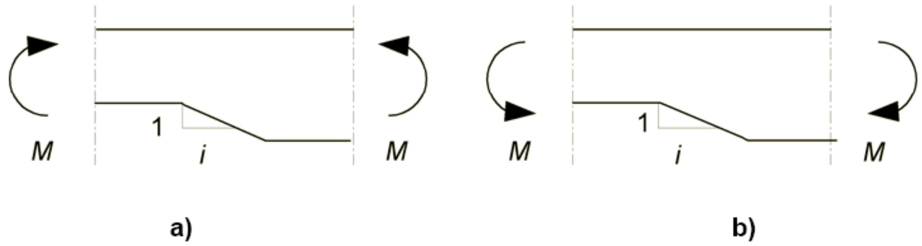

Figure 3. Bending at notch: a) tension stresses at the notch, b) compression stresses at the notch.

Beam with a notch on support

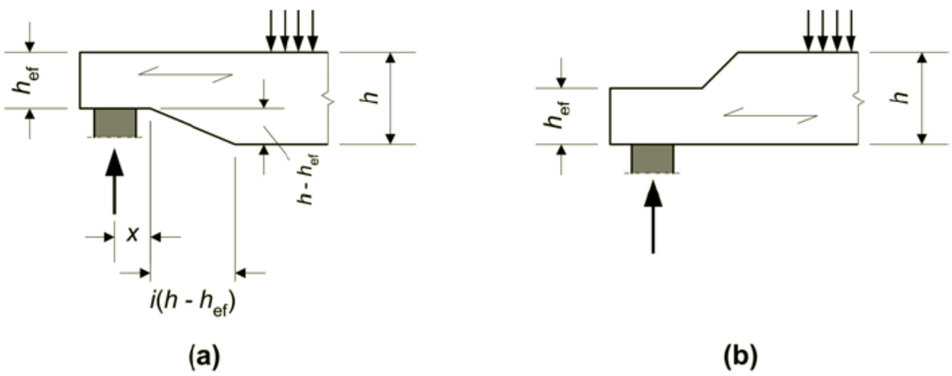

Figure 4. Notch on support, at the end of the beam

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),

$$\tau_d = \frac{1.5V}{b \cdot h_{ef}} \leq k_v \cdot f_{v,d} \tag{33}$$

where k_v is the reduction factor defined as follows:

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

$$k_v = 1 \tag{34}$$

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

$$k_v = \min \left\{ \begin{array}{l} 1 \\ \dfrac{k_n \left(1 + \dfrac{1.1 i^{1{,}5}}{\sqrt{h}}\right)}{\sqrt{h}\left(\sqrt{\alpha(1-\alpha)} + 0.8\dfrac{x}{h}\sqrt{\dfrac{1}{\alpha} - \alpha^2}\right)} \end{array} \right. \tag{35}$$

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

$$\alpha = \frac{h_{ef}}{h} \quad (36)$$

$$k_n = \begin{cases} 6 & \textit{Kerto LVL S-beam} \\ 16 & \textit{Kerto LVL Q-panel} \end{cases} \quad (37)$$

On support, the design shear stress is calculated by:

$$f_{v,0,edge,d} = \frac{k_{mod} \cdot f_{v,0,edge,k}}{\gamma_M} \quad (38)$$

The shear stress capacities for Kerto LVL products are

$$f_{v,0,edge,k} = 4.2 N / mm^2 \quad \textit{Kerto LVL S-beam}$$
$$f_{v,0,edge,k} = 4.5 N / mm^2 \quad \textit{Kerto LVL Q-panel}$$

Design shear force capacity V_k is given by:

$$V_k = \frac{k_v \cdot f_{v,0,edge,k} \cdot b \cdot h_{ef}}{1.5} \quad (39)$$

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

TABLE 3. The shear force capacity V_k [kN] of Kerto LVL 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		50 mm		100 mm		b / 2	
Beam size (b x h)	**V_k without notch**	**i = 0**	**i = 3**	**i = 0**	**i = 3**	**i = 0**	**i = 3**
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 LVL Q-panels 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		50 mm		100 mm		b / 2	
Beam size (b x h)	**V_k without notch**	**i = 0**	**i = 3**	**i = 0**	**i = 3**	**i = 0**	**i = 3**
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