ERASMUS+

BHC structure and safety

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Disclaimer

Contents

1 Fundamentals of forces, moments and stresses

In order to understand at least roughly how mechanics and specifically statics work in a tree house, we must first take an intermediate step and understand what forces, moments and stresses are and how they work. Let's start with the forces.

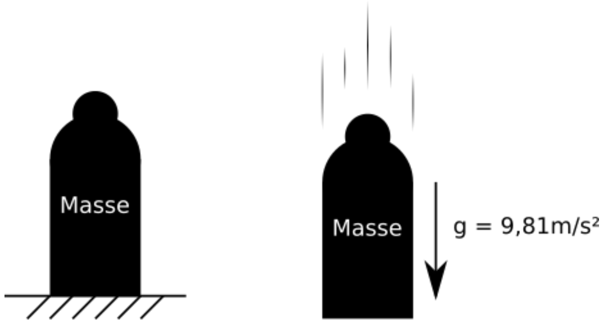

Figure 1: Force equals mass times (earth)-acceleration

Left in figure 1 is shown a weight with a certain mass. The weight stands on a surface such as a table and does not move. On the right in figure 1 we have removed the ground and the weight falls down. So there is a force that sets the weight in motion. This force results from the mass of the weight multiplied by the acceleration with which the mass is set in motion. In our case the acceleration due to gravity. The whole can be expressed by the known formula force equals mass times (earth)-acceleration.

$$F = m * a \tag{1}$$

For the acceleration a due to gravity $g = 9{,}81\frac{\mathrm{m}}{\mathrm{s}^2}$ or rounded by the engineer $g = 10\frac{\mathrm{m}}{\mathrm{s}^2}$ can be used. The weight tends to fall even when standing immobile on its surface. It works the same force. Only the floor prevents the movement. Thus the floor absorbs the force from the weight, which means it opposes the weight with an equivalent force (see figure 2 on the left).

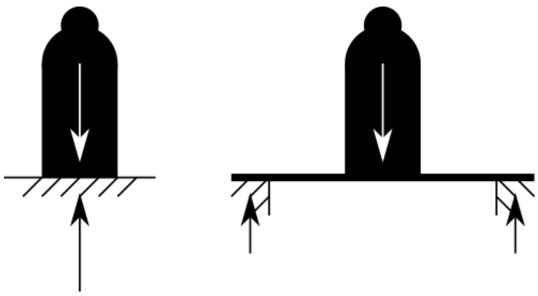

Figure 2: Equilibrium principle

And that brings us to the first decisive principle, the principle of equilibrium. This means that a force always generates a counterforce of the same magnitude. Either in which a mass changes its state of motion and it begins to fall or in which for example the underground absorbs this force. However, the counterforce can also be divided, as shown on the right in figure 2. What is important is that all forces in the system cancel each other out.

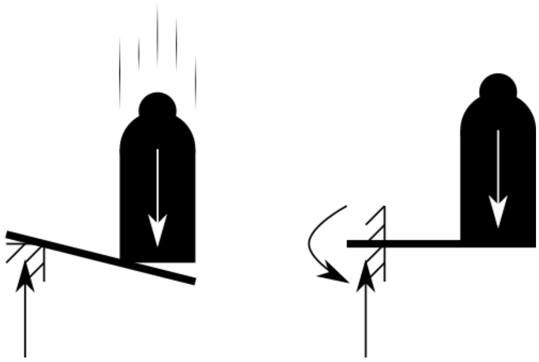

Figure 3: Moment equal force times lever arm

The left picture in figure 3 shows a situation in which the weight starts to fall despite the fact that the forces are in equilibrium. This is because the two forces rotate the beam clockwise on which the weight is standing . The quantity that is responsible for the rotation is called moment and results from the force and the lever arm called distance between the force and counterforce.

$$M = F * e \tag{2}$$

So if we don't want the weight to fall down, we have to clamp the beam on the support in such a way that it is able to generate a corresponding counter moment there. The equilibrium principle also applies here.

But what if we divide the system? Let's take the system on the right from the figure **??** as an example and consider what happens when we mentally cut through the beam at a point next to the weight. Since we don't really cut the beam, everything still stays where it is and the principle of equilibrium applies. This allows us to determine which forces and moments work in the beam (see figure 4).

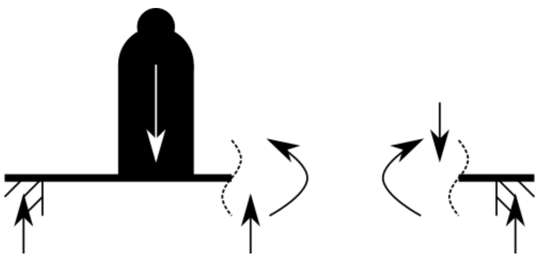

Figure 4: Cutting principle

The method of mental cutting through the system to find out the forces and moments in the system is called the cutting principle and is the second important principle. The forces and moments determined in this way are called internal forces. The two sides of the section on which the internal forces occur are called the cut shore. The internal forces of both cut shores must be of the same magnitude in the opposite direction, since these also have to cancel each other out according to the equilibrium principle when we mentally reunite the system.

And if we now know which forces prevail in the beam, can we then not also predict whether the beam is capable of carrying the weight at all? We are still missing a decisive piece of information. Because while a thick beam might be able to carry the weight while a thin beam might fail. The cross section of the beam is also decisive. So let's take a closer look at what happens in the beam (see figure 5).

Figure 5: Stresses

On the left in the figure 5 we see the left cut shore of the beam and the internal forces acting at this point. But now the beam has an area over which we can distribute the forces and moments, as shown on the right in the figure 5. The forces and moments distributed over the surface are called stresses. We distinguish between two types of stresses, so-called normal stresses, which act parallel to the beam axis, and shear stresses, which are perpendicular to the beam axis. Whether the beam is finally able to absorb these stresses depends only on the material and its characteristic values.

2 Load assumptions

Dead loads

The dead loads are determined according to the weight (see chapter 3 Material parameters) and the cross-section for each element.

Traffic loads

A traffic load of $\mathrm{q}_k = 1{,}5\frac{\mathrm{kN}}{\mathrm{m}^2}$ is used as the area load, which corresponds to category A2 for residential and recreation rooms according to DIN EN 1991-1-1/NA, and a standard man load of $Q_k = 1{,}0\mathrm{kN}$ is used as the individual load for the design of the platforms and their railings.
For stairs the traffic load is $q_k = 3{,}0\frac{\mathrm{kN}}{\mathrm{m}^2}$ and the man load is $Q_k = 2{,}0\mathrm{kN}$, which corresponds to category T1 for stairs and stair landings according to DIN EN 1991-1-1/NA.

Snow loads

No snow loads are assumed, as the buildings are only erected, used and dismantled in summer and no snow is to be expected at this time. Should a tree house actually remain standing in winter, the snow loads must be calculated according to the snow load zone according to DIN EN 1991-1-1 with the respective national appendix.

Wind loads

The wind loads can be neglected due to the small attack surface and the shielding by the surrounding trees. In addition, the tree house should not be used during storms due to other factors such as knocking down branches.

3 Material parameters

Coniferous wood C24

The modification coefficients k_{mod} and deformation coefficients k_{def} typical for timber construction are estimated at a flat rate of $k_{mod} = 1{,}0$ and $k_{def} = 1{,}0$ due to the short service life of the building. If a tree house is to remain standing for longer than three months, the coefficients must be adjusted in accordance with DIN EN 1995-1-1 and the respective National Annex.
The other material parameters for the most frequently used softwood of strength class C24 are taken from DIN EN 338 and listed below.

Bending	Tension parallel	Tension right angle	Compression parallel	Compression right angle
$f_{m,k} = 24{,}0\frac{\mathrm{N}}{\mathrm{mm}^2}$	$f_{t,0,k} = 14{,}0\frac{\mathrm{N}}{\mathrm{mm}^2}$	$f_{t,90,k} = 0{,}4\frac{\mathrm{N}}{\mathrm{mm}^2}$	$f_{c,0,k} = 21{,}0\frac{\mathrm{N}}{\mathrm{mm}^2}$	$f_{c,90,k} = 2{,}5\frac{\mathrm{N}}{\mathrm{mm}^2}$

Shear, torsion	Modulus of elasticity parallel	Modulus of elasticity right-angled	Shear modulus	Weight
$f_{v,k} = 4{,}0\frac{\mathrm{N}}{\mathrm{mm}^2}$	$E_{0,mean} = 11000\frac{\mathrm{N}}{\mathrm{mm}^2}$	$E_{90,mean} = 370\frac{\mathrm{N}}{\mathrm{mm}^2}$	$G_{mean} = 690\frac{\mathrm{N}}{\mathrm{mm}^2}$	$w_k = 7{,}0\frac{\mathrm{kN}}{\mathrm{m}^3}$

The value for wet wood was used as the weight, since fresh logs from the sawmill are used.

Suspension rope

Various types of ropes can be used. More about this elsewhere. Here, for example, the primary rope of the type 'PP10-S' of the manufacturer 'Hamburger Tauwerk-Fabrik' is named with a rated breaking load of $F_{Rd} = 15{,}6\mathrm{kN}$.

4 Knot connections

The lashing knot (see figure 6) is a proven node technique for connecting rods and beams. The technique has been used in seafaring and is still used today in the construction of tents and the like. The knot has also been

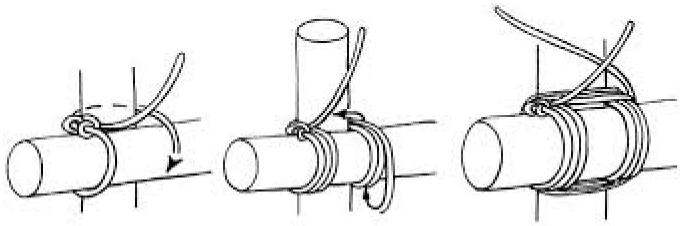

Figure 6: Lashing knot

used for various tree house camps in Germany, Switzerland and the Netherlands. In connection with the used primary rope, it has been shown that the lashing knot is able to transfer at least the simple breaking load of the primary rope during a complete winding and that this result increases linearly with every further complete winding. From this, the following simple formula can be derived for the design of the circular collar.

$$\text{Carrying capacity of the lashing knot } R_k = \text{Breaking load of the primary rope } F_k * \text{Number of winding } n_c \quad (3)$$

More detailed information on the lashing knot and other useful knots can be found elsewhere.

5 Verifications

For the checks, the forces acting on a component must first be determined. Which assumption is made for the different components can be found elsewhere. These forces can then be used to calculate internal forces, i.e. normal force curves, shear force curves and torque curves, via the static system and finally stress curves across the cross-section. These stresses are referred to as existing characteristic stresses. Presence is self-explanatory in this context, characteristic means that no safety factor has yet been included in the stresses. The load safety factor depends on whether a load is constant or variable. For permanent loads such as the dead weight it is $\gamma_G = 1{,}35$ and for variable loads such as live loads, snow loads and wind loads it is $\gamma_Q = 1{,}5$. This results in the following formulas for the existing normal stresses and shear stresses.

$$\sigma_d = \gamma_G * \sigma_{G,k} + \gamma_Q * \sigma_{Q,k} \tag{4}$$
$$\tau_d = \gamma_G * \tau_{G,k} + \gamma_Q * \tau_{Q,k} \tag{5}$$

On the other hand, like any other solid material, wood has permissible characteristic maximum stresses before the material fails. These are also modified with a safety factor suitable for the material. For wood, this safety factor is $\gamma_M = 1{,}3$. This results in the following formulas for the permissible normal stresses and shear stresses.

$$f_{t,0,d} = f_{t,o,k}/\gamma_M \tag{6}$$
$$f_{m,y,d} = f_{m,y,k}/\gamma_M \tag{7}$$
$$f_{v,d} = f_{v,k}/\gamma_M \tag{8}$$

In the case of wood, a distinction is made between tensile strength and bending in the load-bearing capacity and normal direction, hence the three different formulae. The degree of utilisation of the system can be determined by calculating the ratio between existing and permissible stresses. If this is less than or equal to 1,0, the checks are complied with and fulfilled.

$$\frac{\sigma_{t,0,d}}{f_{t,0,d}} + \frac{\sigma_{m,y,d}}{f_{m,y,d}} \leq 1{,}0 \tag{9}$$
$$\frac{\tau_{z,d}}{f_{v,d}} \leq 1{,}0 \tag{10}$$

The maximum loads at the supports and interfaces are held either by direct contact and in this case only have to be fixed constructively or by the lashing knot. Otherwise the loads are held by the lashing knot. In this case, we must first provide the characteristic support forces with the corresponding safety coefficients.

$$F_d = \gamma_G * F_{G,k} + \gamma_Q * F_{Q,k} \tag{11}$$

With the breaking load specified by the rope manufacturer, which usually already includes the safety factor, the maximum load of the knot can be determined and then the load capacity verification can be carried out again via the ratio.

$$R_d = F_{R,d} * n_c \tag{12}$$
$$\frac{F_d}{R_d} \leq 1{,}0 \tag{13}$$

6 Decisive floor

For the floor boards, the cross-sectional area per meter $A = 100 * d$ and the section modulus per meter $W_y = \frac{1}{6} * 100 * d^2$ as well as the dead weight per meter $g_k = 1{,}0 * d * w_k$ can be determined via the thickness d. Another decided size is the maximum span of the boards l. In the statically worst case, the boards bridge only one field leading to the following static systems.

Figure 7: Static systems: Load case 1 (loads on the left permanent, loads on the right variable)

In the first load case shown (Figure 7) it is assumed that the board has to support a uniform traffic load in addition to its own face.

Figure 8: Static systems: Load case 2 (loads on the left permanent, loads on the right variable)

In the second load case shown (figure 8), it is assumed that the board must also accommodate a man in the middle of the attack in addition to its own face.

Both load cases must be verified in order to cover the less favourable of the two in each case.

7 Decisive beams

Round timber is used for the primary beams and secondary beams. The diameter d can be used to determine the radius $r = \frac{d}{2}$ and the radius the cross-sectional area $A = \pi * r^2$ and the section modulus $W_y = \frac{1}{4} * \pi * r^3$ as well as the dead weight per meter $g_k = \pi * r^2 * w_k$. Further decided quantities are the maximum span of the beams l and the load absorption width e. The load absorption width is used to calculate the additional dead weight of the structure as well as the variable loads acting on the beam. This results in the following static system (see figure 9).

Figure 9: Static systems: (loads on the left permanent, loads on the right variable)

Only the uniform traffic load is used for the girders, since a single man load will never be decisive for normal span widths and load intake widths.

8 Decisive railings

Round timber is used for the railings. The diameter d can be used to determine the radius $r = \frac{d}{2}$ and the radius to determine the cross-sectional area $A = \pi * r^2$ and the section modulus $W_y = \frac{1}{4} * \pi * r^3$ as well as the dead weight per meter $g_k = \pi * r^2 * w_k$. Another decided quantity is the maximum span of the railing l. This results in the following static system (see figure 10).

Figure 10: Static systems: (loads on the left permanent, loads on the right variable)

Here only the individual man load is applied, since the railings are only intended to prevent falling down and it is not intended to have to take up an even traffic load.

9 Stairs and footbridges

Frames are used for the stairs and round timber is used for the bridges. For the cross section values of the logs, see the beams or railings. For the frames, the width b and height h can be used to determine the cross-sectional area $A = b * h$ and the section modulus $W_y = \frac{1}{6} * b * h^2$ as well as the dead weight per meter $g_k = b * h * w_k$. Further decided quantities are the length L and the height to be bridged H of the stairs respectively the maximum span of the webs l and the load intake width e. The load absorption width is used to calculate the additional dead weight of the supported structure as well as the variable loads acting on the stairs and webs. This results in the following static systems, here exemplary for the stairs. For the walkways, the systems are equivalent only horizontally flat.

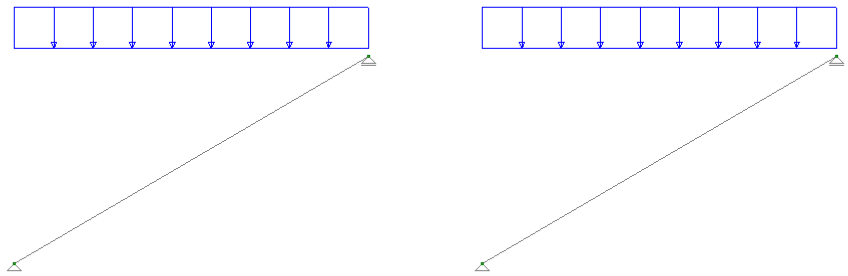

Figure 11: Static systems: Load case 1 (loads on the left permanent, loads on the right variable)

In the first load case shown (Figure 11), it is assumed that the board must also take up a uniform traffic load in addition to its own face.

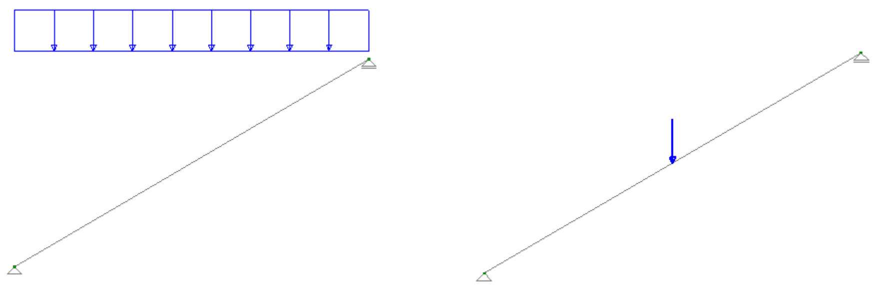

Figure 12: Static systems: Load case 2 (loads on the left permanent, loads on the right variable)

In the second load case shown (figure 12), it is assumed that the board must also accommodate a man in the middle of the attack in addition to its own face.

Both load cases must be verified in order to cover the less favourable of the two in each case.

Literature, standards and programmes

Schneider - Bautabellen für Ingenieure - 20.Auflage - 2012
THM Technische Hochschule Mittelhessen, mb AEC Software GmbH - Bemessungs- und Konstruktionshilfen für Holzbauwerke nach Eurocode 5
DIN EN 1991-1-1/NA
DIN EN 1995-1-1:2010-12
DIN EN 1995-1-1/NA:2010-12
DIN EN 338
Instituts für Statik und Dynamik der Leibniz Universität Hannover - STAB2D (Version 5.78)
Institut für Baustatik und Baudynamik der Universität Stuttgart - STAR^2 (Version 1.2.5)