Deck and Hanger Cable Calculations

Geometrical Properties

Symmetrical, 3-span suspension bridge subjected to uniform load:

$l_m := 14.6\ m$ Main span length

$w_{deck} := 1.5\ m$ Deck width

$l_p := 5\ m$ Live load length

$\lambda_h := 1\ m$ Distance between hangers

$\lambda_t := 0.35\ m$ Distance between transverse beams

$g := 9.81\ \frac{m}{s^2}$ Gravitational acceleration

Material Properties

C18 Timber Strength Properties and Characteristic Values

The values below are taken from:
http://www.onlinestructuraldesign.com/calcs/Wood_documentation/Wood_element_EN338_Table1.htm

$f_u := 360\ MPa$ Steel Ultimate strength (hanger cable)

$f_m := 18\ MPa$ Bending

$f_{t0} := 11\ MPa$ Tension, parallel

$f_{t90} := 0.4\ MPa$ Tension, perpendicular

$f_{c0} := 18\ MPa$ Compression, parallel

$f_{c90} := 2.2\ MPa$ Compression, perpendicular

$f_{vk} := 3.4\ MPa$ Shear

$E_{0mean} := 9\ \frac{kN}{mm^2}$ mean modulus of elasticity, parallel

$E_{0.05} := 6\ \frac{kN}{mm^2}$ 5 percent modulus of elasticity, parallel

$E_{90mean} := 0.3\ \frac{kN}{mm^2}$ mean modulus of elasticity, perpendicular

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$G_{mean} := 0.56 \ \frac{kN}{mm^2}$ mean shear modulus

$\rho_{C18.k} := 380 \ \frac{kg}{m^3}$ characteristic Density

$\rho_{C18.mean} := 380 \ \frac{kg}{m^3}$ mean Density

Section Properties

Boards Cross Section Properties

$b_{board} := 125 \ mm$ board width

$h_{board} := 32 \ mm$ board/deck height

$A_{board} := b_{board} \cdot h_{board} = 0.004 \ m^2$ board cross section

$A_{decking} := w_{deck} \cdot h_{board} = 0.048 \ m^2$ deck cross section

$g_{board} := A_{board} \cdot \rho_{C18.mean} \cdot g = 0.015 \ \frac{kN}{m}$ board weight per unit board length

$g_{decking} := A_{decking} \cdot \rho_{C18.mean} \cdot g = 0.179 \ \frac{kN}{m}$ board weight per unit bridge span length

$W_{board} := \frac{1}{6} \ b_{board} \cdot h_{board}^{\ 2} = \left(2.133 \cdot 10^{-5}\right) \ m^3$ section modulus about y

$I_{board} := \frac{1}{12} \ b_{board} \cdot h_{board}^{\ 3} = \left(3.413 \cdot 10^{-7}\right) \ m \cdot m^3$ moment of inertia about y

Longitudinal Beam Cross Section Properties

$b_{beam} := 100 \ mm$ beam width

$h_{beam} := 200 \ mm$ beam height

$A_{beam} := b_{beam} \cdot h_{beam} = 0.02 \ m^2$ deck cross section

$g_{beam} := A_{beam} \cdot \rho_{C18.mean} \cdot g = 0.075 \ \frac{kN}{m}$ beam weight per unit length

$W_{longy} := \frac{1}{6} \ b_{beam} \cdot h_{beam}^{\ 2} = \left(6.667 \cdot 10^{-4}\right) \ m^3$ section modulus about y

$I_{longy} := \frac{1}{12} \ b_{beam} \cdot h_{beam}^{\ 3} = \left(6.667 \cdot 10^{-5}\right) \ m \cdot m^3$ moment of inertia about y

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$I_{longx} := \frac{1}{12}\, h_{beam} \cdot b_{beam}^{\,3} = (1.667 \cdot 10^{-5})\ m^4$ moment of inertia about x

$I_{beamtor} := \frac{1}{3} \cdot h_{beam} \cdot b_{beam}^{\,3} \left(1 - 0.63 \cdot \frac{b_{beam}}{h_{beam}}\right) = (4.567 \cdot 10^{-5})\ m^4$ torsional moment of inertia

$l_{effbeam} := 0.9 \cdot \lambda_h + 2 \cdot h_{beam} = 1.3\ m$ effective length for LTB - assuming the load is applied on top of the beam - (worst case)

Transverse Beam Cross Section Properties

$b_{beamt} := 75\ mm$ beam width

$h_{beamt} := 150\ mm$ beam height

$A_{beamt} := b_{beamt} \cdot h_{beamt} = 0.011\ m^2$ deck cross section

$g_{beamt} := A_{beamt} \cdot \rho_{C18.mean} \cdot g = 0.042\ \frac{kN}{m}$ beam weight per unit length

$W_{transy} := \frac{1}{6}\, b_{beamt} \cdot h_{beamt}^{\,2} = (2.813 \cdot 10^{-4})\ m^3$ section modulus about y

$I_{transy} := \frac{1}{12}\, b_{beamt} \cdot h_{beamt}^{\,3} = (2.109 \cdot 10^{-5})\ m \cdot m^3$ moment of inertia about y

$I_{transx} := \frac{1}{12}\, h_{beamt} \cdot b_{beamt}^{\,3} = (5.273 \cdot 10^{-6})\ m^4$ moment of inertia about x

$I_{transtor} := \frac{1}{3} \cdot h_{beamt} \cdot b_{beamt}^{\,3} \left(1 - 0.63 \cdot \frac{b_{beamt}}{h_{beamt}}\right) = (1.445 \cdot 10^{-5})\ m^4$ torsional moment of inertia

$l_{efftrans} := 0.9 \cdot w_{deck} + 2 \cdot h_{beamt} = 1.65\ m$ effective length for LTB - assuming the load is applied on top of the beam - (worst case)

Safety Factors

Partial safety factors:

$\gamma_G := 1$ Permanent action

$\gamma_Q := 1.5$ Unfavourable variable action

$\psi_0 := 0.8$ The load combination factor

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$\gamma_M := 1.3$ Material factor for solid timber

$k_{mod} := 0.5$ Maodification factor for solid timber, service class 3, permanent action.

$f_{m.d} := k_{mod} \cdot \frac{f_m}{\gamma_M} = 6.923\ MPa$ Design bending resistance

$f_{v.d} := k_{mod} \cdot \frac{f_{vk}}{\gamma_M} = 1.308\ MPa$ Design shear resistance

Load Calculations

Loads applied on the deck:

$G_{deck} := g_{decking} + 2 \cdot g_{beam} + g_{beamt} \cdot \frac{w_{deck}}{\lambda_t} = 0.508\ \frac{kN}{m}$ Total deck Dead Load per unit span length

$Q_{live} := 100\ \frac{kg}{m^2} \cdot w_{deck} \cdot g = 1.472\ \frac{kN}{m}$ Live load applied over 5m along the span length

$n := 5$ number of people concentrated per square meter

$W_{per} := 75\ kg$ weight of each person

$Q_{liveTrans} := \frac{n}{1\ m^2} \cdot W_{per} \cdot \lambda_t \cdot g = 1.288\ \frac{kN}{m}$ distributed load on transverse beams

$P_{live} := \frac{n}{1\ m} \cdot W_{per} \cdot w_{deck} \cdot g = 5.518\ kN$ Concentrated live load of 5 poeple per square meters

Design value of actions on the bridge span:

$G_{deck.d} := G_{deck} \cdot \gamma_G = 0.508\ \frac{kN}{m}$

$Q_{live.d} := Q_{live} \cdot \gamma_Q = 2.207\ \frac{kN}{m}$

$Q_{liveTrans.d} := Q_{liveTrans} \cdot \gamma_Q = 1.931\ \frac{kN}{m}$

$P_{live.d} := P_{live} \cdot \gamma_Q = 8.277\ kN$

Remark : Since it is a possibiliy that people with gather together, a load case of concentrated load of 5 people per square meter, on the same point along the span has been introduced and used to calculate all the members except the decking boards. This case is more critical than the case of 100kg/m over 5 meters and will be refered to as "Point/concentrated Load" or $P_{live.d}$.

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Hanger Cable Calculations

Load Case 3 (Point load on support/hanger)

$$N_{hanger} := \frac{1}{2}\left(G_{deck.d} \cdot \lambda_h + P_{live.d}\right) = 4.392\ kN$$

$$A_{cb.hanger} := \frac{N_{hanger}}{f_u} = 12.201\ mm^2$$ Area of the required cable

Then, the cable area is increased 15% to stay on the safe side.

$$A_{cb.hanger.d} := A_{cb.hanger} \cdot 1.15 = 14.032\ mm^2$$

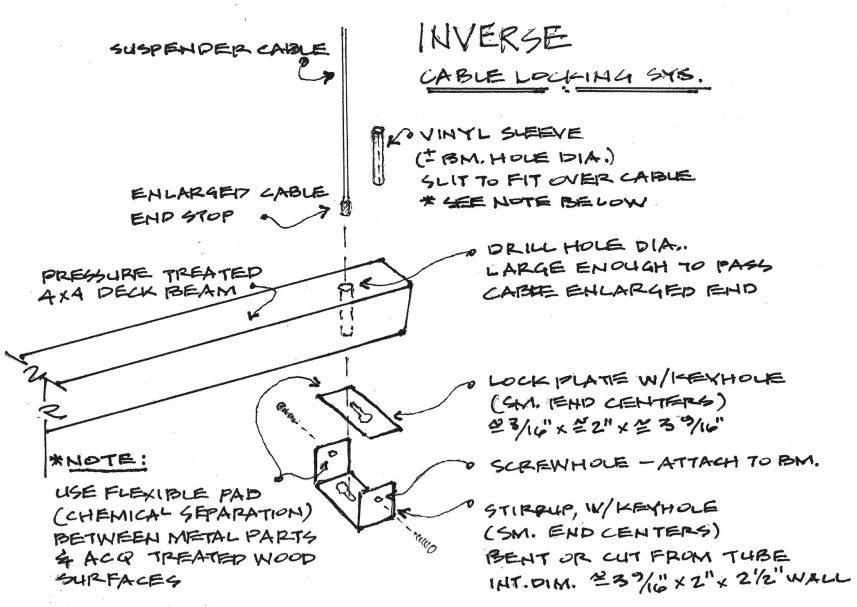
$$d_{hanger} := \sqrt{4 \cdot \frac{A_{cb.hanger.d}}{\pi}} = 4.227\ mm$$ Hanger cable diameter

Remark: The following calculations have been done with the assumption that the hanger cables act as rigid supports, which in reality, they are not. Therefore the deck elements have been chosen a bit larger than needed, to make the deck stiffer. Further calculations will be done to account for hangers not acting as rigid supports.

As a whole, the deck transfers the load from the decking boards to the transverse beams, and then to the longitudinal beams, which are then connected to the hanger cables.

The hangers will be connected to the longitudinal beams via a steel cable locking system similar to the one in the picture below. The hangers as well as the anchor will have adjusting screws to adjust the tension/length of the cables. The transverse beams will be connected to the logitudinal beams via joist hangers

credit:
https://
wildcatman.wordpress.com/
category/building-a-small-
cable-suspension-bridge/



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The deck will be prefabricated in partitions of 1.5-2 meters long, where two hangers (on each side) connects to each partition, allowing us to stand on it and connect the next partition to the next hangers and so on. Also the construction will take place from both sides of the canal simultaneosly, in order to maintain equal sag in the main cable.

Longitudinal Beam Calculations

ULS Calculation

Check of the bending stress:

Load Cases:

Load Case 1 (Point load mid span)

$$M_{maxl} := 0.070 \left(\frac{G_{deck.d}}{2}\right) \cdot \lambda_h{}^2 + 0.203 \cdot \frac{P_{live.d}}{2} \cdot \lambda_h = 0.858 \ \textbf{kN} \cdot \textbf{m}$$

max moment midspan (between two hanger) - Tekni ståbi page 111-3.37 and 3.40

$$\sigma_{mdb} := \frac{M_{maxl}}{W_{longy}} = 1.287 \ \textbf{MPa}$$

$$\frac{\sigma_{mdb}}{f_{m.d}} = 0.186 \qquad \frac{\sigma_{mdb}}{f_{m.d}} < 1 = 1$$ OK

Check of the Lateral torsional buckling:

$$\sigma_{m.crit.beam} := \frac{\pi \sqrt[2]{E_{0.05} \cdot I_{longx} \cdot G_{mean} \cdot I_{beamtor}}}{l_{effbeam} \cdot W_{longy}} = 183.312 \ \textbf{MPa}$$

$$\lambda_{rel.m.beam} := \sqrt[2]{\frac{f_m}{\sigma_{m.crit.beam}}} = 0.313$$

$$k_{cr.beam} := \begin{cases} 1 & \text{if } \lambda_{rel.m.beam} \le 0.75 \\ 1.56 - 0.75 \cdot \lambda_{rel.m.beam} & \text{else if } 0.75 < \lambda_{rel.m.beam} \le 1.4 \\ 1 & \text{else if } 1.4 < \lambda_{rel.m.beam} \end{cases} = 1$$

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$$\left\| \frac{1}{\lambda_{rel.m.beam}^{2}} \right|$$

$\frac{\sigma_{mdb}}{f_{m.d}} = 0.186$ $\frac{\sigma_{mdb}}{f_{m.d}} < k_{cr.beam} = 1$ OK

Check of shear:

$V_{maxld} := 1.250 \left(\frac{G_{deck.d}}{2} \right) \cdot \lambda_h + 1.376 \cdot \frac{P_{live.d}}{2} = 6.012$ ***kN***

max shear on support/ hanger- Tekni ståbi page 111-3.39 amd 3.37

$\tau_{maxd} := \frac{3}{2} \cdot \frac{V_{maxld}}{b_{beam} \cdot h_{beam}} = 0.451$ ***MPa***

$\frac{\tau_{maxd}}{f_{v.d}} = 0.345$ $\frac{\tau_{maxd}}{f_{v.d}} < 1 = 1$ OK

Compression perpendicular to wood grain (on supports/hangers):

$l_A := 10$ ***cm*** Width of able locking system/clamp

$a := 0$

$k_{c90} := 1.5$ for structural timer (1.75 for glulam

$A_{effb} := b_{beam} \cdot l_A = 0.01$ m^2

$\sigma_{c90d} := \frac{V_{maxld}}{A_{effb}} = \left(6.012 \cdot 10^5 \right)$ ***Pa***

$\frac{\sigma_{c90d}}{k_{c90} \cdot \left(k_{mod} \cdot \frac{f_{c90}}{\gamma_M} \right)} = 0.474$ $\frac{\sigma_{c90d}}{k_{c90} \cdot \left(k_{mod} \cdot \frac{f_{c90}}{\gamma_M} \right)} < 1 = 1$ OK

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SLS Calculation

Load Case 1 (Point load mid span)

$$u_{inst} := \frac{5}{384} \cdot \frac{G_{deck.d}}{2} \cdot \frac{\lambda_h^{\,4}}{E_{0mean} \cdot I_{longy}} + \frac{1}{48} \cdot \frac{P_{live.d}}{2} \cdot \frac{\lambda_h^{\,3}}{E_{0mean} \cdot I_{longy}} = 0.149\ mm$$ simply supported

$$u_{inst} := 0.0054 \cdot \frac{G_{deck.d}}{2} \cdot \frac{\lambda_h^{\,4}}{E_{0mean} \cdot I_{longy}} + 0.0093 \cdot \frac{P_{live.d}}{2} \cdot \frac{\lambda_h^{\,3}}{E_{0mean} \cdot I_{longy}} = 0.066\ mm$$ one side fixed one side simply supported - TS pg107

$$\frac{u_{inst}}{\lambda_h} = 0.007\% \qquad \frac{u_{inst}}{\lambda_h} < \frac{1}{300} = 1$$ OK

Transverse Beam Calculations

Distributed Dead load on transverse beams

$$G_{trans} := \left(g_{decking} + g_{beamt}\right) \cdot \frac{\lambda_t}{w_{deck}} = 0.052\ \frac{kN}{m}$$

$$G_{trans.d} := G_{trans} \cdot \gamma_G = 0.052\ \frac{kN}{m}$$

ULS Calculation

Check of the bending stress:

Load Case 1 (Point load mid span)

$$M_{maxt} := \frac{1}{8} \left(G_{trans.d} + Q_{liveTrans.d}\right) \cdot w_{deck}^{\,2} = 0.558\ kN \cdot m$$

$$\sigma_{mdt} := \frac{M_{maxt}}{W_{transy}} = 1.983\ MPa$$

$$\frac{\sigma_{mdt}}{f_{m.d}} = 0.286 \qquad \frac{\sigma_{mdt}}{f_{m.d}} < 1 = 1$$ OK

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Check of the Lateral torsional buckling:

$$\sigma_{m.crit.beamt} := \frac{\pi \sqrt[2]{E_{0.05} \cdot I_{transx} \cdot G_{mean} \cdot I_{transtor}}}{l_{efftrans} \cdot W_{transy}} = 108.321 \ MPa$$

$$\lambda_{rel.m.beamt} := \sqrt[2]{\frac{f_m}{\sigma_{m.crit.beamt}}} = 0.408$$

$$k_{cr.beamt} := \begin{cases} \text{if } \lambda_{rel.m.beamt} \le 0.75 \\ \quad 1 \\ \text{else if } 0.75 < \lambda_{rel.m.beamt} \le 1.4 \\ \quad 1.56 - 0.75 \cdot \lambda_{rel.m.beamt} \\ \text{else if } 1.4 < \lambda_{rel.m.beamt} \\ \quad \frac{1}{\lambda_{rel.m.beamt}^{\ 2}} \end{cases} = 1$$

$$\frac{\sigma_{mdt}}{f_{m.d}} = 0.286 \qquad \frac{\sigma_{mdb}}{f_{m.d}} < k_{cr.beamt} = 1 \quad \text{OK}$$

SLS Calculation

Load Case 1 (Point load mid span - or 5 people peter meter at one point of bridge longitudinal span)

$$u_{inst} := \frac{5}{384} \cdot \left(G_{trans.d} + Q_{liveTrans.d}\right) \cdot \frac{w_{deck}^{\ 4}}{E_{0mean} \cdot I_{transy}} = 0.689 \ mm$$

simply supported

$$\frac{u_{inst}}{w_{deck}} = 0.046\% \qquad \frac{u_{inst}}{\lambda_h} < \frac{1}{300} = 1 \quad \text{OK}$$

Deck boards Calculations

Distributed Dead load on deck boards

$$G_{board} := g_{board} = 0.015 \ \frac{kN}{m}$$

dead of on board

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$G_{board.d} := G_{board} \cdot \gamma_G = 0.015 \ \frac{kN}{m}$ design dead load on board

$P_{board} := W_{per} \cdot g = 0.736 \ kN$ concentrated weight of 1 person

$P_{board.d} := P_{board} \cdot \gamma_Q = 1.104 \ kN$ design concentrated load on board

ULS Calculation

Check of the bending stress:

$M_{maxb} := \frac{1}{8} \left(G_{board.d}\right) \cdot \lambda_t^{\ 2} + \frac{1}{4} \cdot P_{board.d} \cdot \lambda_t = 0.097 \ kN \cdot m$

$\sigma_{md1} := \frac{M_{maxb}}{W_{board}} = 4.537 \ MPa$

$\frac{\sigma_{md1}}{f_{m.d}} = 0.655$ $\frac{\sigma_{md1}}{f_{m.d}} < 1 = 1$ OK

SLS Calculation

Load Case 1 (Point load mid span)

$u_{inst} := \frac{5}{384} \cdot G_{board.d} \cdot \frac{\lambda_t^{\ 4}}{E_{0mean} \cdot I_{board}} + \frac{1}{48} \cdot P_{board.d} \cdot \frac{\lambda_t^{\ 3}}{E_{0mean} \cdot I_{board}} = 0.322 \ mm$ simply supported

$u_{inst} := 0.0054 \cdot G_{board.d} \cdot \frac{\left(\lambda_t\right)^4}{E_{0mean} \cdot I_{board}} + 0.0093 \cdot P_{board.d} \cdot \frac{\left(\lambda_t\right)^3}{E_{0mean} \cdot I_{board}} = 0.144 \ mm$

one side fixed one side simply supported
- Tekni Ståbi pg107

$\frac{u_{inst}}{\lambda_t} = 0.041\%$ OK $\frac{u_{inst}}{\lambda_t} < \frac{1}{300} = 1$ OK

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