Exercise 7: Ice ring roof structure

Updating variables by a semi-probabilistic analysis and verification of structural safety

Background

The structure under investigation is a single-pitch flat roof (with a pitch angle < 30°). The roof is part of a sports hall.

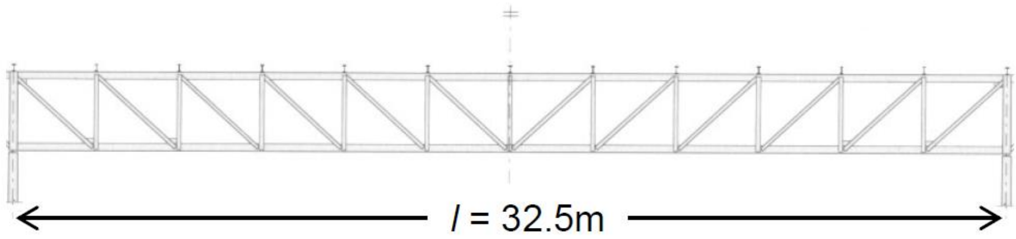


Figure 1: Geometry of the main truss beam.

In the context of this exercise, only the structural safety (type 2) of the tensioned chord at mid-span of the truss is to be verified, considering:

- The results of the condition survey, which showed a structure corresponding to drawings
- The roof and its structure are in good condition. There is no ongoing deterioration that could reduce the strength of the load-bearing elements.
    - Lattice truss (see Figure 1):
    - Span: $l = 32.5$ m;
    - Height: $h = 3.25$ m;
    - Static height: $d = 3.0$ m;
    - Spacing between 2 trusses: $e = 5.0$ m;
- Area of the chord in tension, at mid-span of the truss: $A_a = 110$ cm^2;
- Year of construction: 1952. Structural steel with a nominal strength $f_{yk} = 240$ N/mm^2 (as indicated on the construction drawings);
- Self-weight of the truss, leading permanent action, as executed, recomputed as: $g_a = 1.5$ kN/m;
- The lightweight roof "skin", accompanying permanent action, consists of a metal construction with thermal insulation and gravel. Nominal imposed load as indicated on the construction drawings: $q_{roof} = 2$ kN/m^2;
- The sport hall is located at an altitude of 1575 m.
- Required safety level: $\beta_0 = 4.6$ (following an assessment of the required safety level);
- The sports hall is expected to remain in service for a long time (≥ 50 years).

Objective

The aim of this exercise is to check the structural safety of the main beam (truss in steel construction) using a step-by-step approach (steps 1 and 2) where the deterministic approach is compared to the semi-probabilistic approach.

Step 1: Structural safety check using characteristic values (deterministic methods)

Question 1.1

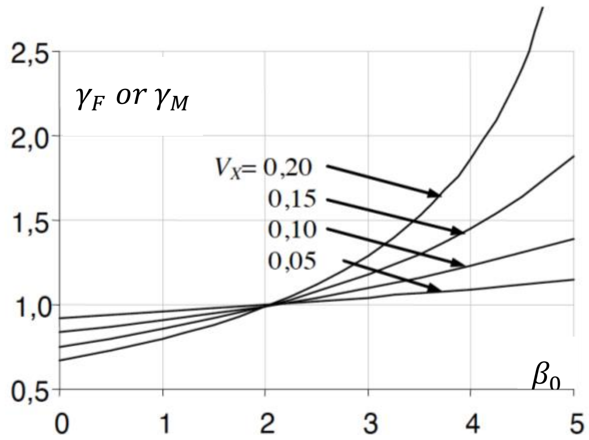
Determine the examination value of the resisting moment of the truss at mid-span.

Hint: Use SIA 269/3, chap. 5

Question 1.2

Determine the examination value of the effect of the actions for the hazard situation with snow as the leading action (wind can be neglected here).

For the unchecked self-weights, a conservative CoV value of 0.12 can be assumed. Use the typical relationship between β_{tgt} ,V_i and γ_i given in course 7 to deduce the corresponding (conservative) value for the load factor to be used.



Discuss the applicability of the β_{tgt} ,V_i and γ_i relationship.

Question 1.3

Determine the degree of compliance and discuss the result, also discuss the safety level required.

Step 2: Structural safety check using updated values with a semi-probabilistic analysis

Mechanical Properties of Structural Steel	
Measurement i	Yield strength $f_{y,i}$ [MPa]
1	260.3
2	262.2
3	268.7
4	270.3
5	273.2
6	275.8
7	276.9
8	282.1
9	287.5

Figure 3: Yield strength laboratory tests

Imposed load with variing gravel thickness	
Measurement i	Imposed load q_i [kN/m^2]
1	1.64
2	1.71
3	1.88
4	2.2
5	2.28
6	2.43
7	2.49
8	2.51
9	2.52
10	2.55
11	2.71
12	2.77
13	2.84
14	2.88
15	3.34

Figure 2: Imposed dead loads measurements

Question 2.1

Determine the examination value of the resisting moment of the truss at mid-span. A laboratory test campaign determined the yield strengths on nine samples of the truss-structure. The results are shown in Figure 3. One can assume that the test results follow a normal distribution.

Hint: Use SIA 269, Appendix C

Question 2.2

Determine the examination value of the imposed load considering that the load due to the roof "skin" has been updated by gravel thickness measurements. The distribution of the updated imposed load on the roof is given in Figure 2. One can assume a normal distribution.

Question 2.3

Determine the examination value for the moment due to the snow (as the leading variable action) by considering the snow load is updated by exploiting the results of a measuring station located in the same village as the sports hall (similar as Figure 4 from TGC 10 p.28).

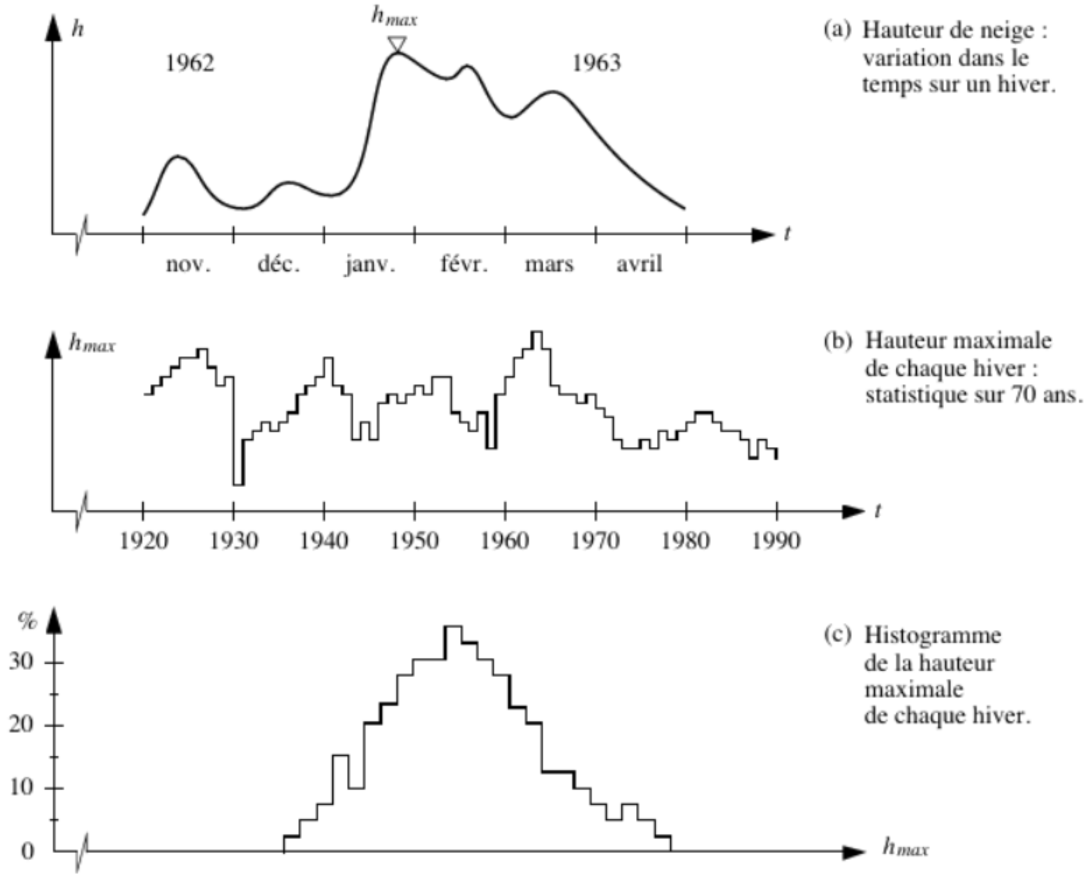


Figure 4: Example of the statistical variation of the snow height

The following results were obtained from an 85-year measurement campaign (Measurement of the maximum snow load per year, based on the water content):

Mean value: $q_{snow,m} = 3.15\ kN/m^2$

Coeff. of variation: $v_{snow} = 0.24$

A table for the cumulative distribution function for the standard normal distribution is given at the end of the document.

Question 2.4

Determine the sum of the examination values of the acting moments for the hazard situation with the snow as the leading action.

Question 2.5

Determine the degree of compliance and discuss the result.

Question 2.6

Determine the degree of compliance for $\beta_0 = 4.2$ and discuss the result.

Appendix 1: Snow load

Characteristic value of snow load on roofs, referred to the horizontal surface covered:

$$q_k = \mu_i \cdot C_e \cdot C_T \cdot s_k$$

with:

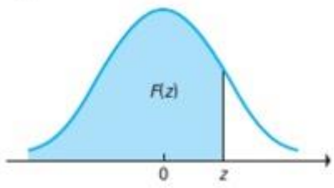
- μ_i the roof shape coefficient, for single-pitch flat roofs pitched at less than 30°: $\mu_i = 1.0$;
- C_e the wind exposure coefficient of the structure, for normal wind exposure: $C_e = 1.0$;
- C_T the thermal coefficient, generally equal to 1.0;
- s_k the snow load on horizontal ground (return period of approximately 50 years), valid up to 2’000 m altitude:

$$s_k = \left[1 + \left(\frac{h_0}{350}\right)^2\right] \cdot 0.4\ \text{kN/m}^2 \geq 0.9\ \text{kN/m}^2$$

  h_0 the reference altitude (in m), depending on location and taking account of regional climate where applicable.

Appendix 2: Table for Cumulative distribution function (normal distribution)

Table 1 Cumulative Distribution Function, $F(z)$, of the Standard Normal Distribution Table



z	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.1	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997

Note: this document is a translation, corrected of the exercise 4, lecture notes Prof. Eugen Brühwiler "Structures existantes I : Examen et interventions – Bases", 2022 edition, course CIVIL-436, courtesy of Prof. Brühwiler.

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