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REASONING ON IMPLEMENTATION OF FROST PROTECTED SHALLOW FOUNDATIONS

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Implementation of frost protected shallow foundations (with insulation) in frost susceptible soils in the areas of the Baltic region is an item under discussion. A design method recommended by EN ISO 13793 has been applied. The design base is the EN 1997-1 which includes conditions and valid climatic data for the localities in the Republic of Latvia. The study contains the results of external air temperature data processing from the last 70 years, and consequently a determination of a freezing index value, and moreover pointing out the variation depending on the reference period taken. Results of temperature data processing for decades of winter seasons testify that quite distinctive frost protection levels may be defined for shallow foundation design parameters depending on the number of frost seasons sampled. The specific design results were obtained for eccentrically loaded columnar spread foundations of an unheated building insulated to reduce heat loss from the soil below the foundations keeping the subgrade soil unfrozen. As a result of the research the conclusion about the benefits expected has been presented, based on the comparison of concrete consumption and soil excavation volumes from different localities in Latvia. It has been concluded that the cost effectiveness of heated foundations correlates closely with the type of frost-heaving soil. Use of frost protected shallow foundations in clayey soils leads to an increase of ground volume to be excavated and filled back, and concrete consumption for foundations decreases. In silty sand soils, if the required foundation depth is less than some definite level, both reductions may be achieved by shifting the ground, and in concrete consumption as well.

Keywords: Data analysis, Freezing season, Gumbel distribution, Codes and standards.

1 INTRODUCTION

Material and labor consumption for building foundation construction relates closely with freezing depth of the frost-susceptible soil.

In this extended study by Andersons and Ozola (2013) the authors aim at the assessment of an effectiveness of implementation of thermally insulated foundations in construction practice of Baltic region regarding the local geological and climatic conditions and subgrade soil properties. In order to assess the parameters of freezing seasons the temperature data samples were processed for some geographically representative localities of Latvia: Riga, Liepaja, Aluksne and Daugavpils having not long distances between but significantly differences regarding climate conditions. The study provides background information for decision making when an innovative construction method has been proposed.

2 CHARACTERISTICS OF FROST SEASONS IN LATVIA

2.1 Analysis of Frost Season's Data

Data of external air temperature where collected for 70 winter seasons from 1945/1946 until 2014/2015 from records of Meteorology stations in Riga, Liepaja, Aluksne and Daugavpils (External Air Temperature Data, 2015), see Figure 1 and Table 1.

Normally the freezing season characterizes the winter period when the differences between the freezing point (θ_f = 0°C) and the daily mean external air temperature ($\Theta_{d,j}$) remain positive: (0-$\Theta_{d,j}$) ≥0. Temperature data of every winter season were displayed graphically in order to estimate the real freezing season period according to the specifications in Annex A of EN ISO 13793. There are great variations both in duration of the freezing season and in temperature range from year to year, as it is typical of coastal regions, see Table 1 and Figure 2(*a*) for illustration. The graph of freezing seasons' average temperatures displays some trend of decrease as it is found from the trend line equation a decrement is in a range from -0.01˚ up to -0.02˚ per year, and a decrement of duration of a freezing season varies between 0.4 and 0.7 days per year.

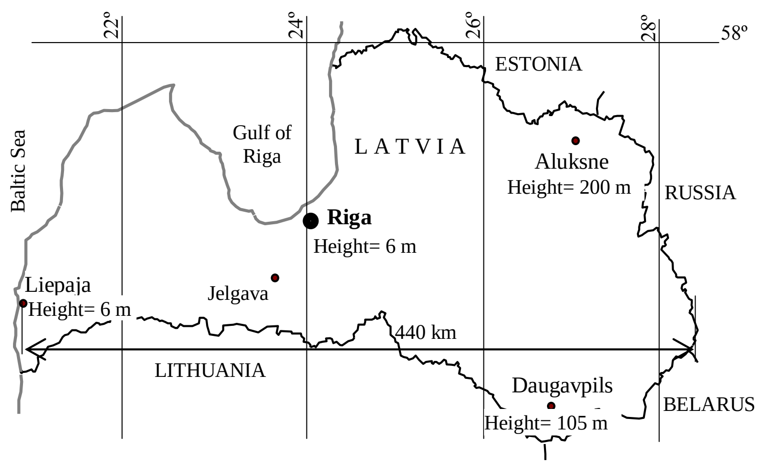

Figure 1. Displacement of meteorological stations monitored in the territory of Latvia.

Table 1. Characteristics of frost seasons for different periods.

Location	**Maximal duration of frost season in last … years, days**			**Minimal daily mean temperature (°) in frost season in last … years**			**Minimal mean temperature (°) of frost season in last … years**		
	70	**50**	**20**	**70**	**50**	**20**	**70**	**50**	**20**
Riga	148	138	138	-9.14	-9.14	-8.79	-29.8	-29.8	-25.0
Liepaja	123	121	116	-9.85	-9.85	-9.85	-27.0	-25.4	-21.7
Aluksne	153	153	153	-11.5	-11.5	-11.5	-34.4	-32.6	--29.2
Daugavpils	153	153	153	-11.2	-11.2	-11.2	-36.0	-32.4	--27.9

The extreme value theory was used for estimation of confident parameters for design as the upper tails of distributions are of great significance. The Gumbel model is the most widely applied for extreme value distribution approximations (Kottegoda

2008). Data samples of temperature cumulates were verified using cumulative distribution function (*G(z)*) of the Gumbel model defined as follows:

$$G(z) = \exp\left(-e^{-\left(\Theta_{y,i} - Mod(\Theta)\right)/\beta}\right), \tag{1}$$

where $\Theta_{y,i}$ is the cumulate of differences between the freezing point and the daily mean external air temperature, $Mod(\theta)$ is mode of data sample, and β is a positive real number. As it shown in Figure 2(*b*) Gumbel distribution shapes produce sufficiently good compatibility with data observed, and consequently we can use the probabilistic parameters recommended by the standard EN ISO 13793 with good reason.

(*a*)

(*b*)

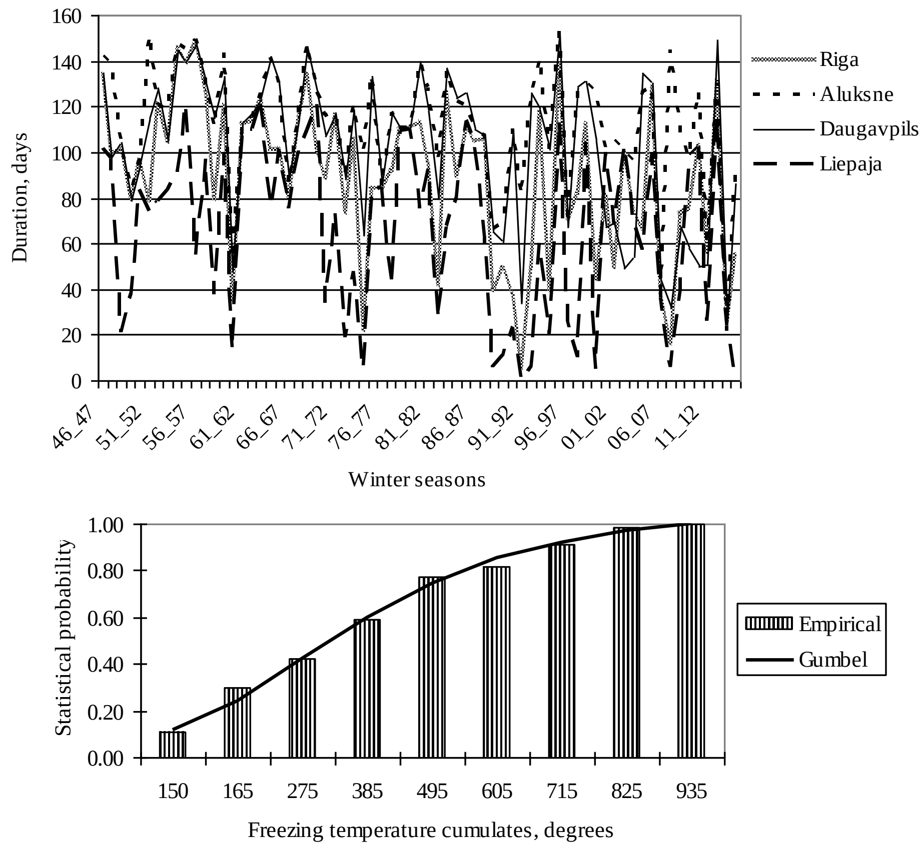

Figure 2. Frost seasons data displays: (*a*) duration of frost seasons; (*b*) cumulative distribution of freezing temperature cumulates (data sample of Riga station, Mode=330 ˚K, β=220).

2.2 Design Freezing Index for Reference Periods

For design purposes the severity of the winter is characterized by the freezing index which is expressed as an annual average of the sum of the differences between the freezing point and the daily mean external air temperature (0-θ_f) in the freezing season multiplied by 24, and supplemented by a correction for the variation so that the value represented statistically may be exceeded once in n years for the locality concerned (EN ISO 13793). Thereby F_n has a 1 in n probability of being exceeded in a given winter. In this study the design freezing index F_n has been calculated using equation (1) using real external air temperature data from records in meteorological stations.

$$F_n = \frac{\sum_{i=1}^{m}\left(24\sum_{j=1}^{k}\left(0-\Theta_{d,i}\right)\right)}{m} + \frac{\sqrt{\sum_{i=1}^{m}\left(F_i-\overline{F}\right)^2 \Big/ (m-1)}}{s_y}\left(y_n - y\right) \tag{2}$$

where $\theta_{d,j}$ is the daily mean external air temperature the average of several readings for day j, in °C; k is a number of days in the freezing season, m is a number of winter seasons included, s_y, y_n and y denote the reduced variable in the Gumbel distribution correspondingly to reference period n.

Table 2. Freezing index values for different temperature data reference period.

Location	**Freezing index values in ˚K•h depending on data reference years**						
	n= 70	**n= 60**	**n= 50**	**n= 40**	**n= 30**	**n= 20**	**n= 10**
Riga	26933	26581	25110	22782	20859	18983	16760
Liepaja	20327	20207	19184	17137	15130	13632	12300
Aluksne	36145	36079	34166	34244	30050	28495	26998
Daugavpils	33192	33552	31268	29015	27036	25570	23205

3 MODEL DESCRIPTION

A single storey unheated building of a size 19x31 m in plan has been taken as a model for numerical testing of a frost protected shallow foundation. The main load bearing structure of the building is a planar steel frame (span 18 m, space 6 m) performed by restrained steel columns and simply supported roof trusses. The sizes of the rectangular pad of the foundation depend on the subgrade soil resistance but no less than the required size at the section of column restraint- 600x600 mm.

The freezing depth of the soil depends on both climatic conditions in area and the properties of the soil. For clayey soils at the locations within Latvia the characteristic frost depth values range from 1.20 up to 1.35 m. For an unheated building tested consequently the design depth of foundation (D_f) for clayey soils is defined D_f = 1.3×1.1≈1.4 m, but for silty sand D_f = 1.3×1.1×1.2=1.7 m.

Characteristics of soils typical of locations in Latvia, such as clays, clay sands, sandy clays and silt sand were included. The design bearing capacity values of subgrade soils were determined according to Terzaghi's theory (Terzaghi 1996, Das 2006). The width of footing (B) has been found as optimal for the transmitting of forces from restrained columns. The capacity values of soil under footing to its width B= 1.2 m vary between 170 and 260 kPa depending on the soil type.

4 RESULTS

For this study extruded polystyrene Styrodur 4000CS (density 30 kg/m^3) has been chosen as the insulation material used by practitioners in European countries, Canada and the United States in recent decades. The verified acceptable long-term (50 years) compressive stress for this material is declared at 180 kPa, creep deformation less than 2% , compression strength at 10% deformation – 180 kPa (Technical Data… BASF).

The concrete consumption for shallow foundations to be built in freezing depth has been estimated and compared with the one for insulated foundations, and it is found that savings may be achieved even two times, see Figure 3.

Cost-effectiveness of building depends considerably on the bulk of ground excavation needed for the foundation. The comparison of soil volumes to be moved during construction for insulated foundations as the ratio to deep ones depending on the depth of foundation has been illustrated in graphs in Figure 4. It is clear that frost protected shallow foundations are effective at a depth less than approximately 0.8 m.

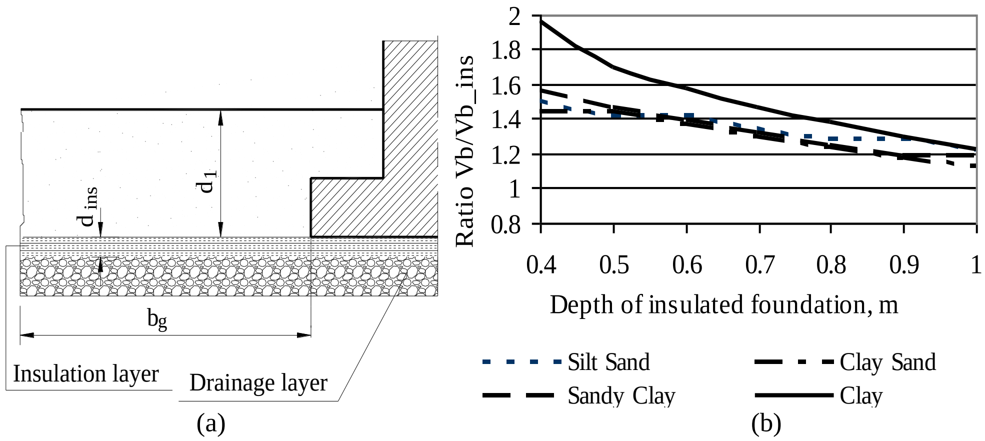

Figure 3. Frost protected foundation: (*a*) section; (*b*) relative concrete consumption.

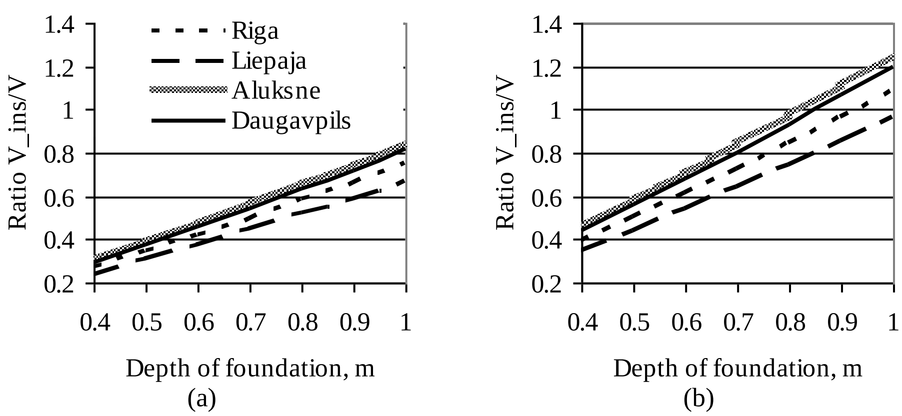

Figure 4. Ground excavation volumes versus depth: (*a*) for silty sands; (*b*) for clay soils.

The decrease of the depth of shallow foundations may be of an exceptional importance when the water table is high.

The use of decreased depth of foundations approved by building codes for heated buildings is an item under discussion when approaching the sustainability aspects of buildings. Normally there are expected periods in service life when the building remains unheated for some season(s). From this point of view frost protected foundations by insulation may be a good safety measure for the expected non-occupation periods of the building when heating may be interrupted due to a change of service conditions.

5 CONCLUSIONS

- Due to the changeable climatic conditions for locations in Latvia the freezing index values vary significantly depending on both temperature data variability and assumed duration of reference period consequently involving the uncertainty for insulation size (width) needed within the range of 20-25%.
- The use of heated foundations in clayey soils, including silty sand leads to an increase of soil volume to be excavated and filled back whereas but concrete consumption for foundations decreases.
- The decreased side area of foundations obtained using the insulation leads to a decrease of heave forces and consequently to more safety in construction regarding human errors in construction (if the backfill is non-quality or the material is off-grade, i.e., contains a clay fraction).
- Insulation of foundations may be recommended for any heated building, which due to consideration of thermal expansion has a reduced depth of foundations, to ensure the sustainability of the building for the possible periods of usage while the object may be left without owner.
- The thermal design may be recommended when the groundwater level is high, since the use of this method does not require lowering the water table during construction.

References

Andersons, G., and Ozola, L., Efficiency of thermal design of shallow foundations. *Civil Engineering'13. 4th International Scientific Conference Proceedings*, Vol.4., Part 1, 21-30, Jelgava, Latvia University of Agriculture, 2013.

Das, Braja M., *Principles of geotechnical engineering*/ Braja M. Das. - 6th ed. - Toronto, Ont., Canada, Thomson, 2006.

EN 1997-1. Eurocode 7 - Geotechnical design - Part 1: General rules

EN ISO 13793. Thermal Performance of Buildings - Thermal Design of Foundations to avoid Frost Heave.

External Air Temperature Data, retrieved from http://www.meteo.lv on June, 2015.

Kottegoda, Nathabandu T., *Applied statistics for civil and environmental engineers*/ Nathabandu T. Kottegoda, Renzo Rosso. Oxford, Malden, MA, Blackwell Publishing, 2008.

Recommended Applications. BASF, retrieved from http://www.styrodur.de on June, 2, 2015

Terzaghi, Karl, *Soil mechanics in engineering practice*/ Karl Terzaghi, Ralph B.Peck, Gholamreza Mesri. New York etc., Wiley, 1996.