EFFICIENCY OF THERMAL DESIGN OF SHALLOW FOUNDATIONS

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ABSTRACT

The article contains results of a preliminary study of specific local prerequisites for the application of a frost protected shallow foundation design method presented in the European standard LVS EN ISO 13793 with the purpose to make a reasonable decision for implementation in the design practice for buildings in frost susceptible soils in the areas of Latvia. The design base is the Latvian building code: LBN 207-01 and valid climatic data for some localities in Daugavpils. The article contains the results of external air temperature data processing and consequently analysis of a freezing index value variation depending on the reference period of frost seasons. The specific design results were obtained for eccentrically loaded columnar spread foundations of an unheated building and 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 has been presented, based on the comparison of material and labour-consumption. It has been concluded that the cost effectiveness of heated foundations correlates closely to the type of frost-heaving soil. Use of frost protected shallow foundations in clayey gravel 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 0.8 m, both reductions are achieved by earth-moving and in concrete consumption.

Key words: Foundations, Thermal Insulation, Codes and Standards

INTRODUCTION

In the majority of locations within Latvia's territory the soils are susceptible to frost heaving, and building foundations must normally be built below the frost depth for this reason. During the last decades the frost protected shallow foundation method has been used in many cold regions (Nordic countries, USA, Canada and others) as a practical alternative to deeper, more expensive foundations (Farouki, 1992; Revised Builder's Guide…, 2004).

The frost-protected shallow foundation technique is an advanced building technology to achieve both lower initial costs and increased energy savings. The risk of frost heave to foundations may be avoided in various ways, such as:

- to have foundations deep enough so they are below the frost penetration depth,
- to replace the frost-susceptible soil with a non frost-susceptible material before constructing the foundations,
- to set up the insulation so as to avoid frost penetrating below the foundations,
- a worthwhile utilization
- of heat loss from the building to keep the soil below the foundations unfrozen.

Furthermore the solution adopted can be a combination of methods listed above.

The simplified procedures for the design of building foundations to avoid damage resulting from frost heave are given in standard LVS EN ISO 13793. Yet these methods are new for construction practices in Latvia because they should be carefully approved of first taking into account the local geological and climatic conditions.

The geotechnical specifications for areas inspected testifies that the water table rests less than 2 m below the depth at which fully frozen soil lies. For such conditions the Latvian code LBN 207-01 specifies that a foundation depth should be not less than 1.4 m for undisturbed clayed soils and not less than 1.7 m for undisturbed sandy-soils. Correspondingly to insulation layer constructed the foundation depth may be reduced up to 0.4 m.

The current study contains the comparison of effectiveness of foundation insulation methods presented in standard LVS EN ISO 13793 with the design results obtained using the Latvian building code LBN 207-01 for columnar spread foundations of an unheated building sized by 18×36 m in plan and insulated to reduce heat loss from the soil below the foundations keeping the soil unfrozen.

AIM AND SCOPE

The aim of this study is to provide some insight on the problem regarding conditions of Latvia's regions and to draw up a methodological background for frost protected shallow foundation design, including analysis of input data range and effectiveness, and practical usefulness of the implementation of a new method regarding local climatic conditions and subgrade soil properties.

The study provides background information for decision making when an innovative construction method has been advanced.

BACKGROUND

Recent investigations in geotechnical engineering clarifies the frost heave phenomena in more detail (Noon, 1996; Manz, 2011). Frost heave i.d., the nonuniform change of a volume of a subgrade matrix occurs not only due to the expansion of freezing water in the soil, since, frequently, the heave effect is much greater than the freezing water in the soil is capable of producing. The process is exceedingly complex and still not fully understood.

Frost heave is caused by the formation of ice lenses in the soil below the foundation (Fig. 1). Water expands roughly nine percent by volume when frozen. When freezing temperatures penetrate a subgrade soil, water moves from the unfrozen area towards the frozen zone. If the soil is susceptible to capillary action, the water migrates to previously formed ice crystals and freezes. The size of the ice lens depends on the quantity of free water available within the soil, from the water table, and time.

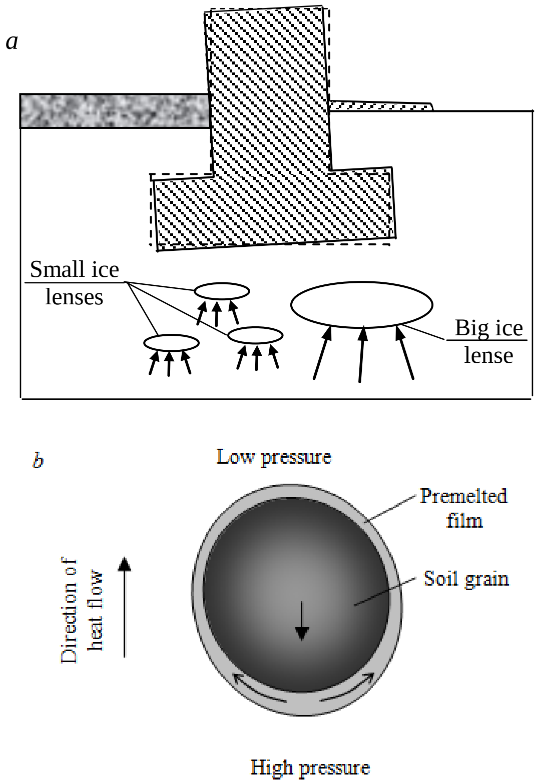


Figure 1. Simplified illustration for frost heave effect in subgrade soil: *a*- growing of ice lenses due to the feed of groundwater from warmer deeper zones, *b*- formation of pressure gradient around soil grain due to grains and ice molecular interactions

In an up-close or secondary frost heave zone of ice lens, a structure of matrix is composed of a multitude of thin crystals growing due to capillary water supply and oriented parallel to the direction of heat flow.

The frost susceptible soil must be sufficiently porous to allow capillary action, yet not so porous as to break capillary continuity.

Water movement in freezing soils is also supported by suction forces (due to pressure differences) that are induced by microscopic interactions between soil grains, nanometer-thick premelted film (formed by liquid water below-freezing temperature), ice, and water within a partially frozen region below the ice lens.

The result of the frost heave force complex is an upward pressure attached to foundations embedded in frost susceptible soil, ranging from 1200 kPa in clay soils, and up to 3000 kPa in silty sand recognized in field tests by researchers during the last decades. Moreover an upward drag of the foundation has been caused by adfreeze stress generated at the side interfaces of foundations ranging from 45 to 1600 kPa for concrete regarding soil type (Domaschuk, 1982).

The incidence of frost heave occur when all of the following three conditions are present:

1) The soil is frost susceptible due to a large silt fraction
2) Soil is above approximately 80 percent water saturation due to the supply in the surrounding area
3) From below, above and/or laterally into the freezing zone subfreezing temperatures penetrate the soil.

Removing one of these factors prevents the possibility of frost damage. Insulation helps with the third one, shielding the foundation from the freezing underlying soil. Soil can hold a great deal of thermal energy, particularly if damp, but it is not a good insulator. For example, 25 mm of polystyrene insulation has an equivalent U-value with 100 mm of soil on average. Depending on the soil type, a layer of 200 - 300 mm depth would be required to provide the same insulation as 50 mm of foam or 80 mm of fiberglass insulation.

Now, a few insulation materials are able to maintain a dry U-value in a moist, below the ground environment over any great length of time. The stress limits declared for insulation material must provide a factor of safety required, according to LVS EN 1990, and a means to limit long-term compressive creep in the insulation layer as well. The high strength extruded polystyrene rigid insulation boards must be appropriate for use under concrete floors and foundations meeting the requirements stated by LVS EN 13164.

Basing on results of the investigations in the related field and due to production of durable insulation materials developed, background has been established for the implementation of insulated foundations.

For unheated buildings the frost protected foundation design methodology is based on conception about the prevention of heat loss from the subgrade soil stored in the ground during the summer.

SOURCE DATA AND METHODS

Design data for building foundations analysed

A numerical analysis has been performed based on real climatic data for an insulated foundation of a single storey building. The main load bearing structure of the building is a planar steel frame (span 18 m, space 6 m) formed by restrained steel columns and simply supported lightly loaded roof trusses (Fig.2*a*). The enclosure system is composed of sandwich panels including a 100 mm thick insulation layer. The cladding panels are supported on purlins which transmit the loads to trusses. Lightweight Z-profiles perform the function of secondary bearing members - purlins. Fourteen column foundations are placed correspondingly in rectangular form (Fig. 2). To corner foundations, placed on axes 1-1 and 7-7, the distinctive portion of external load will be transferred, and the ground insulation layer may be of different sizes. Taking into account these differences, the internal foundations have been chosen for analysis in this study. Generally the height of the foundation depends on the depth. The sizes of the rectangular pad of the foundation depend on the subgrade soil's resistance but no less than the required size at the section of column restraint- 600x600 mm.

The vertical force transferred to bearing system is calculated taking into account a permanent load representing the selfweight of cladding and bearing structures (g_k= 0.6 kN/m^2) and variable snow load. For Latvia's territory the characteristic value of snow load (s_k) declared by Latvian building code LBN 003-01 ranges from 1.10 to 2.80 kN/m^2. In this study the value s_k= 1.60 kN/m^2 has been accepted as defined more often (approximately 80% of territory of Latvia). Eccentrically loaded foundation has been designed for four fundamental combinations of actions according LVS EN 1990:

1) permanent load (selfweight) + snow load;
2) selfweight+ full snow load+decreased wind pressure;
3) selfweight+decreased snow load+ full wind pressure;
4) selfweight+ wind pressure.

Depth of foundation

The depth of the frozen ground depends on climatic conditions of an area and the properties of the soil (porosity, moisture content, particle sizes). For locations within Latvia the characteristic frost depth values range from 1.20 up to 1.35 m for clayed soils as it is defined by Latvian building code LBN 003-01. The codified values are based on the analysis of a valid data set (years 1923-1998), and defined as frost depth values which are expected to exceed one time during 100 years. A real depth of the foundation has been determined depending on the heat regime in the building. In this study the method for an unheated building has been applied, consequently the 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, and provided that the water table is nearer 2 m from the level of the frost depth.

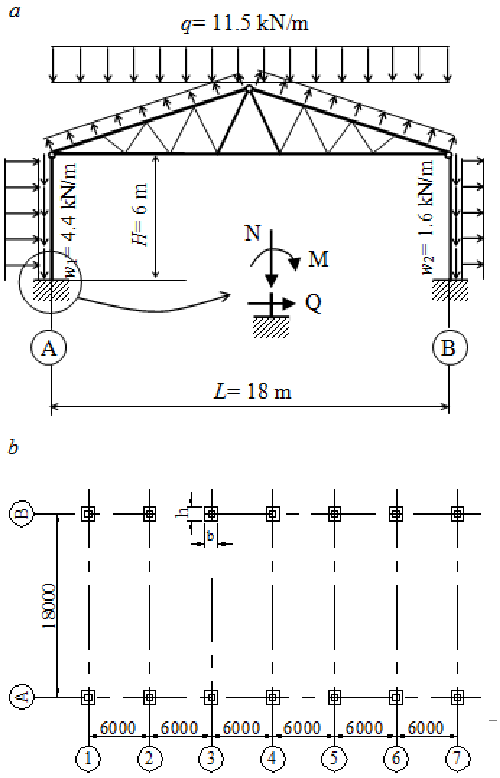


Figure 2. Design model of test building: *a*- design model of planar bearing frame, *b*- plan of column foundations

Usually the snow cover insulates the ground and retards heat loss from the earth decreasing the frost depth except in the cases of weathered ground surfaces or cleaned up from the snow. The unfavourable situation should be taken into account in construction, and thereby there is no consideration about snow cover influence on foundation depth in this study.

Design bearing capacity of soil

Some types of soils typical for locations of Latvia including Daugavpils region, such as clays, clay sands, sandy clays and silt sand were chosen for the analysis regarding effectiveness of subgrade insulation.

The existing Latvia building codes (LBN 207-01, article 58) recommend the equation for calculation of design bearing capacity value is not essentially different from that proposed by Terzaghi many decades before (Терцаги, 1961) and developed for general failure case assuming that resistance expected to be inherent for subgrade soil depends on shear stresses in the frictional-cohesive material (soil) at edges of three zones under the footing and of overburden pressure.

Consequently a bearing capacity may be explained by three factors every one being a function of internal friction angle and related to: 1) cohesion of the soil, 2) depth of the footing and overburden pressure, 3) width of the footing and the length of shear zone in the limit state. The soil capacity to vertical load increases linearly with depth as illustrated by graphs for some characteristic soil types in Figure 3. The following values of soil properties have been introduced for analysis: coefficient of porosity e= 0.65, unit weight γ= 17.5 kN/m^3, plasticity index I_L>0.5. An angle of internal friction φ and effective cohesion c values are as follows correspondingly: φ= 30˚, c = 4 kPa for silt sand; φ= 24˚, c = 13 kPa for clay sand; φ= 19˚, c = 25 kPa for sandy clay; φ= 15˚, c = 45 kPa for clay. Note that soil classification corresponds to that specified in LBN 207-01.

The width of footing (b) has been found as optimal for transmitting of forces from restrained columns. The capacity values in Fig. 3 correspond to width value b= 1.2 m.

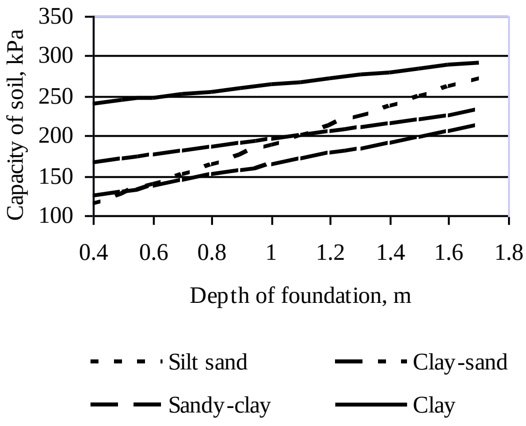


Figure 3. Resistance of soil versus depth of foundation

Analysis of frost season's data

The frost protected shallow foundation design method described in LVS EN ISO 13793 has been recommended for columnar and strip foundations, for slabs on ground and also in regions where the average annual temperature of external air remains above 0°C as the averages range from +4.5°C to +6.7°C referring to observations over a 30-year period (LBN 003-01).

Another more labour-consuming procedure deals with winter temperature data processing in order to make an assessment of duration for each year's freezing season. The frost characteristic is defined as the difference between the freezing point (θ_f= 0°C) and the daily mean external air temperature. The freezing season starts at the point from which the accumulation of aforementioned differences remain positive throughout the winter. If there is initially some freezing followed by complete thawing, the corresponding days are not included. The accumulation, therefore, starts after this. The freezing season ends at the point which results in the largest total accumulation for the winter. If a short thawing period is followed by a longer freezing period both are included; if a thawing period is followed by a shorter freezing period neither is included.

In this study the external air temperature data (averages of daily data set from October 20 until April 10) where collected for 62 seasons from 1950 until 2012 from records at Daugavpils station available in Web page of State Ltd "Latvian Environment, Geology and Meteorology Centre". There are great variations in both duration of the frost season and temperature range from year to year, as it is typical for a coastal region, see Figure 4 for illustration. Similar graphs were drawn for every winter. The frost season duration was estimated manually following the standard conditions described in the previous paragraph. The illustration is presented in Figure 5. Freezing depth of the soil is more affected by temperatures characterised by the sum of differences between freezing point and the daily mean during the frost season (Fig. 6). It is clear from both column graphs presented that uncertainty of the frost season data is explicitly large, particularly as regard temperatures. The extreme value theory was used for estimation of confident parameters for design as the upper tails of distributions are of great significance.

From different probabilistic models developed for statistical characterisation of extremal values in engineering, the Gumbel model is the most widely applied (Kotz and Nadarajah, 2000). Also the design characteristics presented in LVS EN ISO 13793 have been derived using the Gumbel model. For this reason data samples of frost duration and temperature cumulates were verified using cumulative distribution function of the Gumbel model defined as follows:

$$G(z) = \exp\left(-e^{-z}\right), \qquad (1)$$

where G(z) – the cumulative distribution function,

z- normalized variable useful for simplified calculation. For data processing of freezing temperature cumulates variable z is taken as:

$$\mathrm{z} = \left(\theta_{\mathrm{y,i}} - \mathrm{Mod}(\theta)\right)/\beta \ , \qquad (2)$$

where $\theta_{\mathrm{y,i}} = \sum_{\mathrm{i=1}}^{\mathrm{k}} \left(0° - \theta_{\mathrm{daily,i}}\right)$

Mod(θ) – mode of data sample,

β – positive real number.

The variables of frost duration were normalized in a similar manner for the Gumbel test. Evidently the Gumbel distribution shapes produce sufficiently good compatibility with observed data (Fig.7,8), and consequently we can use the probabilistic parameters recommended by standard LVS EN ISO 13793 with good reason.

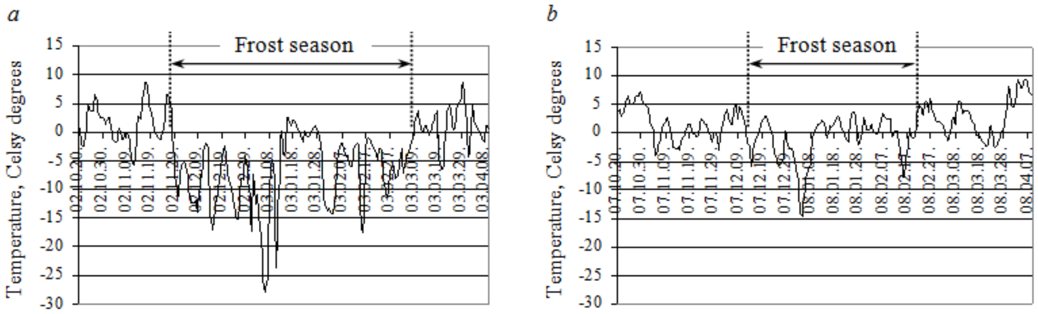


Figure 4. Examples of external air temperature fluctuations in Daugavpils area during time period from October 20 until April 10: *a*- season 2002/2003, b- season 2007/2008

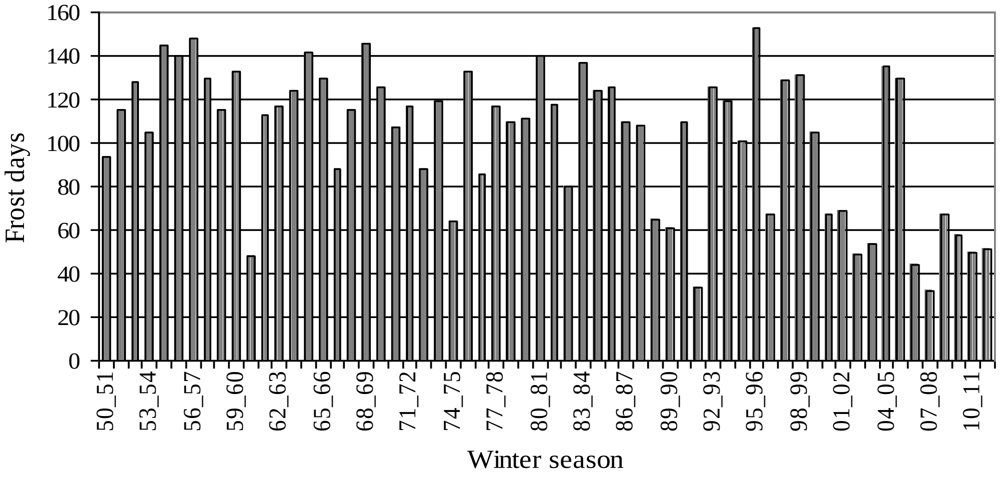


Figure 5. Durations of frost seasons during winters in Daugavpils, years 1950-2012

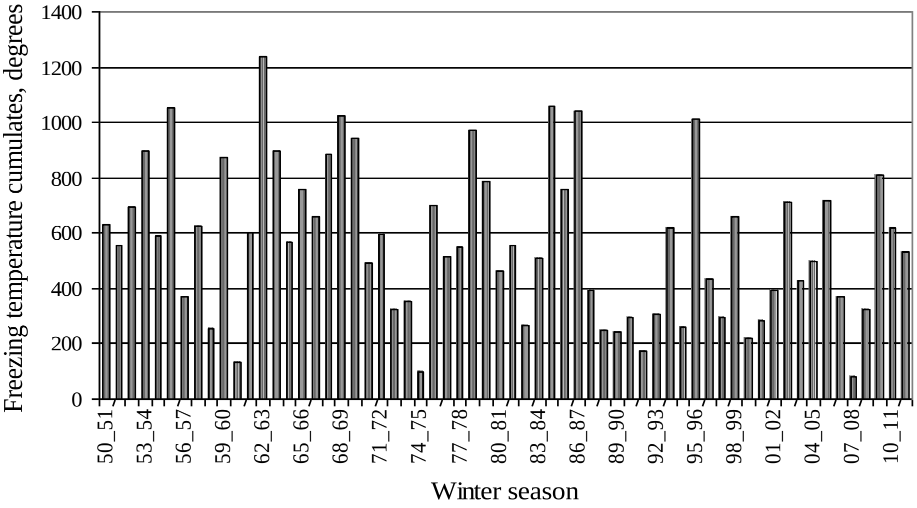


Figure 6. Data range of temperature cumulates during frost seasons in Daugavpils (1950-2012)

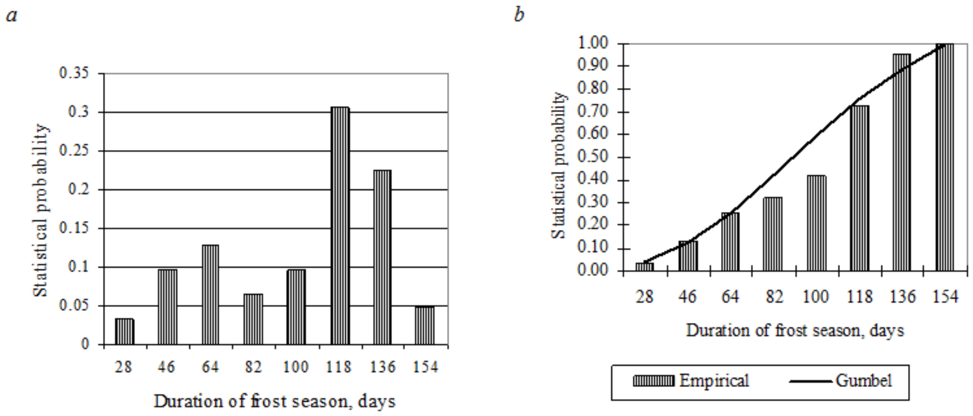


Figure 7. Distributions of frost season duration probabilities : *a*- empirical; *b*- empirical and theoretical cumulates (Daugavpils, years 1950-2012)

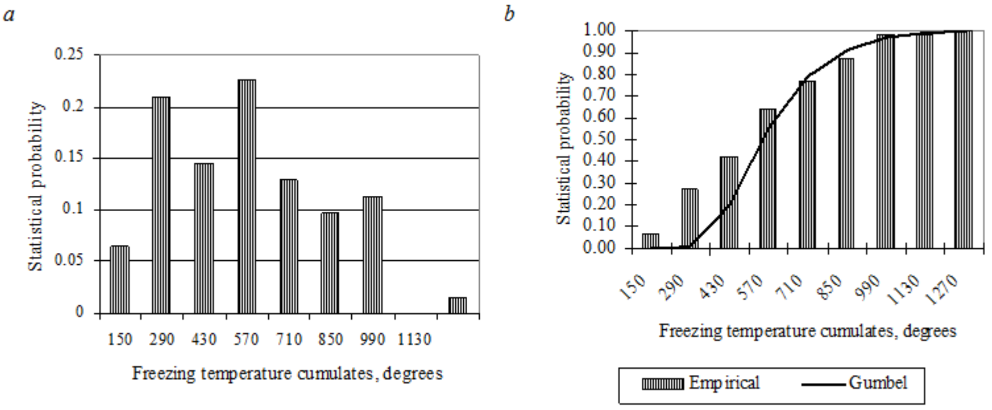


Figure 8. Distributions of freezing temperature cumulates during frost season: *a*- empirical; *b*- empirical and theoretical cumulates of probabilities (Daugavpils, years 1950-2012)

Evaluation of design freezing index

The insulation required for frost protection depends on the severity of the design winter, expressed in terms of the freezing index together with the annual average external air temperature. The design freezing index (F_n) is the value which statistically is exceeded once in n years for the locality concerned, based on recorded meteorological data and calculated according to Annex A of LVS EN ISO 13793. F_n has a 1 in n probability of being exceeded in a given winter. For permanent buildings n is normally chosen as 50 or 100 years; for the test building in this study n = 50.

In this study the design freezing index F_d has been calculated from meteorological records of daily mean external air temperatures for the Daugavpils region. The freezing index F_i (in ˚K·h) for one frost season were calculated as 24 times the sum of the difference between freezing point (θ_f= 0°C) and the daily mean external air temperature:

$$F_i = 24\sum_{j=1}^{k}\left(\theta_f - \theta_{d,j}\right), \qquad (3)$$

where $\theta_{d,j}$ – the daily mean external air temperature the average of several readings for day j, in °C;

k - all days in the freezing season. Both positive and negative differences, within the freezing season, are included in the accumulation. A negative difference implies some thawing of the ground reducing the frost penetration in the ground.

The design freezing index for a given location is obtained from a set of freezing indexes Fi, calculated of m winters at the location (m≥20, in this case m= 62). The Gumbel distribution has been recognized as a suitable statistical distribution that realistically reflects extreme events and recommended for determination of design freezing index (F_n). According to Gumbel the design freezing index is given by:

$$F_n = \overline{F} + \frac{s_F}{s_y}\left(y_n - \overline{y}\right), \qquad (4)$$

where $\overline{F}$ - average of freezing indexes;

$$\overline{F} = \sum_{i=1}^{m} F_i \Big/ m = \frac{844450.9}{62} = 13620\,{}^{\circ}\cdot h,$$

s_f - standard deviation for index data sample;

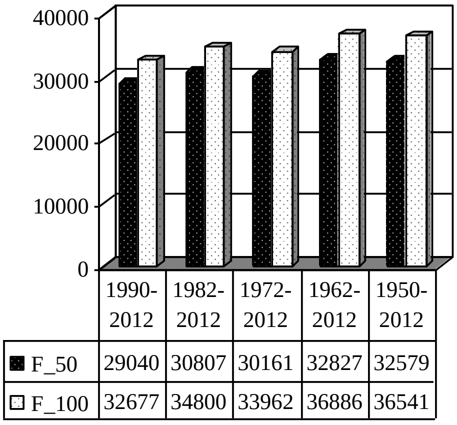
$$s_F = \sqrt{\sum_{i=1}^{m}\left(F_i - \overline{F}\right)^2 \Big/ (m-1)} =$$

$$= \sqrt{2674563867/(62\text{-}1)} = 6621.6\ ^{\circ}\cdot h,$$

$\overline{y}$, s_y – reduction factors for variables in Gumbel distribution regarding the reference period of data processed; in this study $\overline{y}$ = 0.55, s_y= 1.17 correspondingly to data sample of 62 years (LVS EN ISO 13793, Table A.1).

y_n – statistical parameter with regard to the level of safety of the building, dependent on the expected lifetime, y_n = 3.9 correspondingly 50 years lifetime of permanent building. The values estimated were put into formulae (4) resulting to the freezing index for Daugavpils locality according to temperature data sample of 62 winter seasons: F_{50}= 32579 ˚K·h which may be exceeded once in 50 years, and F_{100}= 36541 ˚K·h once in 100 years basing on the Gumbel prognosis.

The prognosticated value of the freezing index for Daugavpils region is quite dependent on the chosen time period upon which the temperature data are processed. The variation of freezing index values determined according to different reference data periods is illustrated by column graphs in Figure 9. It is useful to note that the maximal value of freezing index was obtained upon data of the winter seasons for the years of 1960-1980 (not displayed in Fig.9): F_{50}= 43548 ˚K•h and F_{100}= 49317 ˚K•h for building of life time 100 years.



	1990-2012	1982-2012	1972-2012	1962-2012	1950-2012
■ F_50	29040	30807	30161	32827	32579
☐ F_100	32677	34800	33962	36886	36541

Figure 9. Freezing index (in ˚K•h) versus reference period

Characterisation of average year temperatures

The protection of cold structures relies on the heat consumption available in soil that has been stored in the ground during summer. Therefore the average temperature in a region is one more important factor for design. Figure 10 represents the graph of average temperature values calculated from data of Daugavpils station.

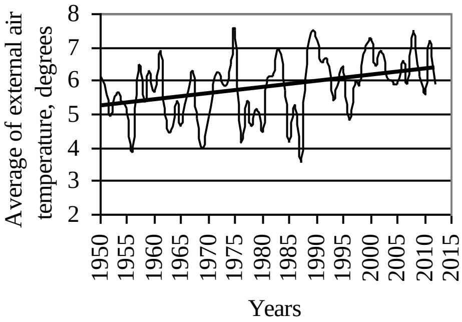


Figure 10. Variation of average temperatures

Frost protected foundation design for unheated building

The main purpose of the thermal design of foundations is to avoid frost heave. The design methodology used in this study has been provided by LVS EN ISO 13793 where it is proposed that no fully frozen soil occurs below the foundation during the design winter. The design procedure presented in the standard has been developed according to the investigations and practical experience for many decades. The parameters included in this study and relevant to frost protection are:

- freezing index and annual average temperature;
- frost susceptibility of the soil;
- thermal properties of the ground, both frozen and unfrozen;
- insulation of the floor;
- internal temperature in the building;
- the geometry, and especially the overall dimensions of the building and the type of foundation used.

The width of ground insulation for an unheated building is determined based upon the data shown in Table 10 presented in standard LVS EN ISO 13793 corresponding to the design freezing index $F_d = F_n$. The required width of the insulation layer, i.d., widening around footing is b_g= 1.7 m (Fig. 11). Such width of the ground insulation for an unheated building may be applied for foundation depth from 0.4 to 1.0 m. Insulation is placed on a drainage layer. The drainage layer consists of coarse material that is not frost susceptible.

The minimum thermal resistance of the ground insulation, R_g, is determined according to the tabulated values in standard LVS EN ISO 13793 for foundations at least 0.4 m up to 1.0 m deep (see Table 1). Expanded or extruded polystyrene with a density of at least 30 kg/m^3 can normally be used in the construction of insulation layer under loaded foundation. Extruded polystyrene (XPS) has the largest compressive strength and can be used in various applications for insulating of building foundations. As compressive loads in value up to the ground bearing capacity may be applied and transferred to the insulation layer, the insulation material selected must be verified for stress limits providing a factor of safety and a means to limit long-term compressive creep in the insulation layer, and the allowable stress limits are defined based on a percentage of minimum insulation compressive resistance.

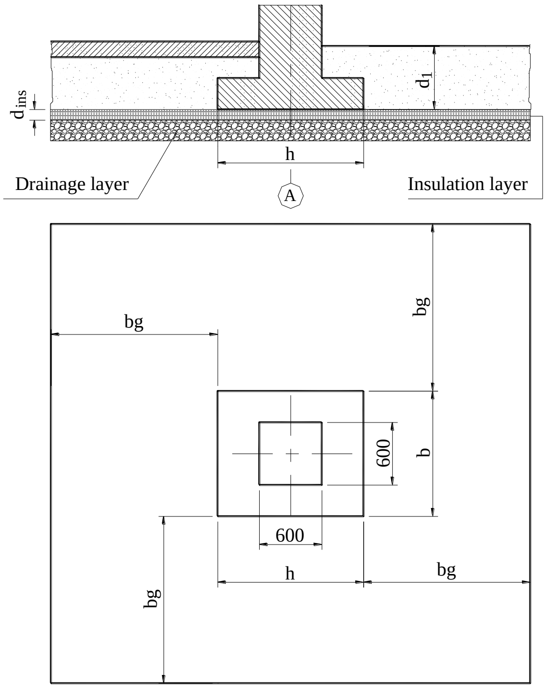


Figure 11. Frost protected shallow foundation

Table 1

Characteristics of ground insulation

d_1, m	R_D, $m^2\cdot°K$/W	U, W/$m^2\cdot°K$	λ_D, W/$m\cdot°K$	d_{ins}, m
0.4	1.90	0.53	0.035	70
0.5	1.68	0.60	0.034	60
0.6	1.47	0.68	0.033	50
0.7	1.25	0.80	0.032	40
0.8	1.03	0.97	0.032	40
0.9	0.82	1.22	0.032	40
1.0	0.60	1.67	0.032	40
Symbols: d_1 – depth of foundation; R – minimal unit thermal resistance of ground insulation required; λ, U – thermal transmission coefficients, d_{ins} - thickness of insulation layer.				

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

RESULTS AND DISCUSSION

Numerical results for case study

The foundation under an unheated buiding has been designed to support the loads (Fig. 2) according to serviceability limit state criteria (LBN 207-01) stated as follows: maximal pressure (σ_{max}) around side line of footing must be less or equal to bearing capacity (R) multiplied by 1.2, and the calculated value of average compression stresses (σ_{mean}) must be less or equal to capacity ($\sigma_{mean} \leq R$). See Table 2.

Cost-effectiveness of building depends considerably on the bulk of ground excavation needed for the foundation. With regard to economical estimations in this case study (Fig. 12), the comparison of soil volumes to be moved during construction for insulated foundations as ratio to deep ones depending on the depth of foundation has been illustrated in graphs in Fig. 13. It is clear that frost protected shallow foundations are effective at a depth less than approximately 0.8 m.

Also the concrete consumption for insulated foundations has been estimated in comparison with ones to be built in freezing depth (see Fig. 14), and savings may be achieved of up to 50 per cent.

Table 2

Design characteristics

d_1, m	Sizes of footing, m	σ_{max} kPa	σ_{mean} kPa	R, kPa	$\sigma_{max}/1.2R$
Silty Sand					
0.4	1.5 × 1.2	133	78.6	114	0.98
0.6	1.4 × 1.2	159	87.5	138	0.96
1.0	1.3 × 1.2	167	91.6	163	0.86
1.7	1.2 × 1.1	294	130	273	0.90
Claysand					
0.4	1.5 × 1.2	133	78.6	123	0.90
0.6	1.4 × 1.2	159	87.5	137	0.97
1.0	1.4 × 1.2	167	91.6	151	0.93
1.4	1.3 × 1.2	220	109	191	0.96
Sandy Clay					
0.4	1.3 × 1.2	174	89.2	165	0.87
0.6	1.3 × 1.2	183	93.3	175	0.87
1.0	1.3 × 1.2	192	97.3	186	0.86
1.4	1.2 × 1.2	257	116	216	0.99
Clay					
0.4	1.1 × 1.0	290	122	239	1
0.6	1.1 × 1.1	278	116	247	0.93
1.0	1.1 × 1.1	291	120	255	0.95
1.4	1.1 × 1.1	332	133	280	0.99

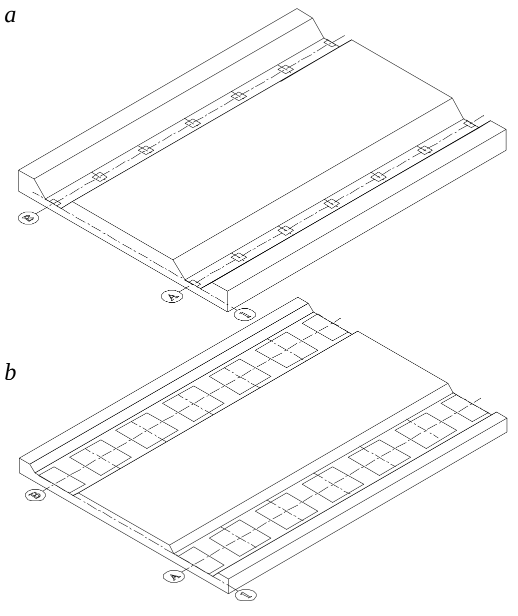


Figure 12. Soil excavation schemes: a- for traditional deep foundations, b- frost protected shallow foundations

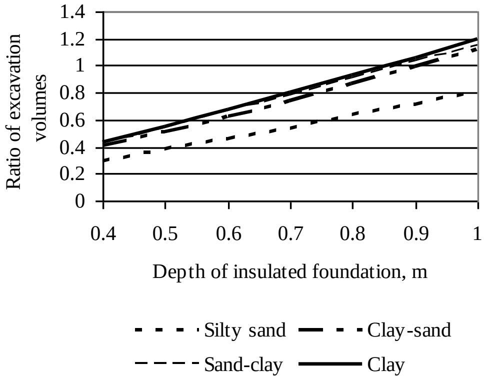


Figure 13. Variation of relative ground excavation volumes versus depth

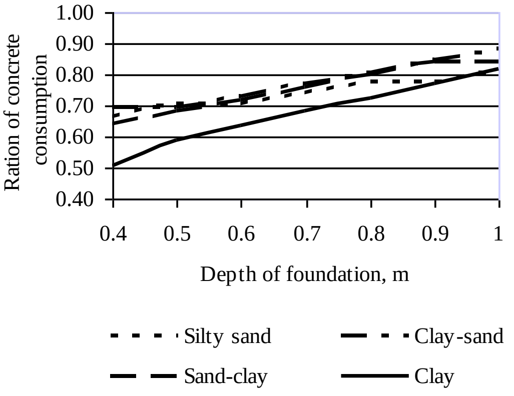


Figure 14. Illustration of relative concrete consumption for insulated foundations

Discussion on uncertainty of freezing index

It is clear that the implementation of frost protected shallow foundation design in the construction practice of Latvia may be accepted when there is no doubt of the fulfillment of the basic requirements for safety and durability of structure performing procedures stated by the standards and code. The main objective in this relation is the value of the freezing index.

Results of temperature data processing for 62 winter seasons according to temperature records in Daugavpils station testify that quite distinctive reliability levels may be defined for shallow foundation design depending on the number of frost seasons (m) sampled remaining under condition ($m \geq 20$) stated by LVS EN ISO 13793. As it is shown in Figure 9, the range of variation of freezing index exceeds 15000 that involves the range of uncertainty for insulation size selected of about 25-30 cm. Normally, the freezing index value derived from a longer reference data period should be of higher confidence level. At the same time the graph of annual average temperatures (Fig. 10) displays some trend of increase as it is found from the trendline equation an increment is $\Delta T = 0.019^\circ$ per year according to the recent 62 year external air temperature data in Daugavpils. Note that this tendency may be characterised as inherent of high statistical uncertainty. Also the development of frozen depth in time under small negative degrees correlates with the thermal conductivity of the soil, and consequently with soil saturation, water table and soil type.

Discussion on future trends

The thermal design method of shallow foundations offers several advantages over the traditional practice when a new building has to be designed in a densely property development area, and moreover the deeper soil layers inherent of lower capacity characteristics and/or the water table is so high that groundwater lowering techniques are needed during construction that may induce an additional nonuniformly settlement of subgrade under the buildings nearby.

Also the use of insulated foundations may be an effective and acceptable method when the required depth of foundations for a new building exceeds the one of an existing building nearby, for example, the design of unheated building close to residence.

Some benefit may be achieved in areas of high water table while construction of shallow foundations enable builders to avoid additional expenses for groundwater lowering, and to reduce the duration of construction.

Lightly loaded frost protected foundations may be a more effective solution in special cases when there is a good chance to remain with footing in the upper sufficiently thick layer of soil inherent of higher capacity not disturbing the deeper layer of lower capacity.

CONCLUSIONS

Some conclusions made as a result of this research could be useful for the evaluation of insulated foundation(s) method and making decisions on their implementation in the construction practice of Latvia:

•Cost effectiveness of insulated foundations according to LVS EN ISO 13793 correlates closely with the type of frost-heaven soil. For example, the use of heated foundations in clayey soils, including silty sand leads to increase of soil volume to be excavated and filled back but concrete consumption for foundations decreases. In dusty sand soils, if the required foundation depth is less than 0.8 m, both reductions are achieved in earth-moving and concrete consumption

•The decreased side area of foundations obtained applying 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)

• There is a lack of tabulated data and/or maps for Latvia regions regarding the design freezing index needed for design, and it is labour consuming procedure to be undertaken.

•The thermal design may be recommended when the groundwater level is high, since using this method there is no need to lower the water table during the construction.

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