ENGINEERING SOFTWARE FOR CALCULATION OF PRE-INSULATED BONDED PIPE SYSTEMS FOR HEAT TRANSMISSION NETWORKS

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Pre-insulated bonded pipe systems (PiPS) are used in the heat transport industry on the heat transmission network. Their specific construction allows laying directly in the ground and transportation of fluids with high operating temperatures and pressures. The article presents a methodology that ensures compliance with the conditions for limit load during operation. Engineering software has been created related to the calculation of stresses and elongations in a certain section, taking into account the change in the length and diameter of the pipe, the depth of laying. This software is based on Design Patterns and uses the developed methodology.

Keywords: Pre-insulated bonded pipe, Design Patterns, engineering software

1. Introduction

The economic aspects of energy production and transmission, as well as the environmental impact of improving energy efficiency, are becoming increasingly important worldwide. The central heating is the best solution for heating modern cities. The transportation of thermal energy from thermal power plants to buildings (residential, administrative, business, etc.) is carried out through the heat transmission network. Pre-insulated pipes (PiPS) are specially designed for heat supply applications, where they are mainly used.

Compared to conventional systems, Pre-insulated pipes offer a number of advantages, including significantly extended service life, reduced investment in repair and maintenance, and easier installation. These factors reduce the cost and time of laying and servicing the Pre-insulated pipes.

For a particular pipeline system, a design and calculation procedure is followed, which includes the following steps [1]:

- Evaluation of project data;
- Classification of actions;

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- Stress analysis, division of the pipeline along the proposed route into sections;
- Determining the class of the project and possibilities for simplified analysis;
- Selection of the combinations of actions to be considered;
- Determination of limit states and safety factors to be applied;
- Determination of transverse forces and displacements due to calculated action combinations;
- Calculation of stresses and elongations;
- Selection of evaluation criteria (limit states and corresponding limit values);
- Verification of calculated stresses, elongations and strains with limit states.

2. Pre-insulated pipe systems. Description

The Pre-insulated pipe systems are a pipe assembly of steel service pipe, polyurethane thermal insulation and an outer shell of high density polyethylene (Fig. 1), [15]. In the heat supply, Pre-insulated pipe systems are usually used, the requirements for which are set in the standard BDS EN 253: 2020 “District heating pipes - Bonded single pipe systems for directly buried hot water networks - Factory made pipe assembly of steel service pipe, polyurethane thermal insulation and a casing of polyethylene” [2], [16], [17], [18], [19], [20], [21].

Pre-insulated pipe systems are dug directly into the ground (Fig. 2), [1] and their design and installation is carried out according to the standard BDS EN 13941-2 “ District heating pipes - Design and installation of thermal insulated bonded single and twin pipe systems for directly buried hot water networks” [1].

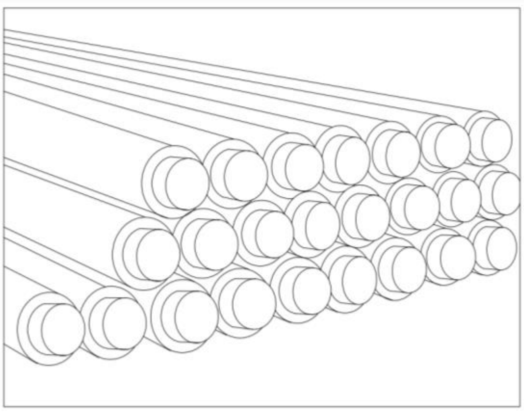


Fig. 1. Pre-insulated piping [15]

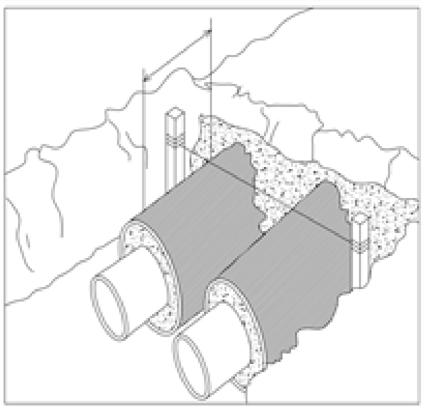


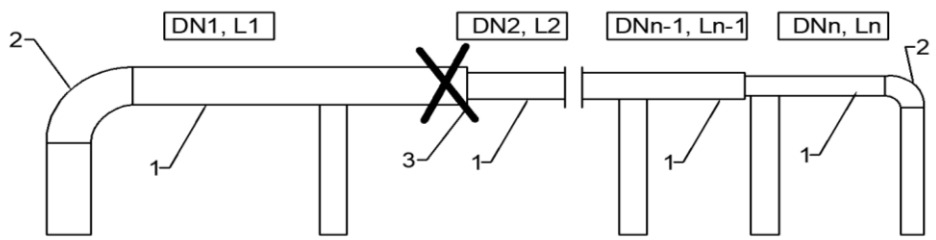
Fig. 2. Installation of PiPS [1]

The main components in the Pre-insulated pipes (steel conductive pipe, polyurethane foam and sheathed polyethylene pipe) form a system as a result of the adhesion forces, i.e. from the temperature loads, the pipes elongate to the same degree. As a result, the external forces from the soil load, as well as the friction forces arising between the sheathed polyethylene pipe and the soil (sand cushion) are transmitted through the rigid polyurethane foam on the steel conductive pipe. In this context, the article discusses a methodology for designing Pre-insulated pipes and an algorithm for calculating stresses and elongations in a given section, taking into account the change in the length, diameter of the pipe and the depth of laying.

3. Methodology for strength calculations of Pre-insulated pipe systems

In the designing and the calculating of the pipelines, it is necessary to confirm that the piping system is able to withstand all loads and meet the requirements for functionality and safety throughout its service life. The methodology chosen ensures compliance with the conditions for limit load during operation. For analysis and sizing, the system of Pre-insulated pipes is divided into sections - part of the pipeline, locked between two compensating elements (elbows). In the methodologies for design of heat pipelines, the middle of such a section is considered as a virtual support, as in the place of the support the compressive stresses are maximum and the elongation is equal to zero [1], [4], [14].

The visualization of a section of heat pipeline composed of N segments is presented in Fig.3. [14]. A part of the section of the pipeline with the same diameter is accepted as a segment. The diameter (DNn) and the length (Ln) are indicated for each segment.



Legend:

1) segment
2) compensating element
3) virtual fixed support

Fig. 3. Visualization of a section with specified pipe diameter and length [14]

Schematically, an algorithm for calculating stresses and elongations in Pre-insulated piping systems for heat supply can be summarized by the following block diagram Fig.4. Once determined, the route is divided into sections. The segments are defined, and a scheme is made for each section. The input parameters required for the calculations are steel pipe diameter, installation length, laying depth, soil type and difference between operating and installation temperatures. The maximum stresses are calculated and compared with the limit values. Depending on the result, a compensation method is determined, or linear extensions are calculated, and design data are extracted.

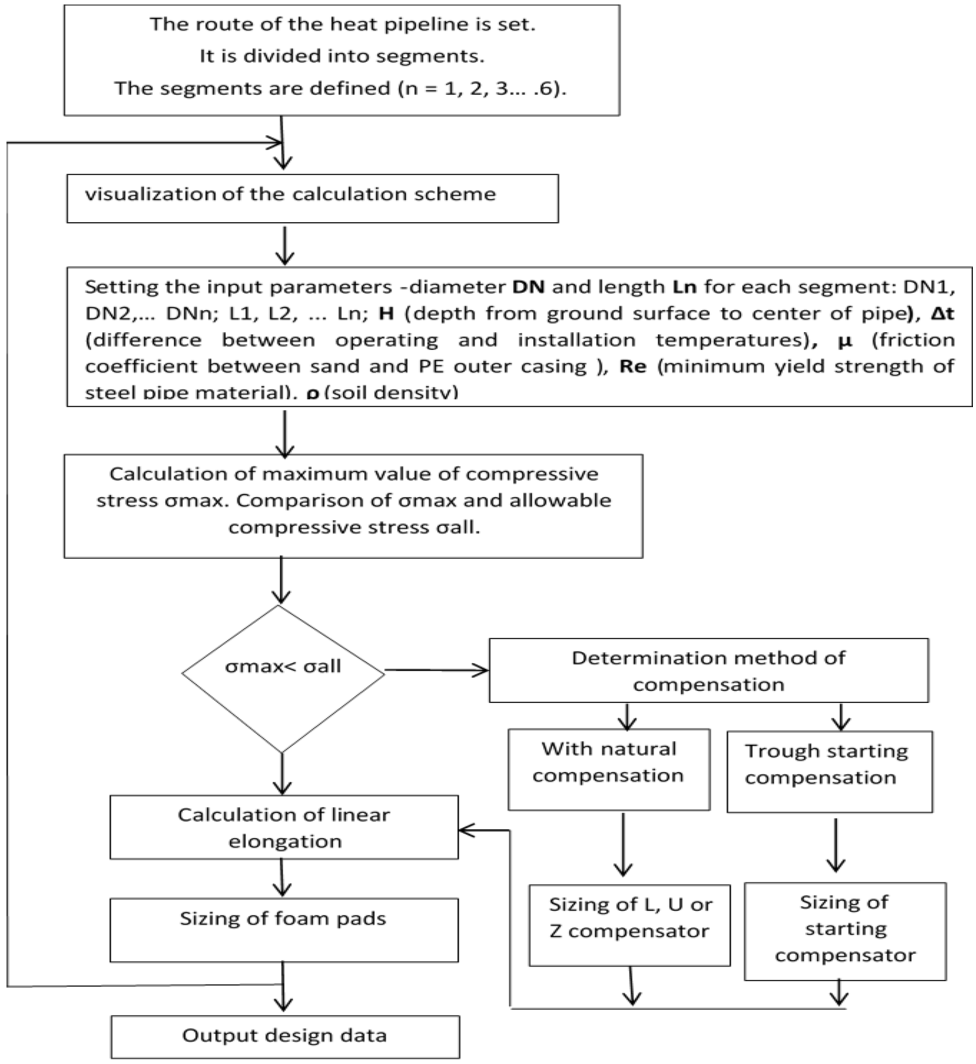


Fig. 4. Block diagram of the algorithm for calculation of stresses and elongations in Pre-insulated pipe systems for heat supply

The strength calculations of Pre-insulated pipe systems are performed in several stages [14].

3.1 Determining the segment in which the virtual fixed support is located

The first step is to calculate the total length of the pipes, divided into two: $Sum\frac{L}{2}$. The resulting value is compared to the length L_1 of the first segment. If $\mathrm{Sum}\frac{L}{2}$ > L_1, then the location of the virtual fixed support is in the segment of length L_1. If $\mathrm{Sum}\frac{L}{2}$ < L_1, compare with Sum (L_1 + L_2), Sum (L_1 + L_2 + L_3) ...., until $\mathrm{Sum}\frac{L}{2}$ > Sum (L_1+$L_{2.....}$+ L_n) is obtained, then the location of the virtual fixed support is in the segment with the last length.

3.2 Setting parameters for Basic calculations

The input parameters for the basic calculations are set by default. The values may vary depending on operating conditions. The remaining parameters are selected according to standard requirements. For the basic calculations [1], [4], [14] are defined the following necessary parameters:

- ρ [kg/m^3] soil density;
- μ friction coefficient between sand and PE outer casing;
- DN nominal pipe diameter;
- do [mm] outside diameter of steel pipe- according to standard requirements to BDS EN 253;
- s [mm] steel pipe wall thickness - according to minimum standard requirements to BDS EN 253;
- Dc [mm] diameter of casing - according to standard requirements according to BDS EN 253;
- P [kg/m] amount of water Standard pipe length Soil cover;
- V [l/m] amount of water;
- H [m] depth from ground surface to center of pipe (Soil cover);
- E [MPa] modulus of elasticity of steel, 210 000 MPa;
- Δt [°C] difference between operating and installation temperatures;
- α [K^{-1}] coefficient of thermal expansion of steel, 0.000012 K^{-1};
- Re [MPa] minimum yield strength of steel pipe material (P235GH).
- g [m/s^2] acceleration of gravity, 9.81 m/s^2.

3.3 Basic calculations

The following formulas are used to calculate Ar, G, Ffr, σall, γ [4], [14]:

- Ar [m^2] cross section of service pipe;
- G [N/m] weight of water-filed Pre-insulated pipe;

- Ffr [N/m] friction force per unit length of pipe;
- Ϭall [MPa] allowable compressive stress in the steel pipe;
- γ [N/m] gravity of soil.

$$Ar = \frac{3.14}{4} * \left(\left(\frac{do}{1000}\right)^2 - \left(\frac{do-2*s}{1000}\right)^2\right), [m^2] \quad (1)$$

$$G = (P + V) * g, [N/m] \quad (2)$$

$$\gamma = g * \rho, [N/m] \quad (3)$$

$$Ffr = \mu * \left(\frac{0.825* \gamma *H*3.14*Dc}{1000} + G - \gamma * 3.14 * \left(\frac{\frac{Dc}{2}}{1000}\right)^2\right), [N/m] \quad (4)$$

$$\sigma all = \frac{Re}{1.5}, [MPa] \quad (5)$$

3.4 Determination of the maximum value of compressive stress σmax for a certain section and verification of the calculated value with the allowable compressive stress σall

The following formulas are used to calculate FfrLL, FfrLR and Ϭmax [14]:

- Ϭmax [MPa] maximum value of compressive stress in steel pipe;
- FfrLL [N/m] total products of the friction force and the length of the pipe on the left side of the section (left of the virtual support);
- FfrR [N/m] total products of the friction force and the length of the pipe on the right side of the section (right of the virtual support);
- Lleft [mm] linear extension to the left of the virtual support;
- Lright [mm] linear extension to the right of the virtual support.

$$FfrLL = (Ffr1 * LL1 + Ffr2 * LL2 + \cdots + Ffrn * LLn), [MPa] \quad (6)$$

$$FfrLR = (Ffr1 * LR1 + Ffr2 * LR2 + \cdots + Ffrn * LRn), [MPa] \quad (7)$$

$$6max = \frac{FfrLL}{Ar*10^6}, [MPa] \quad (8)$$

$$Lleft = \left(\alpha * \Delta t * SumLL - \frac{(FfrLL*SumLL)}{(2*E*Ar*10^6)}\right) * 1000, [mm] \quad (9)$$

$$Lright = \left(\alpha * \Delta t * SumLR - \frac{(FfrLR * SumLR)}{(2 * E * Ar * 10^6)}\right) * 1000, [mm] \quad (10)$$

It is being compared σmax and σall, i.e. maximum value of compressive stress and allowable compressive stress in the steel pipe. IF σmax >= σall, THEN a route correction or compensation method is applied. ELSE σmax < σall and the extensions for the left (Lleft) and right (Lright) part are calculated.

4. Selection and description of Design Patterns. Realization of engineering software through approach based on DP for calculation of Pre-insulated connected piping systems for heat transmission networks

4.1 Selection and description of Design Patterns

The PiPS sizing methodology has been used as a basis for developing engineering software based on design patterns. In software environments, DPs are preferred when creating software, as they have many advantages [11], [12], [13] over writing a white paper code. The implemented software uses 4 software patterns for 4 types of functionality:

- Database connection - Singleton Pattern [8]. Suitable because it allows only one installation of an object of the class. [12]
- Real-time data entry and processing - Data Mapper [3], [6] (Mapper Pattern variant). This is a software layer that separates an object and a database by sending data between them. When used, objects do not need to know about the existence of the database. Data Mapper does not need SQL code and database structure information. [12]
- Input values for each parameter - Fluent Interface [5], [7], [9], [10], [11]. This model corrects the source code. It is designed to implement an object-oriented API. [12]
- Visualization of images and graphics - Abstract Factory [8]. This pattern provides an interface for creating families of objects without specifying their specific classes. This model is designed for products that exist in families and are designed to be created together. The abstract factory can be limited to specific factories, each of which creates different products of different types and in different combinations. [12].

4.2. Realization of engineering software through approach based on DPs

The operation of the software is presented through a demonstration example describing the performed calculations step by step and screenshots of the implemented calculator are presented (Fig. 5 and Fig. 6).

From Fig. 5 you can see the Table Strength screen, which stores basic data such as: DN, do, S, Dc, P and V, detailed in point 3.2., which are used in the calculations.

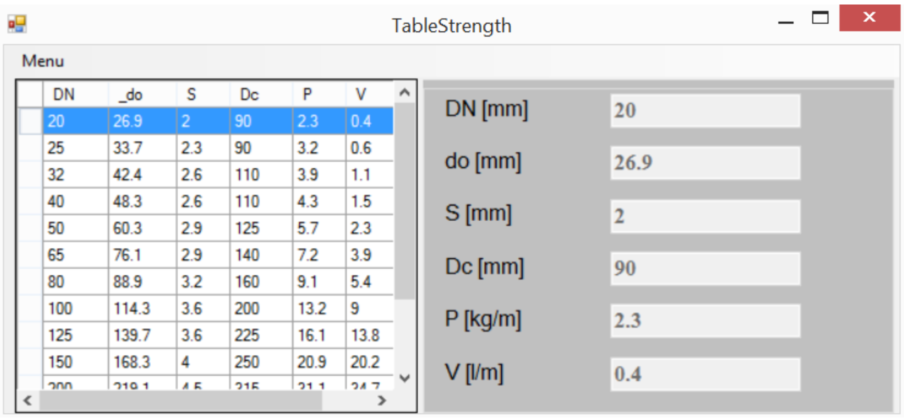


Fig.5. Screen Form – Table Strength of Engineering software for calculation of Pre-insulated bonded pipe systems for heat transmission networks

For the demonstration example, Table 1 describes the specific project assignment and parameters.

Table 1

Project assignment and parameters

project assignment (3 sections)			project parameters
Section 1	DN = 50	L = 10m	μ=0.35; Δt=80 °C H=1.0 m; ρ=1800 kg/m^3 Re=235 MPa
Section 2	DN = 65	L = 28m	
Section 3	DN = 80	L = 22m	

- Determining the segment in which the virtual fixed support is located:

Total length of the pipes:

$$L = L_1 + L_2 + L_3 = 10\text{m} + 28\text{m} + 22\text{m} = 60\text{m} \quad (11)$$

$$Sum\frac{L}{2} = \frac{60}{2} = 30\text{m} \quad (12)$$

$$Sum\frac{L}{2} > L_1 \text{ (i.e. } 30\text{m} > 10\text{m) and } Sum\frac{L}{2} < L_1 + L_2 \text{ (i.e. } 30\text{m} < 10\text{m} + 28\text{m)} \quad (13)$$

Therefore, the location of the virtual fixed support is in the section of length L_2. The section with length L_2 is divided into two segments (Fig.6).

The first segment has a length:

$$L_{2.1} = Sum\,L - L_1 - Sum\frac{L}{2} = 60\text{m} - 10\text{m} - 30\text{m} = 20\text{m} \quad (14)$$

The second segment has a length:

$$L_{2.2} = L_2 - L_{2.1} = 28\text{m} - 20\text{m} = 8\text{ m} \quad (15)$$

- Calculation of Ar and G, relative to the diameter for each segment.

$$Ar_1 = \frac{3.14}{4} * \left(\left(\frac{60.3}{1000}\right)^2 - \left(\frac{60.3-2*2.9}{1000}\right)^2\right) = 0.0005227\ [m^2] \quad (1)$$

$$Ar_2 = \frac{3.14}{4} * \left(\left(\frac{76.1}{1000}\right)^2 - \left(\frac{76.1-2*2.9}{1000}\right)^2\right) = 0.0006666\ [m^2] \quad (1)$$

$$Ar_3 = \frac{3.14}{4} * \left(\left(\frac{88.9}{1000}\right)^2 - \left(\frac{88.9-2*3.2}{1000}\right)^2\right) = 0.0008611\ [m^2] \quad (1)$$

$$G_1 = (5.7 + 2.3) * 9.81 = 78.5\ [N/m] \quad (2)$$

$$G_2 = (7.2 + 3.9) * 9.81 = 108.9[N/m] \quad (2)$$

$$G_3 = (9.1 + 5.4) * 9.81 = 142.2\ [N/m] \quad (2)$$

- Calculation of γ.

$$\gamma = 9.81 * 1800 = 17658\ [N/m] \quad (3)$$

- Calculation of Ffr for each segment.

$$Ffr_1 = 0.35 * \left(\frac{0.825*17658*1*3.14*125}{1000} + 78.5 - 17658 * 3.14 * \left(\frac{\frac{125}{2}}{1000}\right)^2\right) = 1952.9\ [N/m] \quad (4)$$

$$Ffr_2 = 0.35 * \left(\frac{0.825*17658*1*3.14*140}{1000} + 108.9 - 17658 * 3.14 * \left(\frac{\frac{140}{2}}{1000}\right)^2\right) = 2184.4\ [N/m] \quad (4)$$

$$Ffr_3 = 0.35 * \left(\frac{0.825*17658*1*3.14*160}{1000} + 142.2 - 17658 * 3.14 * \left(\frac{\frac{160}{2}}{1000}\right)^2\right) = 2487.2\ [N/m] \quad (4)$$

- Calculation of Ϭall.

$$\sigma all = \frac{Re}{1.5} = \frac{235}{1.5} = 156.6667\ [MPa] \quad (5)$$

- Calculation of FfrLL and FfrLR.

$$FfrLL = (1952.9 * 10 + 2184.4 * 20) = 63217.8\ [MPa] \quad (6)$$

$$FfrLR = (2184.4 * 8 + 2487.2 * 22) = 72193.6\ [MPa] \quad (7)$$

- Calculation of Ϭmax for the section next to virtual support.

$$\sigma max = \frac{63217.8}{0.0005227*10^6} = 120.945\ [MPa] \quad (8)$$

- Comparison of Ϭmax and Ϭall.

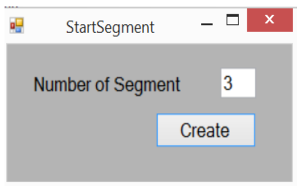
$$Ϭmax < Ϭall \Rightarrow 120.945 < 156.667 \quad (8.1)$$

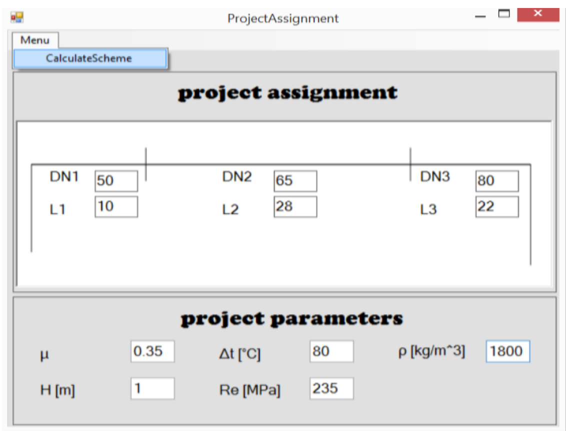
- Calculation of linear elongation Lleft and Lright.

$$Lleft = \left(0.000012 * 80 * 30 - \frac{(63217.8*30)}{(2*210\,000*0.0005227*10^{6})}\right) * 1000 = 20.2\,[mm] \quad (9)$$

$$Lright = \left(0.000012 * 80 * 30 - \frac{(72193.6*30)}{(2*210\,000*0.0006666*10^{6})}\right) * 1000 = 21.1\,[mm] \quad (10)$$

Fig.5 and Fig.6 present screen forms of the program interface.





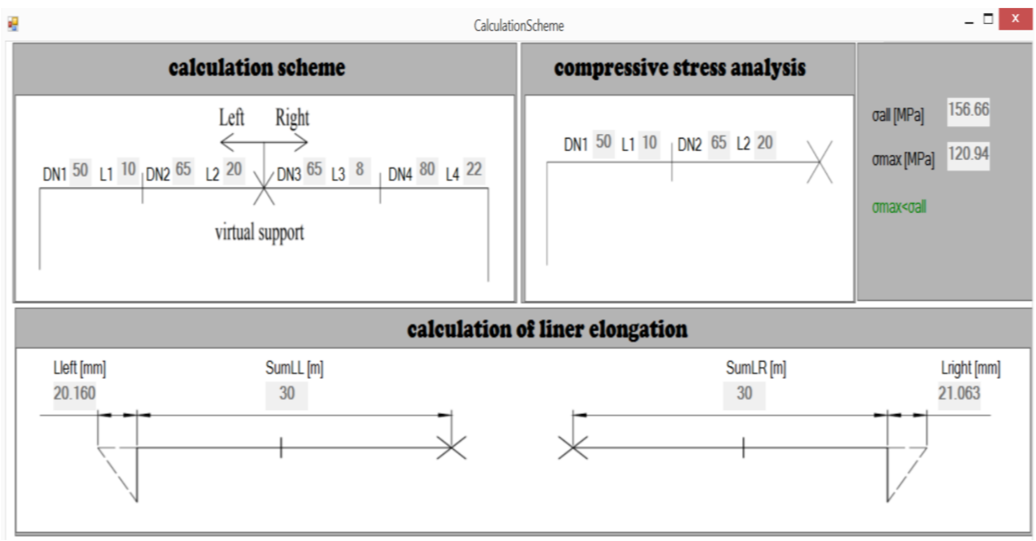


Fig. 6. Screen Form - Calculate of Engineering software for calculation of Pre-insulated bonded pipe systems for heat transmission networks

5. Conclusions

The article provides a brief introduction to the field of heat supply with a description of systems of Pre-insulated connected pipes and indicates their advantages. It offers the pipeline sizing methodology, which includes an algorithm for the distribution of systems of Pre-insulated connected pipes for heat supply. Based on the methodology, an engineering software based on DPs was created to calculate stresses and strains in Pre-insulated connected pipe systems for heat transfer networks, assuming a change in diameter. Design Patterns that are used in engineering software are 4 for 4 types of functionality: visualization of images and graphics (Abstract Factory), defined data and flight parameters (Fluent Interface), database (Singleton), real-time information input and processing (Data Mapper). In conclusion, it can be said that the created engineering software, albeit elementary, has two advantages: on the one hand leads to automation of data processing connected to Pre-insulated piping systems, and on the other hand reduces effort, necessary for design. Efforts in terms of the authors' approach are aimed at expanding the functionality of the software system by adding: sizing compensators; dimension of linear displacement in tees; sizing the number and length of foam pads; and other calculations.

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