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Analysis of the temperature effect on the stresses and deformations of GRP panels during the grouting process when using relining technology

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Abstract: The paper presents a numerical analysis of the behaviour of egg-shaped glass-reinforced plastic (GRP) panels during the grouting process when using short relining technology. The analysis was carried out for panels subjected to temperature changes. The temperature increase was caused by the heat of hydration of the grout. It was shown that temperature had a significant effect on the stresses occurring in the panels' walls and also on their deformations. The analysis involved grout being added in a single stage and then in two stages for comparison. The distribution of stresses and deformations were examined for panels with different wall thicknesses that ranged from 12 to 20 mm. Extensive knowledge about the grouting process and the effect of temperature on the behaviour of GRP panels during the assembly stage when using short relining technology could make this non-disruptive technology more competitive with regards to the time of its implementation and its costs when compared to traditional methods.

Keywords: relining technology; GRP; grouting process; temperature.

1 Introduction

The use of trenchless technology techniques is increasing all over the world. In some countries, it is obliged by law to carry out utility works in a way that minimises disruption to the public [1]. However, in many cases, such an obligation is still not met in practice. This is often due to the fact that trenchless technology techniques are not fully understood and therefore require further research in order to become more competitive regarding the cost and time of their implementation. This especially applies to cases of renovating conduits with non-circular cross-section shapes, for which there is a lack of regulations regarding the design, evaluation of the cost and time of renovation and also structural analysis that includes an assembly stage.

One of the most commonly used trenchless techniques of renovating sewers with non-circular cross-section shapes is relining technology with the use of short panels made of glass-reinforced plastic (GRP) [2]. In this technology, new panels are placed into an old conduit, and after being stabilised, the void between them and the sewer is filled with liquid grout. This stage will be later called the grouting process.

The grouting process is an important and complex issue in short relining technology, especially with regards to gravitational sewers that have relatively thin walls as they are not subjected to significant internal pressures. Over recent years, the use of relining technology has rapidly increased due to the many advantages that it provides when compared to traditional technology [3]. However, past experience indicates that the grouting process causes many problems for contractors [4]. The most common include buckling of panel walls, panels floating on grout after separation from other panels and also deformation of panel shape, which lead to changes in the desired technical parameters. This damage is most often caused by:

- too rapid grout distribution, which causes the level of grout to locally rise,
- neglecting the guidelines regarding the acceptable level of grout filling in subsequent stages,
- asymmetrical grout distribution,
- inappropriate support of panels,
- heat of hydration generated by grout as it hardens and
- changes in the projected parameters of grout.

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All the above-mentioned failures, and also methods of preventing their occurrence, significantly raise the cost of renovation and increase its time.

In Europe, all standards and guidelines for the appropriate dimensioning of panels either do not include the grouting process during the assembly phase or, as it is in German guidelines DWA-A 143-2 [5], include it to a limited degree while devoting little attention to the non-circular cross-section shapes of profiles.

The objective of this paper is to summarise the available knowledge regarding relining technology and to extend it by including the results of the author's recent studies on the impact of the grouting process, especially the effect of temperature on GRP panel behaviour. Based on selected computational examples and with regards to previous own studies [3] and studies on the influence of temperature on the mechanical properties of GRP pipes [6], it was presented that the buoyancy load of a liquid grout acting on panels causes significant stresses in a panel's walls during the grouting process. The article also aims to indicate the problem of the effect of temperature on the behaviour of GRP panels and the problem of assembly errors. This issue requires further research and the conducting of laboratory tests and will be the subject of future publications. Extensive knowledge on the grouting process is required in order to develop methods of protecting panels against their failure, but not by increasing their wall thickness as this results in a significant increase in costs and is often not necessary during the operation stage, but by other methods which will result in the reduction of time and cost of the implementation of relining technology.

2 The Grouting Process – Grout and The Effect of its Heat of Hydration on Grp Panels – Literature Survey

2.1 Types of grout used in short relining technology

Grout has traditionally been defined as a mixture of 'cementitious material and aggregate to which sufficient water is added to produce a pouring consistency without the segregation of its constituents' [7] and was used for filling masonry joints. With time, this definition has been expanded and includes a wide range of concretes and organic compounds that are used to fill masonry joints, stabilise soil when using injection, reinforce cracked structures and also fill voids in or around pipes, conduits or tunnels [8-12].

There are different types of mineral grout that are available for use in short relining technology, including both non-cellular and cellular grouts [13,14]. Cellular grout is a low-density grout that is a mixture of cement and water (or cement, fly ash and water) with a foaming agent that is added in order to inject a large volume of macroscopic air bubbles into the grout mix. Its unit weight ranges from 6 to 15 kN/m^3.

Non-cellular grout (flowable fill grout) is usually a mixture of cement, sand and water, with chemical admixtures added if required. In order to reduce the cost and improve selected properties of a grout mixture, some of the cement can be replaced with fly ash. The unit weight of non-cellular grout ranges from 15 to 23 kN/m^3. However, cellular grouts, due to their lower density, are preferable as they limit the hydrostatic loads acting on panels during implementation.

Quantities of plasticiser and non-shrink additives may be included in the grout mix on special demand. The density then varies, but needs to enable the grout to flow easily through the piping of an injection system. Grout in relining technology must fill the entire void between the sewer and panels, and should therefore be characterised by a very good liquidity, low viscosity, a low tendency to sediment, good pumpability, rapid setting and the required compressive strength. However, the density and composition of grout is often chosen intuitively with the assumption that the lowest cost and availability on the local market is crucial. It needs to be highlighted that some admixtures are exothermic and raise the curing temperature of grout. The heat of hydration should always be considered with regards to the grouting process.

2.2 Function of grout and its distribution in short relining technology

The main role of grout in short relining technology is to fill a void between an old sewer and new panels [20]. However, grout also holds panels in their position, ensures a uniform contact between them and an old sewer, fills any voids in an existing sewer (e.g. missing mortar, parts of bricks, cracks in concrete, etc.), carries the loads transmitted to panels and also reduces the possibility of gas accumulation in a void [26-28].

In addition to the above, grout needs to provide a sufficient resistance to ground water aggressiveness in the case of when an old sewer has significant cracks and ground water infiltrates through it.

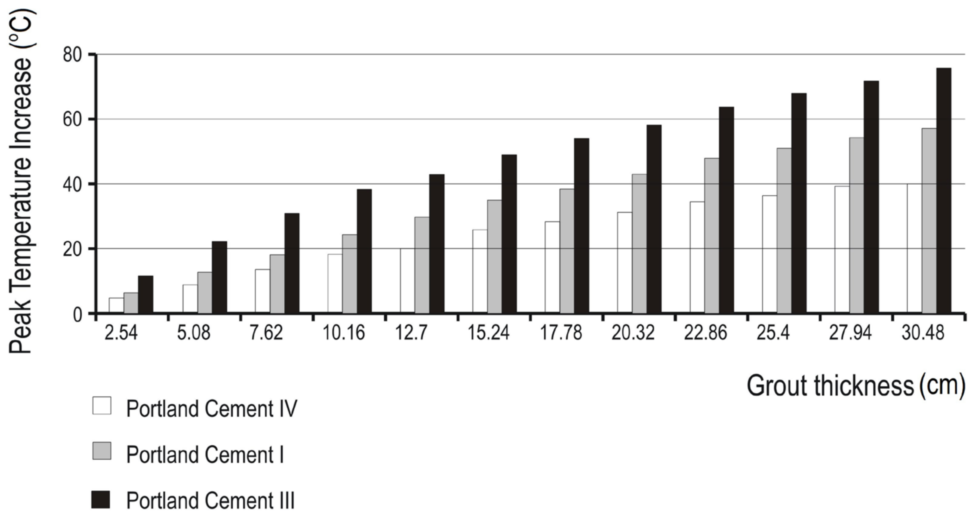

Figure 1: The increase in peak temperature at the casing–grout boundary as a function of grout thickness for three different types of Portland cement grout [16].

Grout can be implemented from the inner side of a sewer through special nozzles in the panels or from the ground level by being added from a concrete mixer through an assembly chamber. It should always be injected with a consideration of buoyancy and floatation, which can be achieved by different methods such as [2-3]:

- installation of horizontal and vertical struts inside new panels,
- the use of stabilising spacers on the perimeter,
- distribution of grout in stages,
- encumbering of panels by filling them up with sewage,
- the use of belts that hold panels in position,

or by a combination of the above-mentioned methods. The way panels are protected against possible failure has a significant impact on the distribution of stresses in their walls [3]. Due to past experience, which has proved that adding grout in one stage increases the risk of panel failure, the grout is usually distributed in many stages [2-4]. The amount of stages depends on the size of both the sewer and panels, the time of grout hardening, environmental conditions and the renovation schedule. However, the number of stages is usually not confirmed by structural analysis at the design stage.

2.3 Heat of hydration of grout with regards to relining technology

Each type of grout generates heat when hardening, which is called heat of hydration [15]. It can significantly raise the temperature of panels (especially those made of thermoplastic materials such as PEHD, PP, PCV or those made of thermoset materials such as GRP). An increase in temperature can lead to a relatively big decrease in a panel's strength and stiffness [15]. The value of the temperature increase and the time required to reach its peak varies due to the type of cement and other admixtures used in the grout [16-19]. It has been proven that if a grout mixture contains Portland cement III, the peak in its heat of hydration is faster than if a grout mixture contains Portland cement I. Moreover, the maximum temperature that the hardening grout achieves is significantly higher when using Portland cement III than when using Portland cement I. Heat of hydration is especially important in cases when the annular space between panels and an existing pipe is large and the grout layer is relatively thick (e.g. when new panels have a different shape than the renovated sewer). In such cases, an increase in the heat of hydration can reach significant values. The temperature increase in relation to the thickness of grout, which was described in paper [16], is presented in Figure 1.

However, a thicker layer of grout can also occur in situations when renovated sewers have circular cross-section shapes and the void between an old sewer and a new panel is not big. This is related to the bad condition of the existing conduit (many cracks and fractures). Due to the infiltration of water, there could be some parts of ground that are washed out around the existing pipe, which, during the renovation process, would fill up with grout and create a big lump. Such places, due to the amount of grout, could locally generate a significant temperature, which could lead to panel failure.

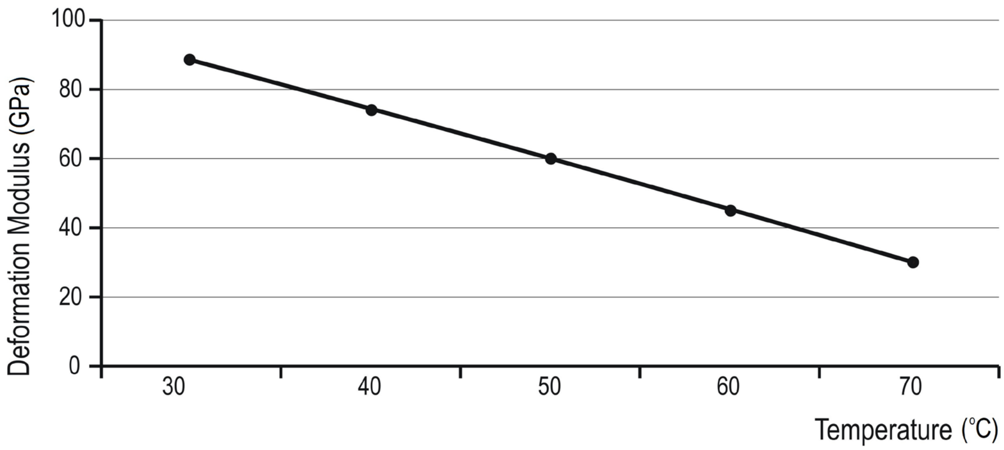

Figure 2: Deformation modulus in relation to temperature for GRP pipes [6]. GRP, glass-reinforced plastic.

Generally, the increase in temperature is much higher in cases where the generated heat is not dissipated radially [15], and therefore when renovating sewers with non-circular cross-section shapes when the void between an old sewer and a new panel is significant. This phenomenon can be enhanced during relining technology, as the generated heat is not dissipated directly to the ground, but is 'trapped' between the sewer that is being renovated and new panels.

The rate of change of heat of hydration primarily depends on the type of cement used in the grout mix, the chemical composition and physical properties of the cement, the water/cement ratio, the types of additives such as fly ash and other chemical additives, and also the curing conditions [17–19]. It is worth noting that heat of hydration not only causes a decrease in panel strength and stiffness, but also the expansion of grout while it is hardening [19], which together can significantly contribute to panel failure.

2.4 The effect of temperature on the mechanical properties of GRP panels – literature survey

GRP composites are commonly used in many industrial applications, especially in sewage systems and large-diameter water mains [21]. The advantages of using GRP composites include their relatively light weight and also their high strength, stiffness and corrosion resistance [22]. As a thermoset material, GRP shows good resistance to thermal loading. However, the resin components of the composite may lose their functionality in high temperatures (over 180°C) [24].

There is little knowledge regarding the behaviour of GRP pipes that are subjected to high temperatures. In 2008, the temperature effect on GRP pipes was analysed and described in paper [6]. According to the authors' experimental studies, the deformation modulus of GRP pipes decreased with an increase in temperature, as presented in Figure 2. The research included a rise of temperatures from 30°C to 70°C, and for this interval, the deformation modulus decreased by 62%.

In 2010, the authors of paper [23] analysed large-diameter GRP pipes that transport hot water; however, the temperature to which the analysed pipes were subjected to was equal to 45°C, and such a temperature did not cause any threat to the pipes' stability. The next attempt of analysing the problem of temperature effect on GRP composites was described in paper [25] in 2014. The mechanical behaviour of GRP composites subjected to different temperatures and exposure time was investigated. It was proved that the ultimate tensile strength and compressive strength of GRP samples rapidly decreased when the temperature was over 100°C, and it was assumed that this was a non-linear issue.

The problem of the effect of temperature in relation to GRP panels is very complex. This is due to the fact that GRP composite is an anisotropic material. Its elastic modulus changes over time regardless of temperature, and it is therefore characterised by two values of elastic modulus, short-term value and long-term value, both determined for GRP panels at a temperature of 25°C.

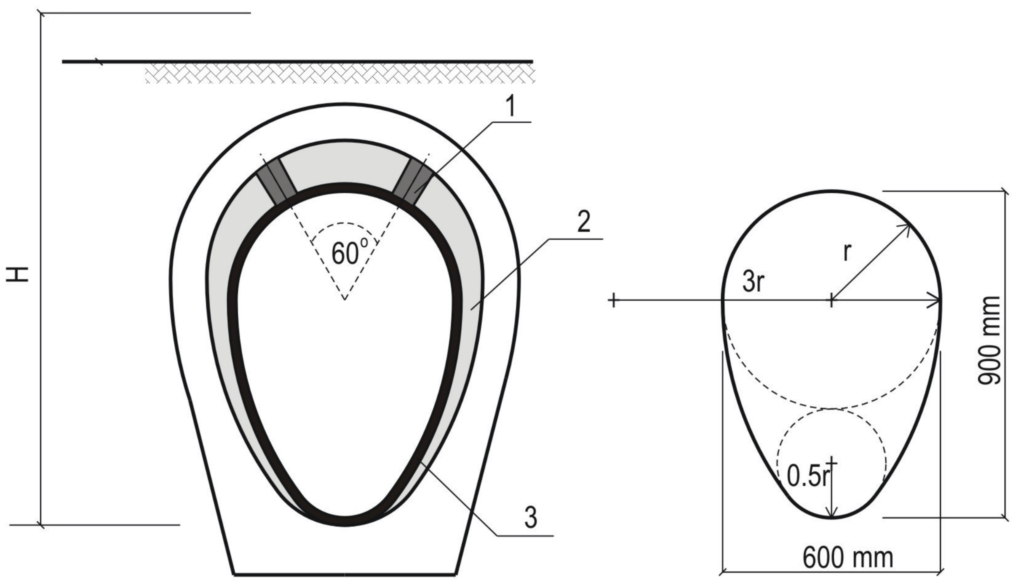

Figure 3: Assembly scheme and geometric characteristics of GRP panels: 1 – wooden spacer, 2 – grout, 3 – brick sewer, H – height from which the grout is distributed.

2.5 Effect of temperature on the behaviour of GRP panels – analysis in situ

The analysis was carried out during renovation of the large-scale reinforced concrete conduit, in which it was necessary to introduce GRP panels with a significantly smaller size of cross section. Therefore, the space between the panels and the conduit, which had to be filled with grout, had a height of up to 0.8 m. Cement mortar was used to fill this void. During the implementation of grout, a noticeable increase in the temperature of the panels was noticed, and the measurements showed that the temperature of the panels reached 52°C (measurements were made on the surface of the panels from the inside of the conduit). In addition, significant deformations of the panels were observed.

In order to prevent failure, it was decided to fill the void between the GRP panels and the repaired conduit in three stages. This decision was undertaken by the contractor on the building site and was not confirmed by appropriate structural strength calculations. Analysis of the effect of temperature on GRP panel behaviour was made for construction purposes and not for scientific research, and there are no detailed results of the panel measurements. It requires further studies in order to obtain the values of deformations and stresses in the panels' walls. However, the conducted analysis confirmed that in the case when the layer of grout has a considerable thickness, the increase in temperature in the walls of the panels may pose a significant threat to their safety.

3 Numerical Analysis of The Influence of The Grouting Process on The Values of Stresses in The Walls of Grp Panels

3.1 General assumptions for the calculations

The paper presents an analysis of the behaviour of egg-shaped GRP panels that were used for the renovation of a brick sewer. The panels have a height of 900 mm and a width, which is measured in their widest place, equal to 600 mm. Panels with such dimensions are produced in a wide range of wall thicknesses (from 12 to 22 mm), depending on their purpose. Those with thinner walls can be used as a liner for gravitational sewers, which require an improvement of their hydraulic parameters or have some small cracks. Those with bigger wall thicknesses are usually used to renovate sewers, which are untightened, cracked and can lose their load-bearing capacity. Figure 3 shows the geometric characteristics of the analysed panels.

Calculations were carried out for the phase when the grout was already added gravitationally from a concrete mixer and its level was stable. The loads acting on panels were static, and therefore, the system is considered as a static problem. In order to highlight the behaviour of panels during the grouting process, the buoyancy of liquid grout, its temperature and also the self-weight of the panels were assumed as the only loads acting on the panels and other loads such as earth pressure, buoyancy of underground water, live load, etc. were omitted. The values of stresses and deformations were analysed for different temperatures of grout and different thicknesses of the panels' walls that ranged from 12 to 20 mm. Analysis of the temperature effect included temperatures from 25°C to 70°C. Temperatures above 50°C are unlikely to occur during the hardening of grout; however, they were also included in the analysis in order to emphasise the non-linear relation between the impact of grout temperature on both the stresses and deformations of GRP panels. Bearing in mind the recent results included in [25] and [6], and also the material characteristics of GRP composite, it was assumed that the change in elastic modulus in relation to high temperatures is non-linear. The computational analysis was carried out with the use of the finite element method (FEM) and with the aid of computational FEM software (Autodesk Robot Structural Analysis Professional 2018). This type of analysis has never been carried out before, and its importance can be crucial in determining the risk of panel failure during the grouting process.

The following assumptions were made for the calculations:

- the temperature of the GRP panels is uniform,
- the short-term elastic modulus during bending of the GRP panels is equal to E = 9000 MPa,
- the Poisson coefficient is equal to $\nu = 0.28$,
- the unit weight of grout is equal to $\gamma = 23$ kN/m^3 and
- the height from which the grout is distributed is equal to 5.9 m.

The numerical analysis consisted of three stages. In the first stage, panels with wall thicknesses that ranged from 12 to 20 mm were subjected to their self-weight, buoyancy of liquid grout and temperatures of 25°C, 40°C, 50°C and 70°C in order to obtain the values of the maximum stresses and deformations in their walls. In this stage, grout was added in a single cycle, as this generates the biggest stresses and deformations and the analysed behaviour of the panels is more significant. After analysing the achieved results, a panel with a certain wall thickness was selected in order to show the distribution of stresses and the shape of its deformation.

In the third stage, panels with wall thicknesses that ranged from 12 to 20 mm were subjected to their self-weight, buoyancy of liquid grout and temperatures of 25°C and 40°C in order to present the values of the maximum stresses and deformations. In this stage, grout was added in two cycles. The paper presents the results of the second cycle, when grout was added from the level of 0.3 m to the ground surface. The results of calculations when panels are loaded with grout that is injected to the level of 0.3 m were not included, as when applying grout to such a low level, the effect of temperature is so small that it can be omitted. The results obtained from the analysis of panels loaded with grout in the second cycle were compared with the values obtained in the first stage of the analysis in order to verify the size of the change in the achieved results.

The numerical model of the GRP panel in Autodesk Robot Structural Analysis Professional 2018 consisted of 6708 finite elements. The panel was modelled as a 3D shell structure with a length equal to 1.1 m. Such a specimen length is sufficient enough to avoid the boundary effect [29].

3.2 Structural analysis for filling the void between the panels and the sewer with liquid grout injected in a single cycle

The evaluation of the behaviour of GRP panels when grout is injected in one stage was the purpose of the first analysis. The panels were considered to be stabilised with the use of two wooden spacers located at the top of them, and the angle between the axes of spacers was assumed to be equal to 60°. The loads acting on the panels were considered as a hydrostatic pressure, which depends on the curvature of the panel walls. The height from which the grout was injected was considered to be equal to 5.9 m.

Tables 1–5 present the obtained results for the panels with wall thicknesses ranging between 15 and 20 mm. Due to the acquired definition of the risk of failure (exceeding the admissible limits of deformation and stresses), the location of maximum normal stresses and deformations is not provided in the tables. The author has only referred to their values. The tables with computational results include the values of the maximum deformations of the panels caused by specific load conditions that include the temperature effect. Deformations were defined, according to the German guideline [5], as the change in the dimensions of the GRP panel compared to its nominal dimensions.

The first computational example involved a GRP panel with a wall thickness equal to 20 mm. The results of the conducted analysis are summarised and presented in Table 1.

The obtained results indicate that stresses and deformations increase with an increase in panel temperature. The maximal normal stresses in each of the assessed cases (for a panel temperature between 25°C

Table 1: The obtained results for the GRP panel with a wall thickness equal to 20 mm.

Temperature of GRP panel (°C)	Maximum normal stresses (MPa)	Deformations (%)
25	27.25	2.71
40	28.24	3.51
50	29.45	4.33
70	39.02	12.76

Table 2: The obtained results for a GRP panel with a wall thickness equal to 18 mm.

Temperature of GRP panel (°C)	Maximum normal stresses (MPa)	Deformations (%)
25	36.56	4.41
40	36.71	5.93
50	39.50	7.75
70	78.67	52.04

Table 3: The obtained results for a GRP panel with a wall thickness equal to 17 mm.

Temperature of GRP panel (°C)	Maximum normal stresses (MPa)	Deformations (%)
25	41.38	5.15
40	43.84	7.28
50	48.63	9.5
70	235.69	Total failure

Table 4: The obtained results for a GRP panel with a wall thickness equal to 16 mm.

Temperature of GRP panel (°C)	Maximum normal stresses (MPa)	Deformations (%)
25	49.59	6.42
40	54.19	9.95
50	62.25	14.53
70	Total failure	

Table 5: The obtained results for a GRP panel with a wall thickness equal to 15 mm.

Temperature of GRP panel (°C)	Maximum normal stresses (MPa)	Deformations (%)
25	61.71	9.5
40	71.07	15.21
50	89.66	28.71
70	Total failure	

and 70°C) did not exceed the permissible value, which, according to GRP producers, is between 80 and 120 MPa. However, in the case of a temperature equal to 70°C, the value of admissible deformations exceeded the critical value, which, according to the German standard [5], is about 10% with a safety coefficient of $\gamma = 2$ for GRP panels.

The subsequent analysis involved GRP panels with wall thicknesses equal to 18 mm, 17 mm and 16 m. The obtained results are summarised in Tables 2–5.

The above results indicate, as was the case with the panel with a wall thickness equal to 20 mm, that the stresses and deformations increased with an increase in temperature. For the panels subjected to a temperature between 25°C and 50°C, the values of maximal stresses did not exceed the permissible value. The value of maximal stresses in the case of a temperature equal to 70°C exceeded the permissible value. The values of deformations did not exceed the permissible value only in the case of panels with a wall thickness equal to 18 mm and a temperature equal to 25°C. In all the other cases, the values of deformations exceeded the permissible value for all the panels.

The next analysis was carried out for a panel with a wall thickness equal to 15 mm. The obtained results are summarised in Table 5.

The results included in Table 5 indicate that the values of maximal stresses did not exceed the permissible value at a temperature equal to 25°C and 40°C, whereas for higher temperatures, the values of stresses exceeded the permissible value. Deformations in each case exceeded the permissible value.

The same analysis was also performed for panels that had a wall thickness equal to 1.2 cm. The obtained value of the maximum normal stresses at a temperature equal to 25°C amounted to 475.2 MPa and exceeded the permissible value. The panel was totally destroyed after being loaded with a grout that was added in one stage.

The panel with a wall thickness equal to 18 mm, after being loaded with grout in a single stage at a temperature of 25°C, was safe with regards to the value of stresses and deformations. However, after being heated to a temperature of 40°C, the deformations exceeded the permissible value. Using the results obtained for this panel, an analysis of stress distribution and the shape of deformations was conducted and the results are presented in Figures 4–7.

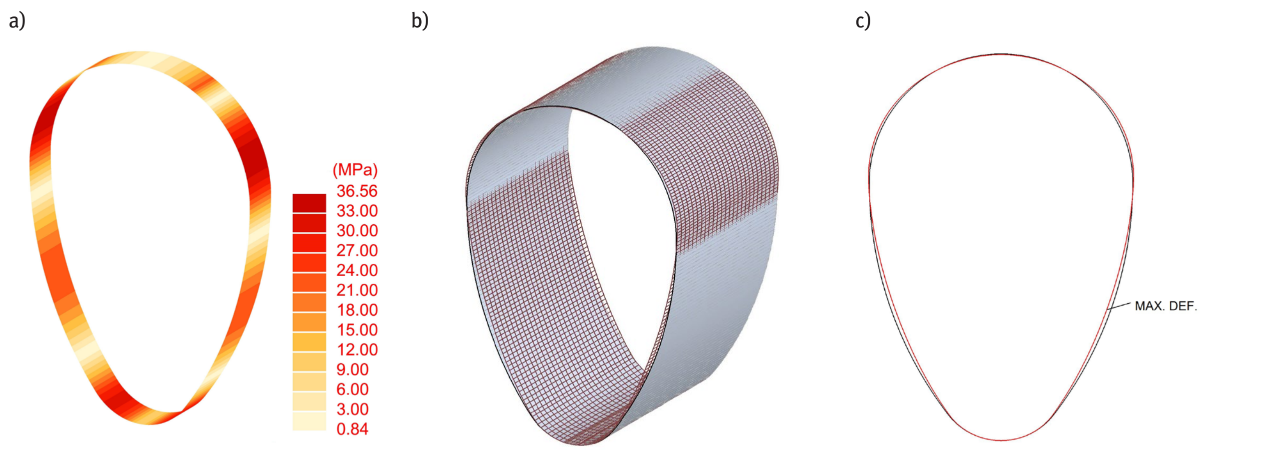

Figure 4: Stress distribution and deformations of the panel when the heat of hydration is equal to 25°C: (a) stress distribution, (b) 3D view of panel deformation, (c) 2D view of panel deformation with an indication of the location where the maximum value occurred.

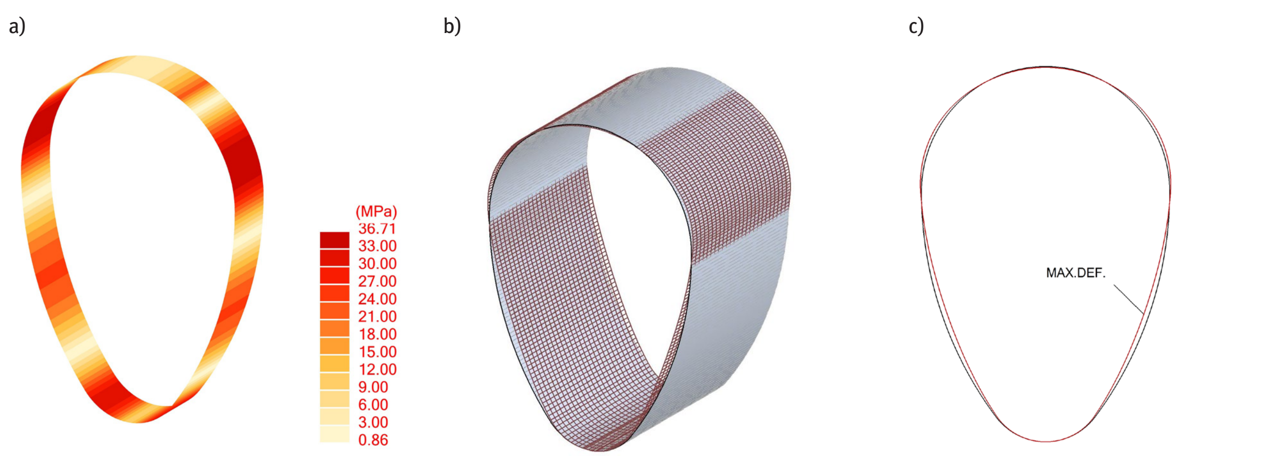

Figure 5: Stress distribution and deformations of the panel when the heat of hydration is equal to 40°C: (a) stress distribution, (b) 3D view of panel deformation, (c) 2D view of panel deformation with an indication of the location where the maximum value occurred.

The stress distribution is presented in colours, and the values corresponding to each specific colour are given in MPa. The deformations are shown in 3D and 2D views, which are both over-scaled in order to highlight the shape of the deformations. The location of the occurrence of the biggest deformations is also indicated in the figures.

3.3 Structural analysis for filling the void between the GRP panel and the sewer with liquid grout injected in two cycles

The second computational case involved liquid grout being added in two stages. The method of protecting and stabilising the GRP panel was the same as in the above cases. The grout was first added to a height of 0.3 m from the bottom of the panel, and after it hardened, the next layer was added up to the ground surface. The computational model included the change of support conditions caused by the hardened grout. The scheme of distributing grout in two stages is presented in Figure 8.

Numerical analysis was carried out for grout temperatures equal to 25°C and 40°C, which are the most probable to occur. Table 6 presents the obtained results for the grout added in the second stage – from the level of 0.3 m up to the surface level. The values of stresses and deformations for the grout added in the first stage were small and did not exceed the permissible values. Therefore, they are not included in the paper, while the values obtained for the second stage are presented in Table 6.

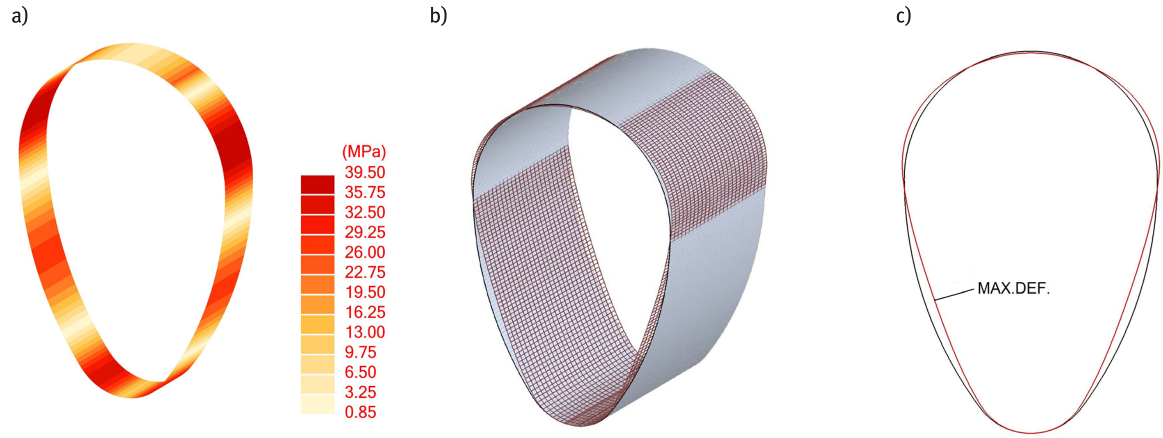

Figure 6: Stress distribution and deformations of the panel when the heat of hydration is equal to 50°C: (a) stress distribution, (b) 3D view of panel deformation, (c) 2D view of panel deformation with an indication of the location where the maximum value occurred.

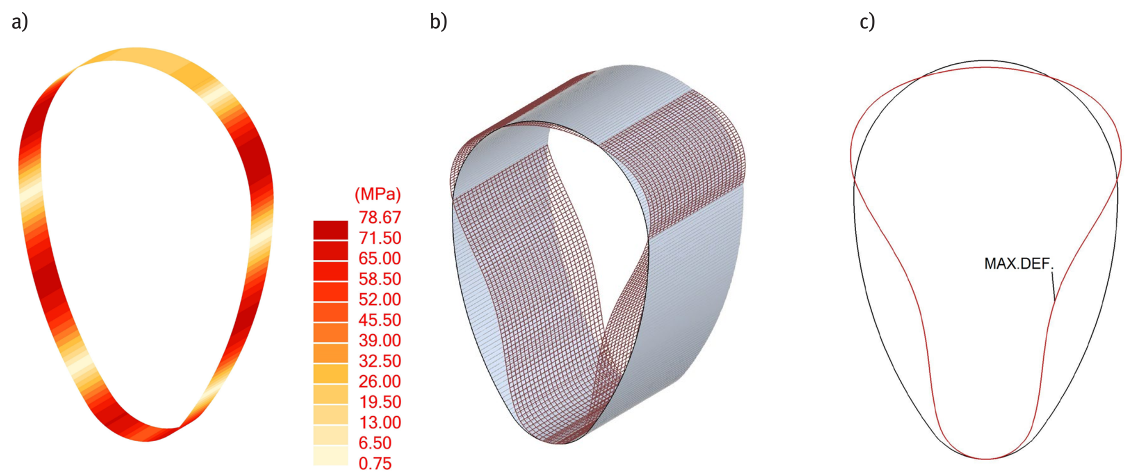

Figure 7: Stress distribution and deformations of the panel when the heat of hydration is equal to 70°C: (a) stress distribution, (b) 3D view of panel deformation, (c) view of panel deformation with an indication of the location where the maximum value occurred.

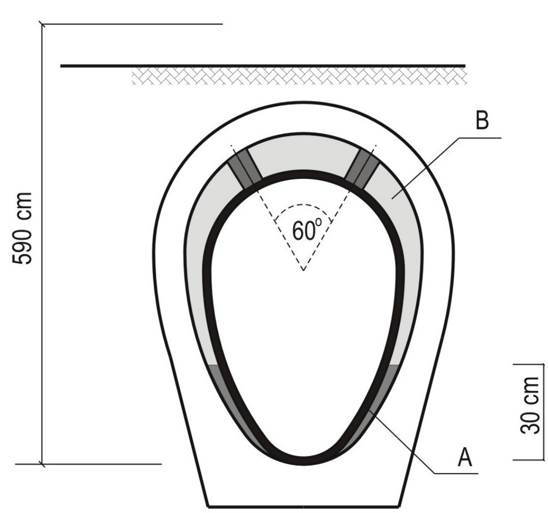

Figure 8: Scheme presenting the distribution of grout in two stages: A – first stage, B – second stage.

The obtained results indicate that when grout is added in two stages, the values of stresses and deformations for the panels with wall thicknesses ranging from 15 to 20 mm did not exceed the permissible values. When grout was added in a single stage, only the panel with a wall thickness equal to 20 mm had values of stresses and deformations that did not exceed the permissible values. In turn, when grout was added in two stages, the values of stresses and deformations decreased in most cases by more than double.

4 Conclusions

The conducted analysis indicated that the values of stresses and deformations increase with an increase in

Table 6: The obtained results for the GRP panels that were heated up to 40ºC with the grout distributed in the second stage.

Wall thickness (mm)	Temperature of grout equal to 25ºC		Temperature of grout equal to 40ºC	
	Maximum normal stresses (MPa)	Deformations (%)	Maximum normal stresses (MPa)	Deformations (%)
20	13.40	0.72	13.74	1.14
19	14.91	1.14	15.17	1.53
18	16.73	1.14	17.08	1.53
17	18.95	1.53	19.45	1.92
16	21.97	1.92	22.47	2.31
15	25.36	2.31	26.46	3.11

temperature, and that this dependency is non-linear. An increase in the panel temperature results in a significant reduction of the elasticity modulus of the material from which the panels are made (GRP), which in turn results in an increase in the deformation of the panels. When grout was added in a single stage and its temperature increased to 40ºC, the values of deformations exceeded the permissible value in the case of the panels with wall thicknesses smaller than 20 mm. Such values of deformations indicate that there is a risk of panel failure, and that grout should be injected in more than one stage.

A change of 1 mm in the wall thickness of a panel resulted in significant changes in the values of stresses and deformations. This is valuable information when analysing panels with regards to assembly or executive errors, and especially when analysing panels with non-circular cross-section shapes. This is due to the fact that their wall thickness often varies along their perimeter.

The performed analyses have shown that an increase in panel temperature of up to 50°C may cause their deformation to increase by more than 100%. It is, therefore, necessary to measure the temperature of the panel walls during the assembly stage when using short relining technology. The series of calculations for different temperatures and different wall thicknesses provided data that compares favourably with the theoretical predictions, and thus makes the computer model useful for characterising the loading scheme that occurs during the grouting process at a construction site. A detailed computer analysis may result in a shorter time of renovation when using short relining technology, which would reduce the cost of its implementation and contribute to its wider use.

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