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Organizing the Crossing of a Gas Pipeline over Guduca Canyon

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Abstract

Gas wells are located far from the consumers. Gas is therefore transported from them using a system of main gas pipelines. A gas pipeline is a closed technological unit consisting of a pipeline with its accompanying equipment and buildings. It traverses different terrain and some of the most challenging among those are waterways, especially when they are also an active naval route. The crossing of a gas pipeline over the Guduca Canyon was a very demanding task, given that the crossing point has a very steep and rocky western slope and a somewhat less steep eastern slope made up of dirt and limestone rock. The crossing was done by a combined method of drilling through the rock on the western slope and inserting the pipeline into the bore, and laying the pipeline in a trench for the rest of the crossing. After the pipeline was connected, but before it was put into use, it was tested to ensure that it met the required standards of quality.

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Keywords: gas pipeline; waterway; canyon; crossing

1. Introduction

Energy is the driving force of the world and the main energy resources are fossil fuels such as oil, gas and coal. These are mostly found in sparsely inhabited regions, so it is necessary to transport these resources over great distances to consumers. [1] In order to transport large quantities of these resources roads, naval routes or pipelines must be created. Natural gas deposits can be found in permeable rock beds surrounded by impermeable beds. Underground natural gas deposits have been identified at the depths from several meters to 5 thousand meters, sometimes under the pressure above 300 bar, and temperatures above 180°C, depending on the deposit depth. [2] Natural gas is extracted in gas wells where it is pumped out due to the high pressure of the underground reservoirs. After extraction from the deposit it is transported through the use of a pipeline system to a loading dock or, if

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possible, directly to the consumers. However, the supply of necessary volumes of gas for the Croatian market practically depends on a single free available import pipeline, the interconnector between Croatia and Hungary. [3] Natural gas is used in households and technological processes (to produce heat and electricity), as well as being used as raw material in the chemical industry, especially in the petrochemical industry. [4] The supply of natural gas to the end-consumer can be done in a number of ways: [5] [6]

- By building a gas pipeline
- By utilizing GTL technology (based on a chemical conversion of natural gas into a stable liquid)
- By transporting it on specialized ships
- By shipping it in special heat insulated tanks by rail or road

Fig. 1. shows the relation between the gas transport costs for various types of gas transport with respect to the distance of transport. The costs are shown in US $/GJ (US dollars per Giga Joule) [7]

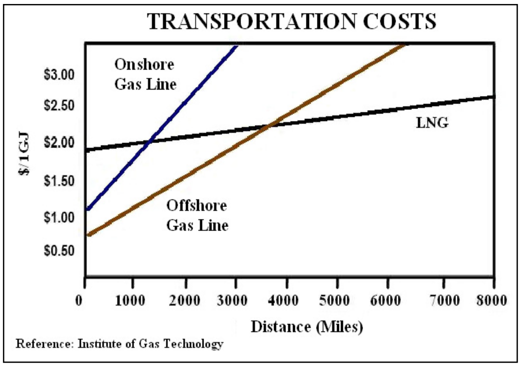

Fig. 1. Relation between transport costs for various types of gas transport.

The way in which gas will be shipped depends on a number of factors such as the distance between the gas well and the consumer, quantity of gas, geopolitical conditions, price, etc. [8] For the distances encountered in the Republic of Croatia, according to Fig. 1, the most acceptable option is the construction of a land gas pipelines.

2. Description of the system and conditions

A waterway or a canyon can be crossed by a pipeline in one of the following three ways: [9]

- On a bridging support structure constructed over the waterway/canyon
- With the pipeline laid into a trench dug in the river or sea bed
- With the pipeline inserted into a drilled bore/micro-tunnel under the waterway/canyon

The support structure can be either purpose built for the pipeline or an existing bridge or support structure if permissible. The pipeline is then attached to the supports or suspended by steel cables from pylons on the banks. AS an exception the pipeline can cross very short distances as a self-standing structure. This is usually done over narrow streams where laying the pipeline into a riverbed trench or directly onto the riverbed is not possible and drilling or bridging would cause unnecessary additional costs. Drilling under the waterway requires specialised equipment, staff and technology. It is used to cross waterways when other approaches are not economically viable or are unacceptable due to other technical, organizational or environmental reasons. Whenever it is possible a pipeline should be placed into a properly prepared trench and therefore the preferred manner of crossing a waterway without constant flow or with a low flow of water is the digging of a trench on the riverbed. Once the pipeline is laid and the trench filled the waterway is returned to near initial condition. This method can also be used on waterways with significant flow, but then the water needs to be either diverted or the process performed underwater at a higher cost.

Fig. 2. gives an overview of different methods of crossing a waterway with a pipeline.

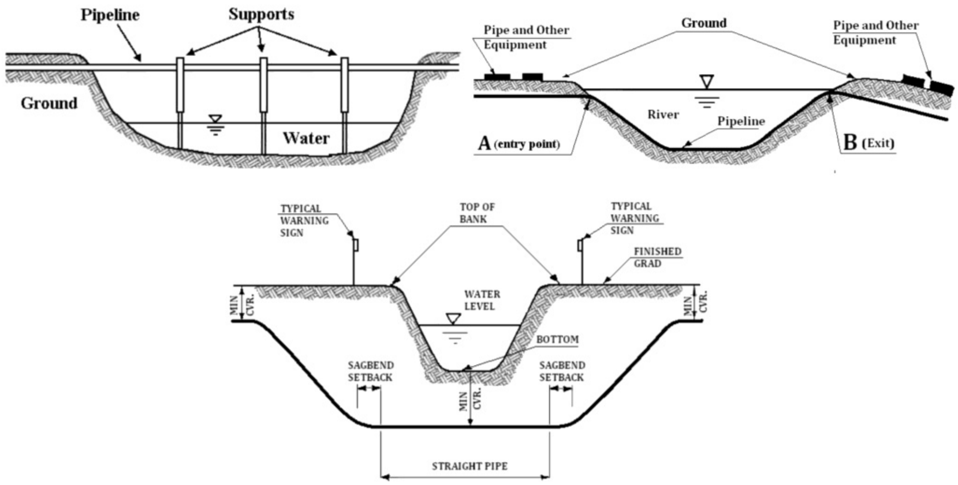

Fig.2. Crossing methods (a) Bridging with a support structure; (b) Laying into a trench on the bottom; (c) Drilling below the bottom.

Guduca Canyon is located at kilometre 221.498 of the gas pipeline Benkovac – Split. A flash-flood river with a significant discharge flows in the canyon during heavy rains, but the canyon is drained during dry weather. While this ensures that the canyon will be dry for the duration of this particular summer project it is necessary to take special precautions to ensure that the pipeline is not exposed to the violent flow once it starts.

The western bank of the canyon has a steep incline while the eastern bank has a gentler slope. Soil testing showed that the western bank is composed of compact rock with a depth of some 50 meters and that the eastern bank is less compact and suitable for digging.

The chosen crossing site is on the northern side of the Zagreb-Split highway in the immediate vicinity of the Guduca viaduct. The span between ground level points of the pipeline before and after the canyon is 300 m.

Due to the close vicinity of the highway and the Krka National Park no explosives can be used in this project. Considering this fact and the incline and soil composition of the western slope digging of a trench is not a technologically and economically viable option. Furthermore, because of safety concerns the pipeline cannot be supported by the existing viaduct and building a separate bridge just for the pipeline isn't financially sound.

On the other hand drilling under the whole length of the canyon is also too expensive due to the possibility of natural water drains and sinkholes characteristic of Dalmatian karst terrain which could be irreparably damaged or cause damage to the pipeline. These would have to be located individually and this land survey alone could potentially rise the cost of the project as well as cause delays.

Therefore the selected method was a combination of drilling and digging. The compact rock on the western slope was to be drilled, while the bottom of the riverbed and the eastern slope were to have a trench dug on their surface.

The drilling was done by a micro-tunnelling machine. As the name implies, micro-tunnelling is a digging technique used to construct small tunnels. Using this technology a tunnel was drilled through the rock with a diameter sufficient to fit a gas pipeline pipe along with its PE insulation and a concrete coating with a thickness of 50 mm and of density of 2,300 kg/m^3, without a protective column.

The remaining part of the pipeline would be laid in a regular trench on the bottom of the riverbed and the eastern bank. However, due to the steepness of the bank the trench could not be layered with sand, but sand bags had to be used instead. This ensured that the bottom layers wouldn't slip down the slope and leave the pipes without proper bedding and susceptible to damage from the sharp underlying rock. The preparations were done on the flat sections of ground on the eastern and western edge of the canyon which were wide enough to enable access and maneuvering of pipes and machinery.

3. Crossing of the Guduca canyon

Many different experts and participants with different specialties and knowledge need to work in unison in order for the pipeline project to be completed successfully. The organizational structure of the project and the crossing depends on a number of factors. The most suitable organizational structure for large infrastructure projects such as a main gas pipeline is a project-type organisational structure. Within such a structure and in accordance with the laws of the Republic of Croatia key figures, such as project managers, need to be identified and appointed beforehand. Project management includes the application of knowledge, skills, tools and techniques in project activities to meet project requirements. [10]

The advantages of a project-type organisation structure are: [11]

- A clearly defined command structure, especially if the project manager is also the executive manager
- A clear focus, since the whole team has a dedicated responsibility towards the project.

Such an organisational structure has to take into account special circumstances found on some critical points, such as at the Guduca canyon crossing site. In this particular location topographical constraints are encountered. To overcome them more easily the following stages are created for the project:

- Geodesic defining and marking of the route
- Clearing and preparation of the route
- Building of a temporary access road to the work site
- Digging the trench for the pipeline
- Transportation, welding and preparation of pipes
- Digging of the entrance and exit pits for the micro-tunnelling machine on the western bank
- Drilling through the rock on the western bank
- Building a work platform for the process of inserting the pipe into the micro-tunnel
- Inserting the prepared pipe section into the micro-tunnel on the western bank
- Laying the remaining pipe section into the trench
- Connecting the pipes
- Testing the welds
- Insulation of the welds and testing of the insulation
- Filling of trenches, marking of the pipeline route, restoration of the environment around the worksite
- Pressure testing of the pipeline
- Calibration of the pipeline
- Putting the pipeline into service

Geodesic survey of the route has to be performed on the route of the pipeline through the Guduca canyon site. Once this is completed the selected route is fenced off, cleared of shrubbery and the work site is set up to enable construction work. This particular site can be accessed by a combination of local roads and the cleared route of the pipeline. However the bottom of the canyon could only be accessed once a temporary serpentine access road was built down the eastern bank of the canyon north of the viaduct. This road should also be extended across the riverbed up to the exit pit on the bottom of the western bank to ensure full access to all relevant points on the site. Pipes and machinery can then be transported via this road to locations where they are needed as specified in the project plan.

To minimize transport costs pipes are brought to caches along the route where they are stored until they are needed. Two caches were created for this particular crossing, one on top of each bank of the canyon. From there they were either directly used or, for the bottom section, transported down the access road to the riverbed trenches either individually or in sections of two or more pipes welded together.

However, most pipes had to be bent before being laid into the trench in order to follow the terrain configuration on the site. In his project all bending and welding of pipe segments was done on the ground level, more specifically the top of the canyon's banks. This meant that suitable machinery had to be present on site for this task, as well as additional hydraulic excavators which were used to transport such pipe segments to the trench. All pipes were laid using a combination of hydraulic excavators and dedicated pipe layers.

Even though welding was done next to the trench whenever possible, some welds had to be done in the trench itself. For these a special welding pit was excavated and the best welders employed. According to the project documentation all welded connections between pipes had to be tested. These welds had to meet specific required criteria which were determined in accordance with their respective standards and regulations.

Testing was carried out by both non-destructive testing methods on site and by destructive methods in licensed laboratories. Non-destructive testing included the following methods: visual inspection, inspection by ultrasound, inspection by Rx beams, etc. Destructive testing was done on cut out test samples. These were tested for strength, hardness and toughness. The percentage of welds which underwent detailed testing depended on parameters of the pipeline section, type of accompanying structures, welding method, conditions on the route, etc. It ranged from 20 % to 100 % of all welds. Welds which were found to be ineffective were either repaired or redone.

Finally all welds had to be given anti-corrosion protection and a coat of insulation. The same overall welding method was used on both sides of the canyon.

While the welds were the same on both sides the laying process was not as on the western bank the rock face had to be drilled through. The first step in this process was the digging of both the entrance and exit pits on predetermined locations. Then a micro-tunnelling machine was set up in the entrance pit and the drilling process started. Drilling was done in stages with increasing bore diameters until the desired diameter was reached. In this specific case this was a diameter of 650 mm, which was wide enough to snugly house the pipe and its coating.

Next, platforms were erected to provide a suitable base for the excavators which were used to position the pipe for insertion into the bore. The pipe had to be positioned at an angle of 30° in order to align with the central axis of the bore opening. In total three platforms of varying heights and sizes were built to house the excavators which held the pipe segment in place. These were built from material which was previously dug out from the entrance pit to decrease costs.

Proper alignment was not the only requirement for the insertion process. The coefficient of friction between the concrete of the pipe's coating and the rock was found to be very high and therefore a liquid slurry was poured down the bore to ensure that the pipe segment could slip down the inclined micro-tunnel. Due to the angle of incline of the bore-hole the slurry could flow freely down covering the lower side of the tunnel and decreasing friction. Additionally this same incline meant that the pipe, once in place, could just be gently slid down the hole without the need for additional pushing from the machines. In the end the excavators simply had to slow down the pipe so that it wouldn't descent to quickly and be damaged in the process.

Finally after the entire length of the pipeline segment was laid and connected final work and testing had to be performed. The trench, entrance and exit pits were filled in and the route of the pipeline marked. The surrounding terrain was then restored to its initial condition as much as possible. Before the pipeline was put into use its strength, tightness and shape had to be tested. This was done primarily by a pressure test according to the regulations found in related legislation and the project documentation. The shape of the pipes was tested during calibration and after it satisfied the pipeline was ready to be but into use.

4. Work organization

Project management is the discipline of planning, organizing, motivating, and controlling resources to achieve specific goals. A project is a temporary endeavor with a defined beginning and end (usually time-constrained, and often constrained by funding or deliverables), [10] undertaken to meet unique goals and objectives, [12] typically to bring about beneficial change or added value.

The primary challenge of project management is to achieve all of the project goals [13] and objectives while honoring the preconceived constraints. [14]

Complex construction tasks have to be completed before a pipeline can be put into use. A multidisciplinary team with many members is usually employed in order to successfully execute these tasks. Members of such a team invariably belong to different branches of engineering and other fields which means that a detailed organizational structure is required to ensure that they are able to work together efficiently. If this condition is met such a team should be able to finish the project on time and within the allocated budget.

Organisational preparedness is therefore crucial for a successful project and a good organisational preparedness can only be achieved if the critical points of a project are correctly identified. On a pipeline project critical points (arising from a waterway crossing) can be determined through the use of the flowchart in Fig. 3.

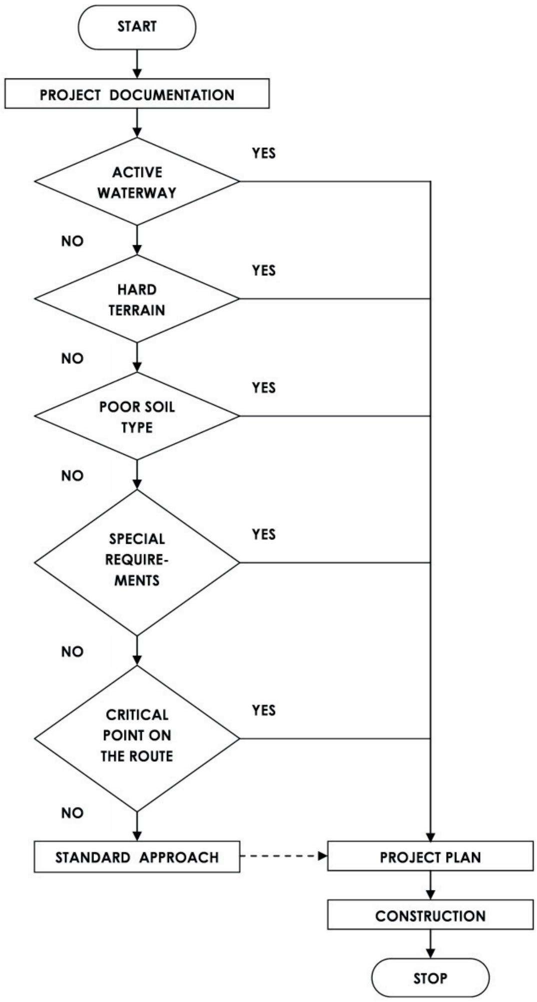

Fig. 3. Flowchart of critical points.

If a point is deemed critical it should be given a separate organizational structure regardless of the integrity of the original project's organizational structure. This is principally due to the fact that such critical points require the use of specific construction technologies and methods which are usually not used project-wide.

Furthermore, critical points often have a separate schedule and deadlines from the bulk of the main project due to their specific circumstances. This is especially true of waterway crossings where additional cost of equipment and varying rates of traffic or flow may constrain the available crossing time.

An example of this project organisation is shown in Fig. 4.

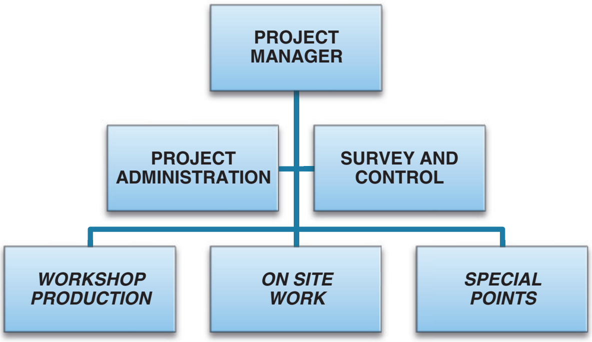

Fig. 4. Organizational structure for projects with special (critical) points of interest.

From the figure above it can be clearly seen that in a project as a whole (and therefore in the crossing of the waterway) the most important role is that of the project manager. According to professor Cala „there is no better condition for a project's failure than the appointment of an unsuitable project manager“. [15] Clearly, the choice of personnel for the project has to be done meticulously and if done properly greatly increases the chance of success.

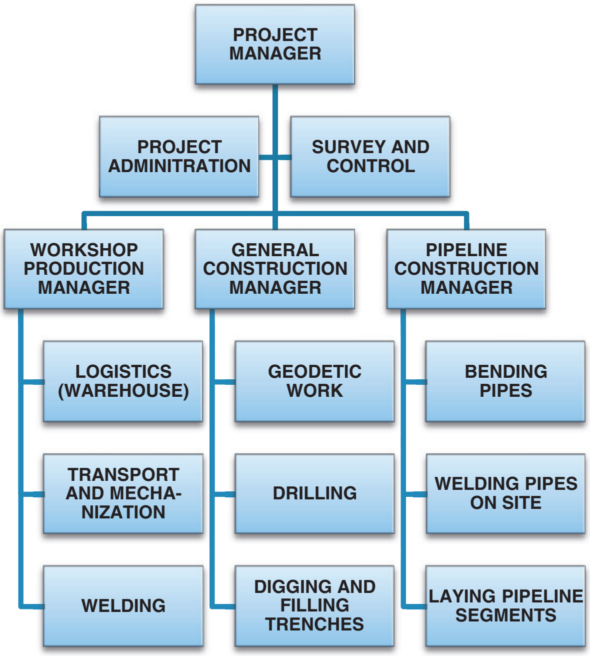

Fig. 5. Shows the organizational structure of a pipeline waterway crossing project.

However, regardless of how well chosen the personnel, an engineering project greatly depends on the quality of the project documentation. This documentation can be made only by a licensed expert according to Croatian law. Furthermore, this person has to provide evidence of past experience in the field in order to guarantee that his work will be of the highest quality. Additionally these references have to be built upon by the references of the company placing that particular bid. Here companies with previous experience in the field should be preferred. Therefore personnel selection starts with the selection of a proposed project solution and signing of the contract with the contractor.

Once the selection process is done the organizational structure for the major waterway crossings is created by appropriating relevant resources from the existing primary gas pipeline organizational structure which was created for the project. Such a structure is shown in Fig. 5. It should be noted here that even though the survey and control functions are not organizationally subordinated to the project manager they are still listed here in order to stress how crucial they are for the project. Also, in the case of the crossing over Guduca canyon only one part of the organisational structure was formed from outside the main organisational structure. Specifically speaking it was the segment concerning micro-tunnelling (drilling).

It is important to stress that merely allocating these resources to the crossing is not sufficient. A well-thought out and documented plan and method of execution of particular activities in the crossing can make or break it. For the Guduca canyon crossing an overview of the course of these activities is shown in the flowchart in Fig. 6. Such a flowchart should also be used to facilitate the creation of an initial assignment schedule for the crossing.

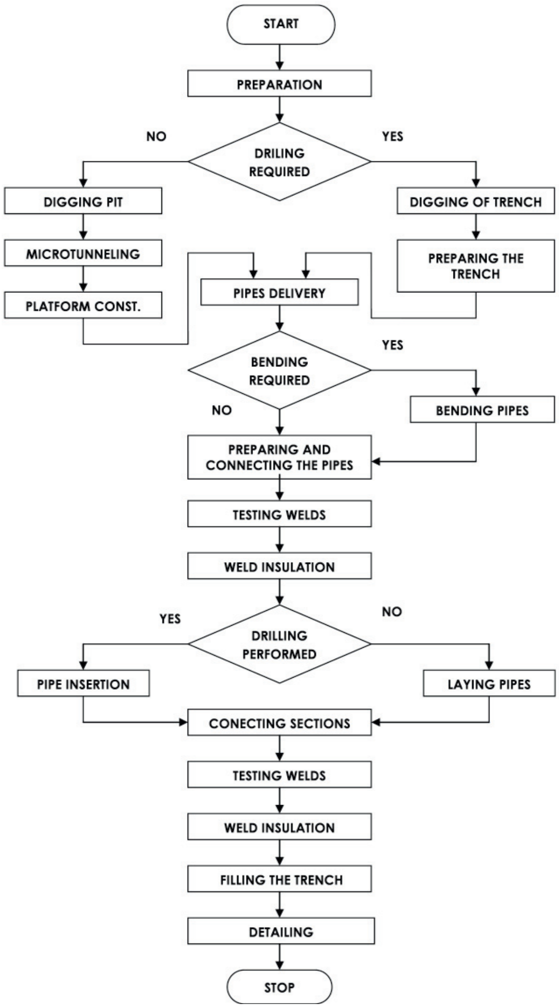

Fig. 6. Flowchart of the construction plan for the Guduca canyon crossing.

With regards to project execution, the team managing the project has to take action which will reduce or eliminate effect of risk i.e. uncertainties. [16] The final schedule was made in a computer program suitable for preparation and monitoring of work on the project. In order to create it, in addition to the list of activities, team leaders had to be assigned to each activity, as well as communication channels through which individual teams could easily coordinate their actions. Furthermore, the final schedule had to include both the preceding and following activity for each task listed.

Table 1 shows an example of an example of an appointment plan from which a final project schedule could be drawn up.

Table 1. An example of an appointment plan.

Description of activity	Duration of activity(days)	Team leader
Preparation (geodetic defining, marking, cleaning and preparation of the route)	Done within project preparation	
Building of access roads, serpetines, etc.	3	A
Diging of the entrance and exit pits	2	A
Transport and setup of the microtuneling machine	1	B
Transport of pipes and equipment	1	B
Drilling	4	C
Building the platform	1	A
Welding the pipes for the section	1	D
Inserting the pipe section into the bore	1	B
Digging and preparing the trench	2	A
Bending the pipes	3	E
Welding the pipes next to the trench	4	D
Testing the welds	1	F
Insulating the welds and testing the insulation	1	G
Laying the pipeline into the trench	2	B
Welding the pipes in the trench	2	D
Testing the welds	Done within the scope of the main project	

Persons listed as A, B, C, etc. lead teams which were tasked with specific parts of the project and were responsible for their completion. This responsibility also included the synchronization of beginning and completion dates, as well as ensuring proper preparation and quality. The duration of each activity is listed in days. Such an approach has the advantage of reserving and allocating necessary resources from within the existing project structure (for the duration of the waterway crossing) which means that there are no unnecessary wait times and confusion about which resources are available for that specific task and when they're available.

The projected duration of the crossing of Guduca canyon was 45 days if separate tasks were not carried out simultaneously. However, by scheduling non-conflicting tasks simultaneously the projected completion time was cut down to 32 days (as shown in table 1), a reduction of 28.89% with respect to the original schedule. In the end (with simultaneous execution of non-conflicting stages) the whole crossing was completed in just 16 work days.

After the completion of the crossing, or speaking generally the completion of any part of a project for which a separate structure was created, an analysis of the work which was carried out needs to be performed and the additional organizational structure disbanded. During analysis any deviations and problems which have occurred during the course of the crossing can be indentified and their causes ascertained. Based on such an analysis conclusions can be drawn which can help in creating a better organizational plan for the next crossing leading to lesser costs and time wasting.

5. Conclusion

A gas pipeline is a complex system used to transport natural gas. The route of the pipeline traverses different terrain and during the pipeline's construction certain obstacles such as waterways can be encountered. Waterway crossing can be done in a number of ways depending on the type and condition of the waterway, as well as the pipeline parameters and surrounding terrain. During the construction of section IV of the gas pipeline system from Benkovac to Dugopolje a number of demanding (critical) crossings were encountered. One such crossing was in the Guduca canyon. It is a river bed of a flash flood river, and while water only flows through it occasionally, when it does the flow is violent. The crossing was specifically demanding due to the steep banks and the solid rock terrain of the western bank. Terrain configuration and material, as well as additional limitations, such as the vicinity of a highway and the Krka National Park, led to drilling through the rock face being used in the crossing. The pipeline then had to be inserted into the bore, while the rest of the crossing could be performed using the regular laying into trench method.

In this paper this combined crossing method is discussed, consisting of drilling/insertion and laying into a trench. The specific requirements of this method and its organizational structure, as outlined here, can be used as a reference in creating future projects in which a similar crossing is needed. Analysis has shown that there was a 28.89% reduction in construction time with respect to the original schedule which was due to non-conflicting tasks being carried out simultaneously. Additional investigation could be undertaken to explore the possibilities of other combination of waterway crossing methods.

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