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DMAIC Method of Quality Improvement of Ground Works Processes: Case Study

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Abstract. The foundations are important part of every building's structure. It can be distinguished square foundations and deep foundations. The process of creating foundations during building construction can be in some cases very complicated and, similar to other construction processes, very costly when errors and problems occurs. Lean construction is a management strategy to eliminate possible errors and wastes during execution of the processes, which is why it is nowadays more widely used for prevention, as well as in the situation of emergency, when solutions already prepared are executed according to the plan. One of the methods that can help in successful implementation of good practices in construction from the quality management perspective is DMAIC, which means Define-Measure-Analyze-Improve-Control. Authors decided to use it for the purpose of this publication. Article presents the use of the DMAIC concept on the example of foundation preparation in the construction site in the city of Koło. The paper presents methods of quality management in the construction process based on foundation works. The quality analysis was based on the DMAIC method, in which the following quality analysis methods were used: Ishikawa diagram, FMEA analysis, Pareto chart. The proposed methods and solutions can be implemented on other construction sites conducting similar processes. Attention is drawn to the need for further research to be carried out to confirm the estimated values of solving problems ratio in groundworks processes, which authors are planning to execute on similar construction site in Poznań.

1. Introduction

Foundations types used according to upper structure of geological conditions are squared foundations and deep foundations. Squared foundations include foundation footings, slabs, strip, grates, boxes and foundation blocks. Deep foundations represent piles, wells as well as caissons and diaphragm walls. The process of creating foundations during building construction can be in some cases very complicated and, similar to other construction processes, very costly when errors and problems occurs. Lean construction is a management strategy to eliminate possible errors and wastes during execution of the processes, which is why it is nowadays more widely used for prevention, as well as in the situation of emergency, when solutions already prepared are executed according to the plan. One of the methods that can help in successful implementation of good practices in construction from the quality management perspective is DMAIC, which is why authors decided to use it for the purpose of this publication.

2. DMAIC in construction

DMAIC is an acronym from the words Define-Measure-Analyze-Improve-Control. This method is based on process improvement according to Deming cycle [1]. This methodology offers a structure for analysis and diagnosis of problems; driven by powerful tools and techniques [3]. It is based on 5 phases



which should be executed step by step. Each of them can be narrowed to the questions that should be answered by its users, which are presented in Figure 1.

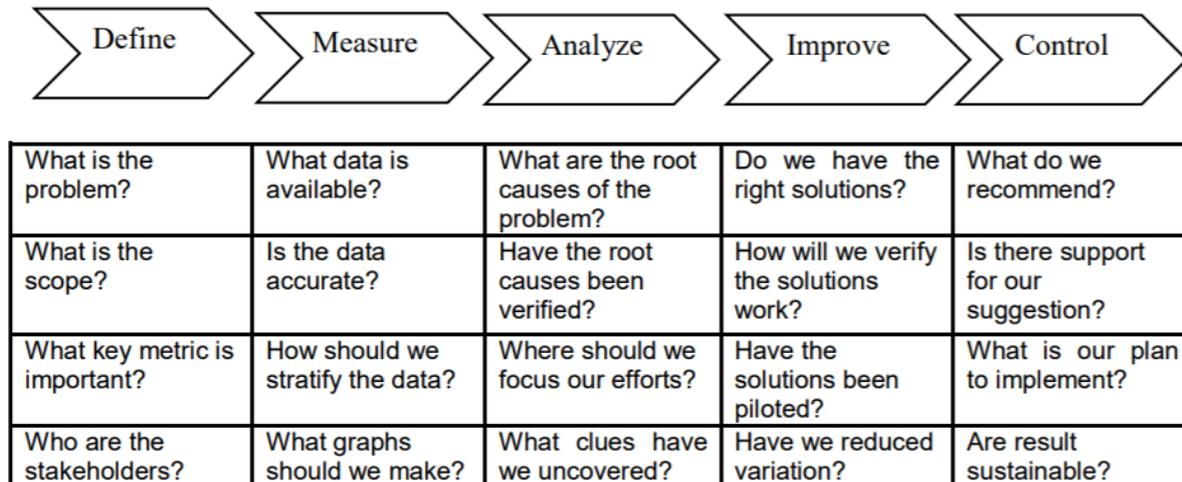


Figure 1. Essential questions for consideration on each step of DMAIC Method [2]

The use of DMAIC method is getting more on more popular in processes that are related not only to the production and manufacturing [7,9,10], but also, IT [6,16,17], healthcare [5,14,15], and many others as well as to the construction [8,12,13]. Based on the literature review [4] authors propose actions that are connected with each step while analysis of construction processes in this article:

Define - Problem definition and possible benefits analysis

- creating a project charter,
- creating a process map in order to identify control points and individual works performed during works,
- creating a justification for the project.

Measure - Converting the problem into a measurable form

- selection of defects detected during the process, which should be measured,
- defining how data should be collected,
- collecting relevant data.

Analyze - Identification of factors affecting the quality standard of the process with the use of:

- Ishikawa diagram,
- FMEA analysis,
- Pareto analysis.

Improve - Improvement of the construction process

- development. solutions eliminating the defect or minimizing the impact of the defect on the process.

Control

- implementation of solutions to maintain the effects of process improvement actions.

3. Communal block of flats in Koło

For the purpose of the article authors decided to analyse building object located in in Koło, at. Stary Rynek street which will be a four-storey residential tenement with 32 apartments and parking spaces for 24 positions, including 2 parking spaces for the disabled.

The designed building is simple in form. The main body is a cube. Elevation the building blends in with the existing historic buildings, details have been preserved architectural in the form of cornices and rustication. In the middle part of the building was used neo-gothic style. The whole building was divided into three parts, so that it would be preserved historical building development. The roof designed above the body is gable, creates a coherent structure the character of the whole object.

Regarding the technology, it has to be said that it is based on plate on load-bearing walls, with a multi-slope roof with main inclination angle it covers 20 ° covered with roofing tiles. Reinforced concrete slabs, poured at the construction site. External walls layered, masonry made of cellular concrete blocks. Foundations underswells in the form of reinforced concrete benches, beams and foundation wells.

Construction began in May 2017. On 20th September 2018 the building should be put into operation. However, due to the fact that the designer incorrectly located the object in the area (one of the gable walls of the building "entered" into the neighbour's building), the construction works were postponed by two months. It was necessary to obtain a new construction permit and re-design the building. Foundation works began in the last week of June and lasted until mid-September. The masonry works on one floor lasted about 3 weeks due to the use of different materials for building by the designer. Different systems caused minor problems. The horizontal partitions of the building were made for three weeks, including reinforcement works and obtaining strength through the ceiling, which allowed further bricklaying of the storeys without increasing the load on it. During the achievement of adequate strength through the ceiling, masonry work inside the facility was carried out. Currently, a wooden roof truss is being made.

3.1. Problem statement for process improvement

Difficulties in systematizing the process are influenced by various application of foundations. The designer decided on the direct foundations in the form of benches and foundation walls as well as indirect foundations - foundation wells. Figure 2 presents the plan of the foundations with the different type of them. Processes that were involved in analysed case are divided into 2 main categories – direct and indirect foundations. Aspects that has to be taken into account during analysis are as follows are presented below for direct and indirect foundations [18]. For better understanding of the process in Figures 3 and 4 examples of executed works are presented.

Squared foundations

- preparatory processes
 - preparation of formwork elements
 - preparation of reinforcing bars and accessories
 - preparation of a concrete mix
 - demarcation and placement
- transport processes
 - transport of formwork elements
 - transport of reinforcing bars and accessories
 - transport of concrete mix
- forming processes
 - setting and assembly of formwork elements
 - insertion of reinforcing elements and distances to the formwork
 - stabilization of reinforcement elements
 - leveling the formwork
 - administration of a concrete mix
 - laying and compacting concrete mix
 - concrete care

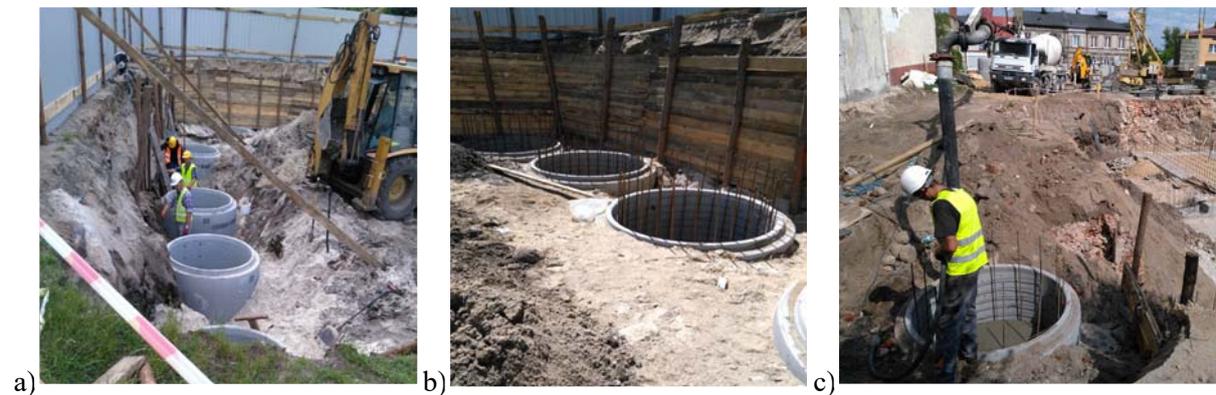


Figure 3. Execution of foundation wells: (a) Overlaying foundation wells (b) Arrangement of reinforcement in foundation wells (c) Arranging high wells, reinforcement and concreting



Figure 4. Execution of direct foundations: (a) Laying of continuous footings and execution of B10 concrete underlay (b) Laying formwork of continuous footings and concreting (c) Stripping and covering foundation

4. Process analysis with the use of DMAIC

DMAIC analysis is a complementary to the analyzes carried out due to the previous used quality assurance tools that are part of the DMAIC process. In the first phase, authors decided to create a project card in accordance with Figure 5. In the second phase, numerical data were used, which concerned the number of defects on the site. In the third phase, the data is analyzed using a cause-effect diagram, FMEA, and the Pareto method. The fourth phase describes possible strategies for solving the biggest problems. Fifth phase presents the idea of monitoring process in the future to assure its reliability.

4.1. Define

This phase consists in creating a process map in order to better understand the mechanisms and checkpoints in operation. The map of the foundation works process for the foundations execution was prepared, as well as project charter which is presented in detail on Figure 5, which aim is to clearly describe what actions are planned to be executed at which step, goals of the project, team members risk factors as well as planned project results, problem description and initial requirements that has to be taken in account.

Project Charter	
1. Project description Main goal: improvement of the work process foundation Specific objectives: process optimization, creating a safe workplace	2. Problem description Problem with foundation wells, lack of employees to work and failures of equipment to thicken backfills.
3. Goal of the project Eliminating emerging problems during the work process foundation or leveling the effects of their creation.	4. Project results <ul style="list-style-type: none"> • new organizational potential • image • additional experience, • additional staff • execution of works without complications and additional financial expenses
5. Plan <ul style="list-style-type: none"> - interviews with employees - team creation - data analysis - solution strategies - control of the implemented solutions 	6. Team Members <ul style="list-style-type: none"> - Works manager, - Construction engineer 1, - Construction engineer 2,
7. Risk Factors Low process knowledge an inaccurate analysis- lack of knowledge about the DMAIC method	8. Success criteria <ul style="list-style-type: none"> - accurate identification of problems - successful strategies to solve problems - control of implemented solutions
9. Initial requirements <ul style="list-style-type: none"> - occurring term - quantitative data appearing 	10. Process description According to the process map

Figure 5. Project Charter for foundation works

4.2. Measure

On the basis of the process map, control points were determined as well as problems that occurred most often during works. They were grouped into categories and presented in the form of Ishikawa diagram (Figure 6). 5 main groups of problems were detected: equipment, workers, technology, investor and materials. The next step was about to define detail problems in each category. Totally there were 23 problems analysed in the next step.

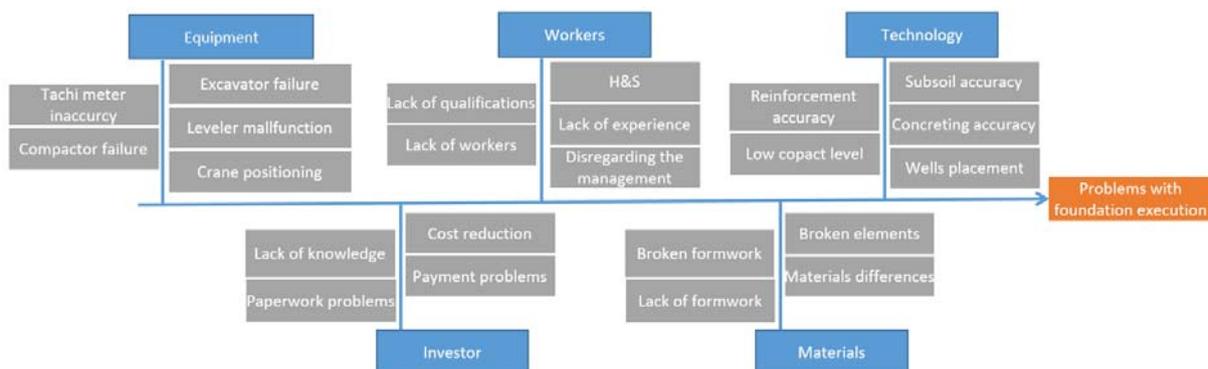


Figure 6. Ishikawa diagram for analysed case process

4.3. Analyse

Tools such as FMEA and the Pareto chart were used for the analysis process. The FMEA analysis shows that the problems with the highest risk factor are not exactly the location of the foundation well, the lack of qualifications of employees and the inaccuracy when measuring the total station (Figure 7). The Pareto chart also points to inaccurate foundations of foundation wells as the main problem, but the second one is failures to compact backfill. The problem related to the lack of qualifications of employees occurred in the group of causes that do not cause large effects during the process.

		Engineer 1				Engineer 2				Construction Manager					
		Detection D, Frequency F, Influence I 1-Low 10-High													
problem		D	F	I	RPN	D	F	I	RPN	D	F	I	RPN	av	RPN
Technology	Subsoil accuracy	7	2	2	28	1	3	5	15	4	4	3	48	30,33	
	Reinforcement accuracy	2	3	8	48	1	2	10	20	2	5	10	100	56,00	
	Concreteing accuracy	2	2	8	32	1	5	5	25	5	2	5	50	35,67	
	Wells placement	5	5	7	175	5	5	7	175	5	4	8	160	170,00	
	Low compact level	9	2	5	90	2	8	5	80	1	2	10	20	63,33	
Workers	H&S	2	8	2	32	1	8	5	40	1	6	8	48	40,00	
	Lack of workers	1	7	10	70	1	8	10	80	1	7	10	70	73,33	
	Lack of qualifications	3	5	7	105	4	3	7	84	2	8	7	112	100,33	
	Disregarding the management	1	5	10	50	1	6	10	60	2	4	8	64	58,00	
	Lack of experience	1	1	7	7	1	1	4	4	3	5	10	150	53,67	
Investor	Cost reductions	1	8	8	64	1	10	10	100	1	10	10	100	88,00	
	Payment problems	2	2	4	16	2	5	8	80	1	7	10	70	55,33	
	Lack of knowledge about technology	3	7	1	21	1	1	1	1	1	8	10	80	34,00	
	Paperwork problems	1	2	10	20	1	1	1	1	1	3	10	30	17,00	
Materials	Broken elements	2	2	8	32	1	2	10	20	1	2	2	4	18,67	
	Materials differences (concrete)	9	2	8	144	10	1	1	10	5	2	3	30	61,33	
	Broken formwork	1	3	9	27	1	1	10	10	1	3	4	12	16,33	
	Lack of formwork	2	2	8	32	1	8	10	80	2	5	7	70	60,67	
Equipment	Tachi meter inaccuracy	8	2	8	128	3	4	10	120	8	3	7	168	138,67	
	Excavator failure	1	1	7	7	1	1	10	10	1	3	4	12	9,67	
	Leveler malfunction	8	2	7	112	5	1	10	50	4	2	5	40	67,33	
	Crane positioning	1	5	9	45	1	1	10	10	1	3	6	18	24,33	
	Compactor failure	1	8	8	64	1	9	10	90	1	7	8	56	70,00	

Figure 7. FMEA diagram for analysed case process

Seven problems were identified for the Pareto analysis, which appeared on the site during foundation works. The baseline data for the analysis come from the site manager. Based on the number of defects, a histogram was created, which is illustrated by the Pareto-Lorenz diagram (Figure 8).

The graph shows that the largest number of problems is generated by the inaccurate location of the foundation wells. Failures related to this problem are as much as 13% of problems occurring during the implementation of the foundation work process. This may be caused by the lack of precise marking out of the place where the concrete rings are located, as well as by difficult communication with the crane operator.

Another major problem are failures to compact foundation dust. This may be due to the long use of equipment or incompetent use of compactors by employees.

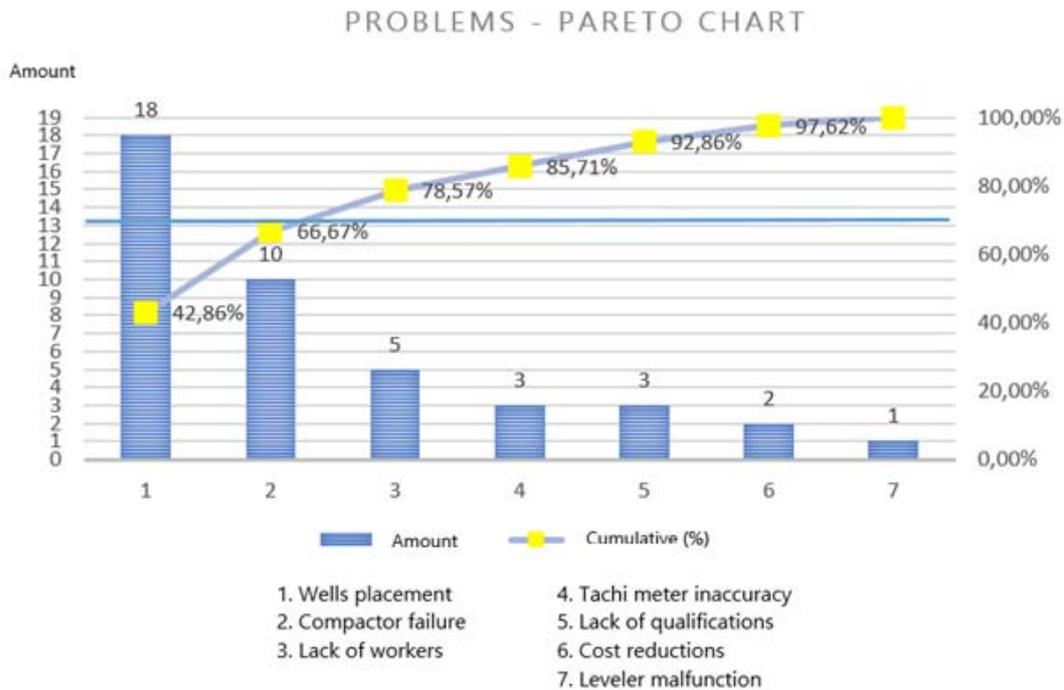


Figure 8. Pareto chart for analysed case process

4.4. Improve

In this phase authors decided to present a solution strategy for three problems with the largest RPN coefficient according to FMEA analysis:

1. an inaccurate location of foundation wells:

- accurate reading of coordinates from the project,
- uninterrupted communication with the operator of the crane and people at the foundation well,
- appointment of a person for measurement who has relevant experience in this area.

2. lack of qualifications of employees:

- training for employees,
- employment of qualified employees,
- division of the workforce into work crews and appointing a foreman who will control the work of employees.

3. inaccuracy when measuring the tachi meter:

- measuring equipment that guarantees the accuracy of measurements,
- checking the person using the total station.

4.5. Control

To maintain a constant ability to verify and monitor the process in terms of emerging problems, it was decided to create a control plan. This is to maintain the quality of the foundation work process at the appropriate quality level. In order to control the location of control wells, it is recommended to introduce a type c control card. The constant sample size is maintained due to the constant number of employees and working hours. Assuming that the process of laying foundation wells takes two weeks, manager should note each day the number of wells that could not be planted the first time and if the dimension did not agree with the documentation [18].

It is also necessary to set the tolerance limits for the works performed, e.g. 1 cm. These are the upper and lower limits that should be applied to the control card. On the basis of the results obtained, it is possible to examine whether the proposed solution strategies have their impact in improving the quality of the process and which elements of the works should be noted. If the limits are exceeded, the management should be notified immediately and the subsequent strategies should be implemented.

The application of the solution strategy for the problems of inaccurate foundations of foundation wells, problems related to the lack of qualifications of employees and failures of equipment to thicken backfills should improve the process of foundation works efficiency by 40%. Due to the fact that the analysis was made during the construction site, and the progress of works where immediate, it was impossible for authors to perform full Control phase in this process – but received solution will be used in the next construction site with similar processes being executed.

5. Conclusions

The paper presents methods of quality management in the construction process based on foundation works. The quality analysis was based on the DMAIC method, in which the following quality analysis methods were used:

- Ishikawa diagram,
- FMEA analysis,
- Pareto chart.

The methods and analyzes presented in the article led to the following conclusions:

- Quality management tools can be useful in the construction process. They affect its improvement and elimination of problems generating the largest losses and can help to find the source of problems, so you can avoid them in the future.
- It is estimated that introduction of the proposed solution strategies for foundation works will allow to eliminate problems or reduce the effects of their creation by about 40%.
- People involved directly in the process did not heard about the concept of Lean Management and related methods. However, after presenting the methods, they willingly responded and paid attention to emerging problems.

The proposed methods and solutions can be implemented on other construction sites conducting similar processes. Attention is drawn to the need for further research to be carried out to confirm the estimated values of solving problems ratio in groundworks processes, which authors are planning to execute on similar construction site in Poznań.

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