



Implementation of Six Sigma Method in Defect Control for Sustainable Construction (Case Study: Structural Work of Building Construction Project)

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Abstract. One of the main issues in construction projects is the high rate of structural defects, which contributes to material waste, increased costs, and project delays. This contradicts the principles of sustainable construction, which emphasize resource efficiency, waste reduction, and improved building quality to achieve a longer service life. This research aims to manage such defects using a quantitative descriptive method with Six Sigma analysis and the DMAIC approach. The result of this study indicates that there were a total of 76 defects were identified in the Hilton Garden Inn Extension project, with the highest occurring in column structure (25 defects), slabs structure (23 defects), beam structure (20 defects), and stairs structure (8 defects), mainly due to porous concrete and uneven surfaces. Sigma levels for all structural concrete works range from 2.808 to 4.745, with an average sigma level of 3.828, indicating moderate quality performance. The corresponding average DPMO across all structural components is 75,394.436 per one million opportunities. Key defect causes include unskilled labor, poor supervision, SOP non-compliance, improper concrete mixing, difficult formwork removal, low-quality materials, inadequate tools, and poor execution practices.

Keywords: Construction Projects, Defects, Six Sigma

1 Introduction

The excessive use of non-environmentally friendly construction materials, unplanned development, and energy inefficiencies contribute to the reduction of green spaces, exacerbating global warming. According to the World Green Building Council, buildings contribute to at least 33% of global CO₂ emissions, 17% of water use, 25% of wood consumption, 30–40% of raw material consumption, and 40–50% of energy usage during operations (Afiq, 2024). To address these issues, the concept of green building has emerged, emphasizing environmentally sound practices throughout the project lifecycle. Green construction, as its implementation, integrates sustainability principles throughout all construction phases. A green building is one that incorporates environmental principles in design, construction, operation, and management, especially in responding to climate change impacts (Adeswastoto et al., 2023). Key criteria for green buildings include the use of eco-friendly materials, efficient water and

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energy use, effective waste management, health considerations, sustainable site management, and disaster mitigation facilities (Kurniawan et al., 2020). The goal is to reduce environmental harm by maintaining ecological balance through sustainable planning and project execution (Peginusa et al., 2024). However, construction defects, particularly in structural work, continue to challenge sustainability goals. These defects lead to material waste, cost overruns, and project delays, contradicting the emphasis on resource efficiency, waste minimization, and enhanced building durability that is central to sustainable construction. Structural defects, while sometimes within acceptable tolerance limits, can have serious repercussions on cost, time, and material use (Prihatno et al., 2020). The causative factors include design, workmanship, and materials (Christian & Alifen, 2020). The issue of defects in construction work hurts costs, time, and resources. One of the methods that can be used for defect management is the Six Sigma method. This method enables quality improvement with a stationary base that prioritizes high discipline, thereby eliminating the root cause of problems using the Define-Measure-Analyze-Improve-Control (DMAIC) approach (Effendi et al., 2021). The Six Sigma DMAIC method is used to identify and mitigate defects with a systematic approach (Saidatuningtyas & Rizal, 2023). DMAIC is a continuous cycle that plays a crucial role in identifying key factors that contribute to achieving the final target in the Six Sigma method (Michelle et al., 2023). Previous research has demonstrated that Lean Six Sigma can help reduce project delays (Wijaya & Widiyanti, 2024). Other research indicates that the majority of total defect list jobs are found in the fields of architecture, civil engineering, and IT work, where each contractor has a percentage above 15% (Veen, 2023). In the Hilton Garden Inn Extension Hotel project, a five-story building with a steel roof structure was found to have major structural defects, including porous columns and beams, untidy corners, and beam deflections. These defects resulted in significant rework, increased material usage, labor costs, and project duration, thereby reducing resource efficiency and contradicting the principles of sustainable construction. This study aims to evaluate the application of the Six Sigma methodology for defect control in structural works. While previous research has utilized Six Sigma to identify and quantify construction defects, limited studies have explored the root causes, control strategies, and corrective actions for these defects in depth.

2 Methodology

2.1 Research Design

The research uses a quantitative descriptive method. The method aims to make a systematic, factual, and accurate description of a phenomenon under investigation (Dewi et al., 2023). The research data comprise both primary and secondary sources. Data collection methods with surveys, brainstorming, and interviews. The analysis method employs the Six Sigma method with the DMAIC approach, beginning with the identification of defects in the building structure work, calculating the sigma level

value, determining the factors causing the defect, and providing the corresponding treatment.

2.2 Research Data

This study utilizes both primary and secondary data. Primary data were collected through field observations, documentation, and interviews with the Project Manager, Site Manager, Quality Control, and Supervisor. Observations focused on identifying defects in structural elements such as columns, beams, slabs, and stairs, while documentation captured detailed defect records. The interviews provided valuable insights into the root causes and offered suggestions for improvement. Secondary data were sourced from previous research and relevant project documentation.

2.3 Data Analysis

The data analysis process in this study was carried out in several stages. The first stage was the Define Phase, which involved identifying the types of occupational defects through field observation. This identification was conducted using a checklist during direct observation in the field to record the types of defects that occurred in each structure work and to calculate the number of occurrences. The second stage was the Measure Phase, which consisted of several steps, including calculating the defect value per unit (DPU) for each construction defect unit, calculating the Defect Per Million Opportunity (DPMO) value, and determining the Sigma value. The level of Six Sigma was then determined by converting the DPMO values using the Six Sigma Conversion Table. The third stage was the Analyze Phase, where an analysis of the factors causing defects in concrete construction was conducted using a fishbone diagram. This analysis summarized the causes into categories such as machine, man, method, material, quality, and environment. The required data for this phase were collected through interviews with the Project Manager, Site Manager, Quality Control personnel, and Supervisors.

3 Result and Discussion

3.1 Define Phase

The define phase focuses on identifying construction work defects that occurred during the implementation of the Hilton Garden Inn Extension project, with emphasis on the main structural components. Defect data were collected from quality control reports, specifically structural defect reports per floor, and through direct field observations, allowing for precise localization of each defect. Based on the compiled observation data and defect reports, a summary of identified defects and their frequencies was generated for the structural elements under review. A total of 76 defects were recorded across four types of structural works. In addition to defect identification, the quantity of defects and the corresponding work volumes for each structural component were also calculated. A summary of these findings is presented in the table below.

Table 1. Identification of Defects and Number of Defects

No.	Types of defect	Number of defect events	Defective quantity	Total quantity	Unit
1	The stair landing column concrete has voids	1	1,000	120,000	pcs
2	The remaining column formwork has not been dismantled	3	3,000	120,000	pcs
3	Concrete is honeycombed	15	15,000	120,000	pcs
4	The tie rod used to support the formwork has not been cut	1	1,000	120,000	pcs
5	Column corners are not neat	2	2,000	120,000	pcs
6	Column concrete shows deformation	1	1,000	120,000	pcs
7	The concrete surface is chipped	1	1,000	120,000	pcs
8	The column rebar overhang has not been cut	1	1,000	120,000	pcs
9	The tie rod used to support the beam formwork has not been cut	4	26,900	984,400	m'
10	Beam concrete is honeycombed	13	75,812	984,400	m'
11	Concrete beam B3 is misaligned	1	20,250	984,400	m'
12	The beam is deflecting	1	4,050	984,400	m'
13	The beam rebar overhang has not been cut	1	8,300	984,400	m'
14	The concrete slab surface is uneven	12	427,375	2445,895	m ²
15	The edge of the concrete slab is uneven	1	76,950	2445,895	m ²
16	Concrete has honeycombing	3	32,745	2445,895	m ²
17	The concrete slab is sagging	1	62,370	2445,895	m ²
18	Concrete slab has voids	3	69,520	2445,895	m ²
19	The fascia board is misaligned	2	56,000	2445,895	m ²
20	Slab formwork has not been removed	1	1,800	2445,895	m ²
21	Stair concrete is honeycombed	6	6,374	18,908	m ³
22	The remaining stairs formwork has not been dismantled	1	2,414	18,908	m ³
23	Deflection observed in the stair landing slab	1	2,875	18,908	m ³
Total		76			

Table 1 above shows the various problems found in concrete work in a construction project. A total of 76 defects were identified in the concrete works of the HGI

Development structure. The column works exhibited the highest number of defects, totaling 25, with porous concrete being the most frequent issue (15 occurrences). Column inspections covered 120,000 units each on the ground and fourth floors. Concrete blocks had 20 recorded defects, with porous blocks being the most prevalent (13 occurrences). The total inspected beam volume was approximately 984,400 m³. In concrete slabs, 23 defects were found, with the most frequent being uneven slab surfaces (12 occurrences), across a total inspected area of around 2,445,895 m². Stair concrete works showed 8 defects, predominantly porous concrete (6 occurrences), from a total inspected volume of 18,908 m³.

3.2 Measure Phase

At the measure phase, a calculation was made of the Defect Per Unit (DPU) value and the percentage of defect occurrence to further analyze the Defect Per Million Units (DPMO) value and sigma level. Analysis of the DPU value is carried out to identify and track the number of defects in a process. DPMO value analysis is used to measure the number of defects in a process per one million opportunities and to derive sigma-level values to assess the quality of a process by determining how many variations exist in the process and how often the results are outside the desired specifications. The result is shown in the following Table 2. Table 2 indicates that porous concrete is the most prevalent defect across all structural concrete elements, particularly in columns and stairs, with defect percentages of 12.50% and 33.71%, respectively, and the highest Defects per Unit (DPU) values. Uneven surfaces on concrete slabs are also significant, accounting for 17.47% of defects. High DPU values reflect a greater impact on overall quality. Notably, porous concrete in stairs exhibits a critical DPU value of 0.337 and a defect rate of 33.71%, highlighting this as a high-priority issue for quality improvement. Sigma level analysis shows that concrete columns have the highest sigma level at 3.200 and the lowest at 4.409, with an average DPMO of 26,041.667 and a sigma value of 3.910. Concrete blocks have a sigma range from 3.730 to 4.745, with an average DPMO of 27,491.264 and a sigma value of 4.181. Concrete slabs show sigma values ranging from 3.144 to 4.900, with an average DPMO of 42,447.798 and a sigma value of 4.060. Concrete stairs present the lowest process capability, with sigma values between 2.808 and 3.341, an average DPMO of 205,597.017, and a sigma value of 3.161. Overall, sigma levels for all structural concrete works range from 2.808 to 4.745, with an average sigma level of 3.828, indicating moderate quality performance. The corresponding average DPMO across all structural components is 75,394.436 per one million opportunities, suggesting further quality improvement measures are needed, particularly for stair concrete works.

Table 2. DPU Value, Defect Percentage, DPMO Value, and Sigma Level

No.	Types of defect	DPU value	Defect percentage	DPMO value	Sigma level
1	The stair landing column concrete has voids	0.008	0.83%	8,333.333	3.957
2	The remaining column formwork has not been dismantled	0.025	2.50%	25,000.000	3.883
3	Concrete is honeycombed	0.125	12.50%	125,000.000	3.200
4	The tie rod used to support the formwork has not been cut	0.008	0.83%	8,333.333	3.957
5	Column corners are not neat	0.017	1.67%	16,666.667	4.409
6	Column concrete shows deformation	0.008	0.83%	8,333.333	3.957
7	The concrete surface is chipped	0.008	0.83%	8,333.333	3.957
8	The column rebar overhang has not been cut	0.008	0.83%	8,333.333	3.957
Average				26,041,667	3.910
9	The tie rod used to support the beam formwork has not been cut	0,027	2.73%	27,326.290	4.271
10	Beam concrete is honeycombed	0,077	7.70%	77,013.409	3.730
11	Concrete beam B3 is misaligned	0,021	2.06%	20,570.906	4.165
12	The beam is deflecting	0,004	0.41%	4,114.181	4.745
13	The beam rebar overhang has not been cut	0.008	0.84%	8,431.532	3.996
Average				27,491,264	4.181
14	The concrete slab surface is uneven	0.175	17.47%	174,731.540	3.144
15	The edge of the concrete slab is uneven	0.031	3.15%	31,460.876	3.783
16	Concrete has honeycombing	0.013	1.34%	13,387.737	4.640
17	The concrete slab is sagging	0.025	2.55%	25,499.868	3.967
18	Concrete slab has voids	0.028	2.84%	28,423.133	4.454
19	The fascia board is misaligned	0.023	2.29%	22,895.505	3.533
20	Slab formwork has not been removed	0.001	0.07%	735,927	4.900
Average				42447,798	4.060
21	Stair concrete is honeycombed	0.337	33.71%	33,7087.196	2.808
22	The remaining stairs formwork has not been dismantled	0.128	12.77%	127,651.225	3.333
23	Deflection observed in the stair landing slab	0.152	15.21%	152,052.631	3.341
Average				205,597.017	3.161
Total Average				75,394.436	3.828

3.3 Analyse Phase

The analyse stage is the phase of finding and determining the root of the problem using a fishbone diagram or cause-and-effect diagram. At this stage, brainstorming and interviews were conducted with the parties involved to gain an understanding of the implementation and construction defects, specifically with the Site Manager, Quality Control, and Supervisor. The result show that the cause of the defect such as labor (unskilled workers; ineffective supervision; non-compliance with work procedures); machine (damaged or malfunctioning equipment); material (reuse of formwork material; concrete has started to set; excessive use of water in concrete mix; inconsistent slump value; tie rods that are too long or too stiff); method (construction techniques not in accordance with standards); environment (poor housekeeping in the work area; ambient temperature) and quality (inaccurate calculations; quality control not in accordance with standards; lack of inspection before and after construction activities; absence of checklist forms for certain work items).

4 Conclusion

There were various problems found in the concrete work in a construction project. A total of 76 defects were identified in the HGI project, with the highest occurring in columns (25 defects) and slabs (23 defects), mainly due to porous concrete and uneven surfaces. Sigma level values based on DPMO range from 2.808 to 4.745, with an average sigma level of 3.828 and an average DPMO of 75394,436. Key defect causes include unskilled labor, poor supervision, SOP non-compliance, improper concrete mixing, difficult formwork removal, low-quality materials, inadequate tools, and poor execution practices.

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