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SENSITIVITY OF SUB-TASK REQUIREMENTS TOWARDS QUALITY DEVIATIONS AND CONSTRUCTION DEFECTS

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Studies on the construction defects and quality deviations have been commissioned and published in many countries, showing the global status of the issues related with construction defects. Therefore, the quality of the adapted practices in construction projects can be improved if the pattern of the sub-task, specifically the quality deviations and construction defects from the requirements and specifications is identified and understood. The aim of this study is to improve understanding of the pattern of the more sensitivity sub-task requirements (STRs) through examine the number of ppm are non-conforming or defects. Multiple cases studies were conducted include 3,030 samples of 17 Sub-tasks requirements STRs from compression concrete members (i.e., column).

Keywords: Construction tasks, Quality, Building code requirements, STR patterns.

1 INTRODUCTION

Quality-related issues often affect construction management practices, and construction defects and quality deviations are probably among the most renowned issues (Sommerville 2007). Despite the improvements in the construction industry quality practices; as remarkable developments were made in terms of the project management tools, methods and strategies; often capable of meeting the specifications and forming explicit contributions to reduce the project cost overruns by limiting the construction defects that primarily exist during the execution phase (Sommerville 2007).

A significant amount of research literature has highlighted the greater proneness of the construction industry to defects and rework compared with other industries, such as the manufacturing industry (Tchidi *et al.* 2012). This phenomenon has recently become a global issue (Barker 2004), and it usually leads to projects exceeding the cost constraints and causes delays in handover to the client.

Therefore, the current study examines the extent of task sensitivity to defect exposure during execution phase and determines the number of parts per million (ppm) are non-conforming or defects. Multiple case studies on 17 STRs were conducted from 27 residential project sites in Saudi Arabia.

2 BACKGROUND

Considerations based on the nature of industry have to be made to counter the hurdles that can drain the time, cost and quality of construction projects. Inappropriate analysis and evaluation of the project sub-tasks are among these considerations (Love *et al.* 2009), specifically, the susceptibility to construction defects. Construction defects, during execution phase, have numerous types of sources and may occur any time during a project's life (Priemus and Ale 2010). These sources have been divided in literature into two main areas: task elements and non-task elements. Task elements are related to the nature of task characteristics (e.g., task size) (Bonner 1994, Pitz and Sachs 1984), whereas non-task elements are related to requirements needed to perform a task (i.e., human factor) and a task's surroundings (i.e., weather) (Fayek *et al.* 2003).

Task characteristics (e.g., task's size or information loads) differ from task to task (Campbell 1988). This differentiation has its own reasons, which stem from the nature of each task. For example, increasing information loads may increase task complexities, whereas raising a task's size may not influence a task's complexity. Task complexity indicates to the extent influence of each characteristic on the task, which has strong evidence to support its ability to influence tasks more than other characteristics (Bonner 1994). This study will focus on variation rates between tasks.

The majority of earlier studies have concentrated on the categorization or classification of the quality deviations and construction defects at macro level such as task, activity, package of work, construction item/element (Macarulla *et al.* 2013). In contrast, the studies have rarely investigated the deviations at the micro on the STR level. This may justify the purpose of this study to examine this issue in a more accurate manner. The sub-task characteristics (i.e., the nature of sub-task) form the basic viewpoint of this paper to focus upon the construction defects and deviation problems.

3 METHODOLOGY AND DATA COLLECTION

This study used a quantitative approach to calculate the number of ppm are non-conforming of the STRs. The non-conforming and defects STRs are obtained through the calculation of difference between the design and code specifications and the actual dimensions of the output work at the project site. The study covered a data set developed after visiting 27 different project sites in Saudi Arabia. Multiple case studies for 17 STRs of a column element in concrete structure were employed for data collection and approximately 3,030 STRs were focused. The data resources such as the drawing and specifications from design provisions; building code requirements (Saudi Building Code SBC-305A&B and American Concrete Institute Code ACI-318A & ACI-117) as well as the inspection checklist of the actual project site work were utilized.

4 RESULTS AND DISCUSSION

In this section, 17 STRs were analyzed and discussed as shown in Table 1.

STR.1: Steel cross-section area (A_{st}): The acceptable range of the tolerance of STR.1 shall be not less than $0.01A_{st}$ nor more than $0.08A_{st}$ times gross area (A_g) of section to meet preset specifications. Table 1 shows that the capability process index $C_p = 4.2106 > 1$, which indicates that the specification spread is 4.2106 times greater than the 6-sigma σ spread in the process. This reveals that there are roughly 129,032.29 ppm are non-conforming and revealing that defectives are being produced.

Table 1. Number of ppm that are non-conforming.

Tasks	Mean	Cp	PPM < LSL	PPM < USL	PPM Total
STR. 1	0.0128	4.2106	129,032.29	0.00	129,032.29
STR. 2	0.0094	0.5174	50,420.17	92,436.97	142,857.14
STR. 3	9.9479	0.0922	193,277.31	605,042.00	798,319.33
STR. 4	0.1300	0.5563	0.00	500,000.00	500,000.00
STR. 5	-0.3377	0.7536	26,315.79	0.00	26,315.79
STR. 6	0.0149	1.0362	0.00	0.00	0.00
STR. 7	1.9765	0.3486	20,242.91	380,566.80	400,809.72
STR. 8	1.0297	0.3293	71,428.57	275,510.20	346,938.78
STR. 9	-0.8082	1.0407	0.00	0.00	0.00
STR.10	12.651	0.5218	11,278.20	199,248.12	210,526.32
STR.11	17.030	1.2873	0.00	68,965.56	68,965.56
STR.12	6.8371	0.2077	0.00	784,000.00	784,000.00
STR.13	0.9466	0.1616	114,503.82	366,412.21	480,916.03
STR.14	0.1667	0.4263	41,666.67	125,000.00	166,666.67
STR.15	0.3300	0.3795	74,626.87	194,029.85	268,656.72
STR.16	0.2965	0.6464	0.00	182,608.70	182,608.70
STR.17	0.4193	0.5363	41,152.26	78,189.30	119,341.56

STR.2: Longitudinal Bars Length: The acceptable range of the tolerance for STR.2 shall be between ±50mm of the designed length of the to meet preset specifications. Table 1 shows that the capability process index $C_p = 0.5174 < 1$, which indicates that the specification spread is 0.5174 times less than the 6-sigma σ spread in the process. This reveals that there are roughly 142,857.14 ppm, indicating that it is non-conforming and revealing that defectives are being produced.

STR.3: Lap splices: The acceptable range of the tolerance for STR.3 shall be permitted to be multiplied by 0.83 with ±25 mm, but lap length shall not be less than 300 mm. to meet preset specifications. Table 1 shows that the capability process index $C_p = 0.0922 < 1$, which indicates that the specification spread is 0.0922 times less than the 6-sigma σ spread in the process. This reveals that there are roughly 798,319.33 ppm, indicating that it is non-conforming and revealing that defectives are being produced.

STR.4: Offset bars: The acceptable range of the tolerance for STR.4 shall not exceed 1 in 6 to meet preset specifications. Table 1 shows that the capability process index $C_p = 0.5563 < 1$, which indicates that the specification spread is 0.5563 times less than the 6-sigma σ spread in the process. This reveals that there are roughly 500,000.00 ppm, indicating that it is non-conforming and revealing that defectives are being produced.

STR.5: Ties width: The acceptable range of the tolerance for STR.5 shall not exceed ±10 mm ($D \leq 200$ mm) or ±15 mm ($D > 200$ mm) to meet preset specifications. Table 1 shows that the values of the capability process index $C_p = 0.7536 < 1$, which indicates that the specification spread is 0.7536 times less than the 6-sigma σ spread in the process. This reveals that there are roughly 26,315.79 ppm, indicating that it is non-conforming and revealing that defectives are being produced.

STR.6: Ties depth: The acceptable range of the tolerance for STR.6 shall not exceed ±10 mm ($d \leq 200$ mm) or ±15 mm ($d > 200$ mm) to meet preset specifications. Table 1 shows that the capability process index $C_p = 1.0362 > 1$, which indicates that the specification spread is 1.0362 times greater than the 6-sigma σ spread in the process. This reveals that roughly 0.00 ppm are non-conforming and that the process is capable.

STR.7: Ties: Hooks dimensions: The acceptable range of the tolerance for STR.7 shall be equal (bar $\phi = x$) $x \leq 16\phi$ ($6d_b$ ±15 mm) or $x = 20\phi - 25\phi$ ($12d_b$ ±15 mm) to meet preset specifications. Table 1 shows that the values of the capability process index $C_p = 0.3486 < 1$, which indicates that the specification spread is 0.3486 times less than the 6-sigma σ spread in the process. This reveals that there are roughly 400,809.72 ppm, indicating that it is non-conforming and revealing that defectives are being produced.

STR.8: Ties Angular º: The acceptable range of the tolerance for STR.8 shall be equal (bar $\phi = x$) $x \leq 16\phi$ ($6d_b$ ±15 mm) or $x \leq 25\phi$ (90º or 135º ±2 ½ degrees) or $x > 25\phi$ (90º ±2 ½ degrees) to meet preset specifications. Table 1 shows that the capability process index $C_p = 0.3293 < 1$, which indicates that the specification spread is 0.3293 times less than the 6-sigma σ spread in the process. This reveals that there are roughly 346,938.78 ppm, indicating that it is non-conforming and revealing that defectives are being produced.

STR.9: Ties: Bend dimensions: The acceptable range of the tolerance of STR.9 shall be equal (bar $\phi = x$) $x \leq 16\phi$ ($4d_b$ ±25 mm), $x = 16\phi$-25ϕ ($6d_b$ ±25 mm), $x = 28\phi$-36ϕ ($8d_b$ ±25 mm) or $x > 40\phi$ ($10d_b$ ±25 mm) to meet preset specifications. Table 1 shows that the capability process index $C_p = 1.0407 > 1$, which indicates that the specification spread is 1.0407 times greater than the 6-sigma σ spread in the process. This reveals that there are roughly 0.00 ppm are non-conforming and that the process is capable.

STR.10: Horizontal spacing between longitudinal bars: The acceptable range of the tolerance for STR.10 shall be between the minimum not less than $1.5d_b$ nor less than 40 mm to meet preset specifications. Table 1 shows that the capability process index $C_p = 0.5218 < 1$, which indicates that the specification spread is 0.5218 times less than the 6-sigma σ spread in the process. This reveals that there are roughly 210,526.32 ppm, indicating that it is non-conforming and revealing that defectives are being produced.

STR.11: Vertical spacing between ties: The acceptable range of the tolerance of STR.11 shall be not exceed 16 longitudinal d_b ($x = 16\ d_b$), 48 tie d_b ($x = 48\ d_b$), or least dimension of the compression member (x = least column width) ±25 mm to meet preset requirement or specifications. Table 1 shows that the values of the capability process index $C_p = 1.2873 > 1$, which indicates that the specification spread is 1.2873 times greater than the 6-sigma σ spread in the process. This reveals that there are roughly 68,965.56 ppm, meaning it is non-conforming and that defectives are being produced.

STR.12: Spacing above the slab: The acceptable range of the tolerance for STR.12 shall be equals one-half tie spacing above slab (0.5**x*) ±25 mm to meet preset specifications. Table 1 shows that the values of the capability process index $C_p = 0.2077 < 1$, which indicates that the specification spread is 0.2077 times less than the 6-sigma σ spread in the process. This reveals that there are roughly 784,000.00 ppm, indicating that it is non-conforming and revealing that defectives are being produced.

STR.13: Cross-sectional dimensions: formwork width: The acceptable range of the tolerance for STR.13 shall be equals if width $x \leq 30$ cm, (+0.9525 cm) (-0.635 cm), if width 30 cm < $x \leq 90$ cm, (+1.27 cm) (-0.9525 cm), or if width $x > 90$ cm, (+2.54 cm) (-1.90 cm) to meet preset specifications. Table 1 shows that the values of the capability process index $C_p = 0.1616 < 1$, which indicates that the specification spread is 0.1616 times less than the 6-sigma σ spread in the process. This reveals that there are roughly 480,916.03 ppm, indicating that it is non-conforming and revealing that defectives are being produced.

STR.14: Cross-sectional dimensions: formwork depth: The acceptable range of the tolerance for STR.14 shall be equals if depth $x \leq 30$ cm, (+0.9525 cm) (-0.635 cm), if depth 30 cm < $x \leq 90$ cm, (+1.27 cm) (-0.9525 cm), or if depth $x > 90$ cm, (+2.54 cm) (-1.90 cm) to meet preset specifications. Table 1 shows that the values of the capability process index $C_p = 0.4263 < 1$, which indicates that the specification spread is 0.4263 times less than the 6-sigma σ spread in the process. This reveals that there are roughly 166,666.67 ppm, indicating that it is non-conforming and revealing that defectives are being produced.

STR.15: Concrete cover: The acceptable range of the tolerance for STR.15 shall be equals $d \leq 200$ mm, $x = 40$ mm (±10 mm) or $d > 200$ mm, $x = 40$ mm (±15 mm), but not less than 1/3 Cover (SBC 304A, Section 7.5.2.1, ACI, Section 7.5.2.1) to meet preset requirement or specifications. Table 1 shown that the values of the capability process index $C_p = 0.3795 < 1$, which indicates that the specification spread is 0.3795 times less than the 6-sigma σ spread in the process. This reveal that there are roughly 268,656.72 ppm, indicating that it is non-conforming and revealing that defectives are being produced.

STR.16: Deviation from plumb for column: The acceptable range of the tolerance for STR.16 shall be equal, for the top of foundation and a height of 26 m, 0.3% of the height until a maximum dimension of +2.5cm (26 m and less, x = 0.3% of high until maximum +2.5 cm) (ACI 117, Section R4.1.1) to meet preset requirement or specifications. Table 1 shown that the values of the capability process index $C_p = 0.6464 < 1$, which indicates that the specification spread is 0.6464 times less than the 6-sigma σ spread in the process. This reveal that there are roughly 182,608.70 ppm, indicating that it is non-conforming and revealing that defectives are being produced.

STR.17: Column positioning - Deviation between horizontal elements: The acceptable range of the tolerance for STR.17 shall be equal, for distance greater than 30 cm (12 in), $x = \pm 5$ cm (ACI 117, Section 7.2.2) to meet preset requirement or specifications. Table 1 shown that the values of the capability process index $C_p = 0.5363 < 1$, which indicates that the specification spread is 0.5363 times less than the 6-sigma σ spread in the process. This reveal that there are roughly 119,341.56 ppm, indicating that it is non-conforming and revealing that defectives are being produced.

5 CONCLUSION

This study aims to identify the level of quality practice related to the design specification and building code requirements in Saudi Arabia. The number of defective ppm were examined for 17 different sub-task requirements. Findings show that the variation of the number of defective ppm between sub-tasks indicate that sensitivity to defect exposure and rates of defects differ for each sub-task. This indicates that each STR has different patterns. So, this study recommends that it should understand the pattern of each STR to reduce the non-conforming and defects.

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