Research Article

Risk Rating of Precast Concrete Pile Fabrication Process: A Case Study in Bandung, Indonesia

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Abstract

The utilization of precast concrete pile has become prevalent in Indonesian construction industry. The business process within the fabricator of precast concrete pile includes fabrication and installation process. This study is intended to fill research gap in fabrication process since most of the risk studies focus on the installation process. This study is aimed to identify and rate all risks related to the precast concrete pile fabrication process, followed by a recommendation of mitigation strategy. The preliminary risks are identified through field observation to a precast concrete pile fabricator in Bandung, Indonesia. The preliminary risks are validated using Delphi technique, resulting 22 final risk factors. The final risk factors are rated using risk matrix method. The high and medium category of the rated risks are sling failure; bar-cutter and/or bar-bender machine failure; hoist crane failure; and pile chip defect. Since most of those risks occur on the respective machine, the general mitigation strategies are to provide a backup machine and the frequent monitoring and maintenance. Besides, an adequate standard operation procedure of each fabrication stages needs to be established and its implementation should be monitored carefully.

Keywords: Risk rating, Precast concrete pile, Fabrication

1 Introduction

The utilisation of pile as building's foundation has been a common practice in Indonesian construction industry [1], [2]. Pile foundation is mostly pre-fabricated, which leads to several benefit in terms of time and quality [1], [3]. The quality of pre-fabricated pile foundation could be carefully monitored in order to ensure its capacity and durability [1]. In addition, It allows a more efficient piling process duration [1]–[3].

There are four types of pile foundation in accordance with its material, which are concrete, timber, steel, and composite [1], [2]. As a type of composite pile foundation, [1] stated that reinforced concrete pile is preferable to timber in terms of dimension flexibility, load capacity, and weather sensitivity. Furthermore, compared to steel pile, reinforced concrete has more capability to resist corrosion [1].

This study discusses about the risk related to the process of reinforced concrete pile fabrication. The aim of this study is to identify and rate all risk related to fabrication process. A set of recommended risk mitigation is also provided in order to prevent material and time waste which could lead to cost overrun.

2 Literature Review

The literature of risk management related to concrete pile foundation has been commonly conducted. Most of the literature, including code and standard, focusses on the risk during pile installation process [4]–[7].

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A study embracing risk during fabrication has been delivered by [8], but it mainly discusses the risk related to health and safety aspect. This study is intended to fulfil the research gap by scrutinizing the risk related to time and cost overrun during concrete pile fabrication process. The risk is identified in accordance with the stages during pile fabrication process.

The typical precast concrete fabrication process comprises seven stages which are:

1. Pile frame material preparation

This process mainly consists of the preparation of the steel reinforcement, including main and spiral steel reinforcement. This preparation utilises bar cutter and bar bender machine. The steel reinforcement is cut and bended in accordance with the pile proposed size.

2. Pile frame assembly

The steel, from the previous stage is assembled to construct the pile frame. The main and spiral steel reinforcement is knotted using steel wire.

3. Mould clean-up and setting

The mould surface is clean up in order to remove any concrete stain from the previous pile concrete works. The mould is then lubricated by spraying lubricator from spray tank.

4. Pile-head installation

This process begins with the installation of pile frame inside mould. The pile head is then welded to the frame, and followed by painting process.

5. Concrete works

This process begins with decking concrete to keep the gap between pile frame and concrete cover. The concrete is prepared at the batching plan, then brought to fabrication site. The concrete is placed on bucket and then lifted up using hoist crane and poured to the mould. The concrete is then compacted using vibrator stick. The curing process is performed for 30–45 min, followed by 12 h resting. The pile is then painted with code and production date.

6. Pile dismantling (from mould)

The pile is dismantled form mould by lifting it using hoist crane. The sling connects spider beam to the lifting point on the pile.

7. Storage process

The pile is firstly placed in a temporary storage area, and then located to the storage area using forklift machine.

3 Methodology

In general, the methodology of this study consists of three major phases, which are risk identification; risk rating; and risk mitigation.

3.1 *Risk identification*

The risk identification covers two stages which are preliminary risk identification and risk validation.

3.1.1 Preliminary risk identification

The preliminary risk identification is conducted by field observation to a concrete pile fabricator in Bandung, Indonesia. The selection of this fabricator company is based on the production size. Besides, this fabricator company allows a comprehensive observation throughout all fabrication stages, which all take place within the company's fabrication site.

The observation is limited to the fabrication of PC Square Pile (20 × 20 cm^2-D13 and 25 × 25 cm^2-D16) and PC Triangular Pile (28 cm-D13 and 32 cm-D16 side length). The length of pile is 3 m and 6 m for both shape, K-450 concrete, and 5 mm spiral reinforcement. This observation generates set of preliminary risks which are needed to be validated accordingly.

3.1.2 Risk validation

The preliminary risks are validated using Delphi technique in a group of five members, who are fabrication manager, quality control manager, project manager, and senior operator from five precast concrete pile fabricator companies in Bandung, Indonesia. All group member has more than ten years' experience to ensure the validity of their opinion.

Delphi technique is defined as a method to achieve consensus among several experts regarding a particular issue [9], [10]. Delphi technique is selected in order to enhance the efficiency during risk identification phase, specifically in construction industry [10]–[12]. All preliminary risks are discussed in terms of its suitability based on member's experience. Each preliminary risk is discussed, whether it needs to be discarded or not. The discussion is iterated until a consensus is reached [13], [14]. This stage generates final set of risks which will be rated in the next phase.

3.2 *Risk rating*

The risk is rated based on its severity and probability of occurrence [15]–[18]. The rating process utilises Delphi technique in the same group as in the risk validation phase. The rating process is iterated until a consensus is achieved. The output of this process is a single value of severity and probability of occurrence of each risk.

The severity (R) is assessed using the parameter introduced by [19], which is shown in the tables below.

Table 1: Severity (R) Assessment [19]

Value	Risk Rating	Criteria	
		Impact on End User	**Impact on the Next Fabrication Stage**
9–10	Very High	Affect the operational safety and/or violate regulation	Product must be discarded and could endanger operator safety
7–8	High	The product loses its main function and cause high level of end user dissatisfaction. Does not affect the operational safety and/or violate regulation	Product must be discarded
4–6	Moderate	Cause moderate level of end user dissatisfaction	Product could be partially discarded or repaired
2–3	Low	Cause minor disruption to end user	Product could be partially repaired on-site without any discard
1	Minor	Cause minor disturbance to the product without any defect, which could not be perceived by end user	Could pass to the next fabrication stage

In order to provide a clearer understanding of the time and cost impact, several information has been gathered from fabrication site as a complement to Table 1. A partial repaired pile could cost up to 9 USD per metre of pile length and could delay the fabrication of the repaired pile by up to one day. A full discarded pile could spend up to 16 USD per metre of pile length and up to two days' delay on the fabrication of the discarded pile.

Table 2 shows the parameter of the assessment of the probability of occurrence (L introduced by [19].

Table 2: Probability of Occurrence (L) Assessment [19]

Value	Occurrence	Criteria
10	Occur	1 out of 2
9		1 out of 10
8	Likely	1 out of 20
7		1 out of 40
6	Possibly	1 out of 80
5		1 out of 100
4		1 out of 150
3	Unlikely	1 out of 250
2		1 out of 500
1	Almost not occur	1 out of 1000

The risk is then rated using risk matrix based on risk criticality value [20] which is shown in Table 3. Risk criticality value (C) is equal to risk severity value (R) times risk probability of occurrence value (L).

Table 3: Risk Rating Criteria [20]

Risk Criticality Value (C)=(R)*(L)	Rating
1–19	Negligible
20–30	Low
31–48	Moderate
49–89	High
90–100	Extreme

3.3 *Risk mitigation*

The risk mitigation is performed for the rated risk with moderate to extreme rate category. The recommended mitigation strategy is obtained through an interview to the respondent subsequent to the rating process.

4 Results and Discussion

4.1 *Results*

There were 30 preliminary risk factors which are identified during field observation. These risk factors cover seven different stages during concrete pile fabrication. The stages are pile frame material preparation; pile frame assembly; mould clean-up and setting; pile-head installation; concrete works; pile dismantling (from mould); and storage process.

The validation process towards the preliminary risks results 22 final risk factors. The group of experts reached consensus in discarding 8 preliminary risks.

The group of experts was then deciding the severity (R) and probability of occurrence (L) of each final risks. The consensus regarding those values were achieved through several iterations.

The risk critical value was then calculated based on R and L value, resulting three high rate risks, three medium rate risks, and 16 low rate risks. There are no negligible and extreme rate risks. The detail of the identified risk, validated risk, and rated risk are presented in Table 4.

Table 4: Risk Identification, Validation, and Rating

Fabrication Stage	Risk Code	Identified Risk		Risk Rating			
		Risk Factor	Validation	Severity (R)	Prob. of Occurrence (L)	Criticality (C) = (R)*(L)	Rating
Pile Frame Material Preparation	X1	Failure on bar-cutter and/or bar-bender machine	Valid	8	7	56	High
Pile Frame Assembly	X2	Measurement error on reinforcement length	Discard	Not rated			
	X3	Measurement error on spiral reinforcement spacing	Valid	4	5	20	Low
	X4	Inadequate knot between main and spiral reinforcement	Valid	6	4	24	Low
Mould Clean-up and Setting	X5	Inadequate mould surface clean-up	Valid	3	7	21	Low
	X6	Inadequate mould clean-up and lubrication	Valid	4	6	24	Low
	X7	Failure on lubrication spray tank	Discard	Not rated			
Pile-head Installation	X8	Inadequate pile frame installation inside mould	Discard	Not rated			
	X9	Failure on welding equipment	Valid	5	5	25	Low
	X10	Failure on ampere value setting during welding process	Valid	5	4	20	Low
	X11	Discrepancy on pile-head paint colouring	Valid	5	4	20	Low
Concrete Work	X12	Failure on decking concrete installation	Valid	5	5	25	Low
	X13	Failure on mix design and cylinder sample	Valid	4	5	20	Low
	X14	Failure on batching plant machine	Valid	6	5	30	Low
	X15	Failure on sling which carries bucket to moulding area	Valid	7	7	49	High
	X16	Failure on hoist crane during concrete work	Valid	6	7	42	Moderate
	X17	Inadequate concrete compaction using vibrator stick	Valid	5	5	25	Low
	X18	Failure on vibrator stick	Discard	Not rated			
	X19	Inadequate lifting point installation on concrete	Discard	Not rated			
	X20	Failure on code and production date naming	Valid	5	4	20	Low
	X21	Inadequate sprinkling during curing process	Valid	6	4	24	Low
Pile Dismantling (from mould)	X22	Failure on sling which connects spider beam to lifting point	Valid	9	7	63	High
	X23	Failure on lifting point under hoist cable pulling	Valid	6	5	30	Low
	X24	Failure on hoist crane during pile dismantling	Valid	6	6	36	Moderate
	X25	Unbalance lifting point during pile dismantling (from mould)	Discard	Not rated			
	X26	Chip defect on pile during dismantling	Valid	7	5	35	Moderate
Storage	X27	Failure during pile placement on temporary storage area	Discard	Not rated			
	X28	Failure during final product sorting	Discard	Not rated			
	X29	Failure on forklift machine	Valid	5	5	25	Low
	X30	Chip defect on pile during storage	Valid	6	4	24	Low

4.2 *Discussion*

The discussion covers all moderate and high rate risks, including the recommended mitigation strategy.

4.2.1 Sling failure

There are two high rate risks related to sling, which are failure on sling which carry bucket to mould area, and failure on sling which connects spider beam to lifting point. The sling used in this study has 12 mm diameter and 40 m length, which is made from steel with 10 tones capacity. In accordance with the interview to respondent, these failure is mainly generated by the high intensity of sling usage which reaches ten hours a day. Furthermore, the failure during sling rolling and elongation are also key factors to the sling failure. If the sling rolling and elongation is not conducted in perfect vertical position, the sling will be pinched for long period of time. This will lead to a reduction of sling service life.

The respondent stated that the company could produce up to 300 piles per day. The sling failure could damage the pile, danger the operator safety, and stop the production process. Moreover, the respondent informed that this failure could potentially cause up to two days’ delay, followed by up to 15,000 USD cost overrun per day. The recommended mitigation strategy is to provide backup sling and conduct frequent monitoring and maintenance on the sling. Besides, the Standard Operation Procedure (SOP) on sling rolling and elongation should be established, followed by an adequate monitoring.

4.2.2 Bar cutter and bar bender failure

The observed bar cutter machine could cut up to 16 mm diameter steel bar. The bar bender has the maximum capacity of 10 mm diameter steel bar. Based on the interview, both machine could produce approximately 200–300 piles in one day. The common failures on the machine are the electrical sensor, the bender axle, and the cutter.

The respondent stated that the failure on the electrical sensor usually cause by the dirt on the sensor. While the failure on the bender and cutter are caused by high intensity of machine utilisation. The high intensity of usage causes the cutter become easily blunt, and the inaccurate bending degree. The respondent said that these consequences could lead to production time delay by up to one day followed by up to 5,000 USD cost overrun. The recommended mitigation strategy is to provide backup machine and conduct frequent monitoring and maintenance on the machine.

4.2.3 Hoist crane failure

The hoist crane is utilised to mobilised all equipment during fabrication process. The observed hoist crane has the capacity of 10 tones. The respondent pointed out that the hoist crane failure is significantly resulted by high intensity of usage. This crane usually operates 15 h a day from the dismantling process in the morning, concrete works in the afternoon, until the storage process in the evening. The failure points are located in the brake canvass and the electric contactor.

The hoist crane failure could severely damage the productivity of the fabrication process since it is involved in the whole fabrication stages. The respondent informed that these consequences could lead to production time delay by up to one day followed by up to 10,000 USD cost overrun. The recommended mitigation strategy is to provide a vendor for backup crane renting which is located near the site and could mobilise the crane immediately if such an incident occurs. Besides, a frequent monitoring and maintenance on the crane must be conducted. Moreover, a group of technician should be placed on site to anticipate any incidental failure.

4.2.4 Pile chip defect

According to the interview, pile chip defect often occurs during the dismantling and storage process. During dismantling process, the defect is generated from an uneven applied lubricant on the mould. During storage process, the defect is usually caused by a collision throughout pile loading-unloading activity. Besides, an inappropriate selection of lifter clamp could also lead to chip defect.

The severity of chip defect impact depends on its degree of defect. On a minor degree defect, it could be directly repaired using dry mix concrete fill. On major degree, it could significantly impact the pile capacity, so that it must be discarded. But the respondent stated that this degree of defect occurs in a very small probability. In general, pile reparation in every degree could lead to time and cost overrun, reducing the fabrication productivity.

The recommended mitigation strategy is to monitor the mould lubrication process, monitor the pile loading-unloading activity, and sharpen the pile sorting process. An effective pile sorting process allows an early detection of pile chip defect occurrence. Consequently, if such defect occurs, the amount of reparation time could be minimised.

5 Conclusions

There were 30 preliminary risk factors which are identified during field observation. These risk factors cover seven different stages during concrete pile fabrication. The stages are pile frame material preparation; pile frame assembly; mould clean-up and setting; pile-head installation; concrete works; pile dismantling (from mould); and storage process.

The preliminary identified risks are then validated, resulting 22 final risk factors. The final risk factors are rated using risk matrix, generating three high rate risks, three medium rate risks, and 16 low rate risks. The high and medium category of the rated risks are sling failure; bar-cutter and/or bar-bender machine failure; hoist crane failure; and pile chip defect.

Since most of those risks occur on the respective machine, the general mitigation strategies are to provide a backup machine and the frequent monitoring and maintenance. Besides, an adequate standard operation procedure of each fabrication stages needs to be established and its implementation should be monitored carefully.

References

[1] N. Nurdiani, “Pekerjaan pondasi tiang pancang: Cara pemancangan, kendala, dan teknologi terbaru,” *ComTech*, vol. 4, no. 2, pp. 776–784, Dec. 2013.

[2] M. M. Riza. (2011, May). Pondasi Tiang Pancang (Pile Cap Foundation). ARS Group, Bellevue, USA [Online]. Available: http://www.perencanaanstruktur.com/2011/05/seluk-beluk-pondasi-tiang-pancang.html

[3] KITASIPIL. (2017, Apr.). Mengenal Pekerjaan Tiang Pancang (Pile). KITASIPIL, Bellevue, USA [Online]. Available: http://www.kitasipil.com/2017/04/mengenal-pekerjaan-tiang-pancang-pile.html

[4] Federation of Piling Specialists. (2010, Jul.). Examples of Hazards associated with Piling and Diaphragm Walling Works and how these might be managed within the design phase of a project (neither exhaustive nor exclusive). Federation of Piling Specialists, London, England [Online]. Available: https://www.fps.org.uk/content/uploads/2017/05/SID-Examples-of-Piling-Hazards-and-Risks.pdf

[5] T. Bles, S. Al-Jibouri, and J. V. D. Adel, “A risk model for pile foundations,” presented at the 20th International Symposium on Automation and Robotics in Construction ISARC 2003 The Future Site, Eindhoven, Sep. 21–23, 2003.

[6] A. G. Gibb, R. Haslam, T. C. Pavitt, and K. Horne, “Designing for health – reducing occupational health risks in bored pile operations,” *Construction Information Quarterly, Special Issue: Health and Safety*, vol. 9, no. 3, pp. 113–123, 2007.

[7] T. M. Zayed and D. W. Halpin, “Pile construction productivity assessment,” *Journal of Construction Engineering and Management*, vol. 131, no. 6, pp. 705–714, 2005.

[8] L. K. Putri and I. W. Suletra, “Analisis risiko K3 di proses produksi tiang pancang dengan metode JSA dan risk matrix: Studi kasus di PT X,” presented at the Seminar dan Konferensi Nasional IDEC 2017, Surakarta, May 8–9, 2017.

[9] A. P. C. Chan, E. H. K. Yung, P. T. I. Lam, C. M. Tam, and S. O. Cheung, “Application of delphi method in selection of procurement system for construction projects,” *Construction Management and Economics*, vol. 19, no. 7, pp. 699–718, 2001.

[10] A. B. Renzi and S. Freitas, “The delphi method for future scenarios construction,” *Procedia Manufacturing*, vol. 3, pp. 5785–5791, 2015.

[11] I. A. Kıral, Z. Kural, and S. Çomu, “Risk identification in construction projects: Using the delphi method,” presented at the 11th International Congress on Advances in Civil Engineering, Istanbul, Turkey, Oct. 21–25, 2014.

[12] E. E. Ameyaw, Y. Hu, M. Shan, A. P. C. Chan, and L. E. Yun, “Application of delphi method

in construction engineering and management research: A quantitative perspective," *Journal of Civil Engineering and Management*, vol. 22, no. 8, pp. 991–1000, 2016.

[13] S. More and T. Hirlekar, "Effectiveness of risk management and chosen methods in construction sector," *International Research Journal of Engineering and Technology*, vol. 4, no. 11, pp. 2006–2009, 2017.

[14] A. Sourani and M. Sohail, "The delphi method: Review and use in construction management research," *International Journal of Construction Education and Research*, vol. 11, no. 1, pp. 54–76, 2015.

[15] M. Abdelgawad and A. R. Fayek, "Risk management in the construction industry using combined Fuzze FMEA and Fuzzy AHP," *Journal of Construction Engineering and Management*, vol. 136, pp. 1028–1036, 2010.

[16] D. Baloi, "Risk analysis techniques in construction engineering projects," *Journal of Risk Analysis and Crisis Response*, vol. 2, no. 2, pp. 1–9, 2012.

[17] S. M. Renuka, C. Umarani, and S. Kamal, "A review on critical risk factors in the life cycle of construction projects," *Journal of Civil Engineering Research*, vol. 4, no. 2A, pp. 31–36, 2014.

[18] K. Mhetre, B. A. Konnur, and A. B. Landage, "Risk management in construction industry," *International Journal of Engineering Research*, vol. 5, no. 1, pp. 153–155, 2016.

[19] D. H. Stamatis, *Failure Mode and Effect Analysis*. Wisconsin: ASQ, 2003.

[20] S. Mortimer and D. Mortimer, *Quality and Risk Management Tools.* Cambridge, England: Cambridge University Press, 2015.