Risk assessment on occupational accident of apartment building structural work with Failure Mode and Effect Analysis (FMEA) method

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Abstract. The apartment is a vertical building used for residential purposes. It is included in a high rise building category with high occupational risk accident level due to its work complexity, or high elevation factors. This research discussed the risk assessment of occupational accident at one of the apartment constructions in Surabaya in order to determine its dominant risk factors and mitigation. Failure Mode and Effect Analysis (FMEA) method was applied to this research. It is a risk assessment method based on severity, occurrence, and detection. Following the relevant assessment, it resulted in 3 types of occupational accidents with the highest Risk Priority Number, namely height work accident, falling material from tower crane, and risk of landslide excavation.

1 Introduction

Housing or residential development currently focused on vertical-shape buildings (upward construction). Among them, the apartment shows attractive and progressive building. The apartment construction will affect the area for housing construction due to high population rate [1]. The apartment is classified as a high-rise building category, thus, it should have more than six floors. According to Mulyono [2] a high-rise building is a building with six floors and 20-meter in height.

The construction of a high-rise building category should include occupational safety principles in its operational aspects concerning high occupational accident risks. The higher the building, the higher accident risks occur [3]. Some factors such as human behavior, work environment, operational method, and equipment can cause occupational accident risk. According to Ramli [4], the impacts of the occupational accident are not only harm employees or workers, but also affect the time period and costs.

Based on the statement above, it is necessary to conduct an occupational accident risk assessment in apartment construction. Currently, some methods including HIRA, HAZOP, HIRARC, *fault tree analysis* (FTA), and *failure mode and effect analysis* (FMEA) can be used to study risk assessment. Among them, The FMEA method by US MIL-STD 1629 is

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widely well-accepted. The development of FMEA method has been applied by Sinaga [5] on occupational accident risk assessment of Surabaya - Mojokerto Toll Road Construction Project. This FMEA method is suitable or appropriate to assess the occupational accident risks in order to find the priority of mitigation on apartment construction risk.

2 Research methodology

2.1 Research concept

This research is a case study to assess and response the occupational accident risk at one of apartment project constructions in Surabaya. The FMEA method was used to assess the dominant risk, recognize the response, for its mitigation, and avoid its recurrence.

2.2 Research variables

The accident risk variables in this research were related to the worker or human, operational method performance, and equipment risks. The risks were classified based on the upper and lower structural work in apartment construction.

2.3 Population and sample

There were 37 out of 76 population samples of this research taken from contractor workers at one of the apartment constructions in Surabaya. The samples were taken from staffs, supervisor to project manager level in the organisational structure. The stratified random sampling method was applied to select qualified respondents within the research criteria [6]. The samples were proceeded from professional and experienced workers in risk mitigation sector.

2.4 Research Steps

2.4.1 Risk identification

The risk identification variables refer to previous study Sinaga and Haryanto [5, 7], occupational accident data of August 2017-January 2018 during the apartments constructions in Surabaya, and interview session with Quality Safety Health Environment (QSHE).

2.4.2 Risk analysis

Risk analysis was undertaken by:

- 1) Preliminary questionnaire were distributed to check the validity and reliability of risk variables to selected respondents.
- 2) Main questionnaire were assigned to obtain a risk assessment of valid variables. The assessment with the FMEA method was conducted under the following steps: 1) Accident frequency level (Occurrence) assessment, 2) Accident severity level (Severity) assessment, 3) Accident detection level (Detection) assessment, 4) RPN (Risk Priority Number) value calculation. The related parameter was measured in the range of 1 to 10 scale assessment, presented in Table 1.

Table 1. Occurrence, severity, and detection assessment scale [8].

Scores	Occurrence (O)	Severity (S)	Detection (D)
1	Hardly ever	No effect	Almost certain
2	Very rare	Very minor	Very easy
3	Quite rare	Minor	Easy
4	A little bit rare	Very low	Quite easy
5	Rare	Low	So-so
6	A little bit frequent	Moderate	Somewhat difficult
7	Quite frequent	High	Quite difficult
8	Frequent	Very high	Difficult
9	Very frequent	Serious	Very difficult
10	Almost always	Very dangerous	Almost impossible

RPN Calculation Formula is as follows:

(RPN) = Severity x Occurrence x Detection

(1)

Risk level finding with FMEA Criticality matrix Diagram presented in Fig. 1.

Fig. 1. Critically matrix diagram [9].

Since the high-risk level has a higher mitigation priority, the causal of dominant occupational accident risks was examined based on critical and high-risk level variables. The dominant risk causal factors were described in the *fishbone* diagram. Dominant risk mitigations were descriptively specified from the literature study, and interview session/discussion with the QSHE (Quality Health and Safety Environment).

Table 2. Variable identification on occupational accident risks [5] and interview

Work description	Risk variables	
Excavation and Pile	1	Accident during heavy equipment mobilization
	2	Hit by excavator during excavation
	3	Crashed by dump truck
	4	Slipped on graving
	5	Buried by landslide
	6	Dust inhalation from excavation and piling process
Erection	7	Stroke by pole during lifting
	8	Slipped on graving due to land condition
	9	Vibration influence due to erection work
	10	Hearing disorder
Foundation raft ironing	11	Blistered hand due to iron direct contact
	12	Wedged during iron lifting
	13	Stubbed during transportation
	14	Slipped during installation
Casting	15	Mixer, concrete pump movement hazard
	16	Hit by concrete pump pipe
	17	Stroke/ splashed by concrete material
	18	Dust and cement material inhalation
Scaffolding installation	19	Stroke by mold material (from the same height)
	20	Slipped during installation
	21	Hit/ stabbed during installation/ dismantling
	22	Fell (person) during dismantling at height
Tablefoam and Polywood Installation	23	Injured hand during polywood installation
	24	Fell from height during table foam installation
	25	Dust splash on eyes during polywood cutting
Reinforced	26	Blistered hand due to iron direct contact
	27	Splashed during iron cutting
	28	Wedged during iron lifting/ putting

Work description	Risk variables	
	29	Slipped/ stubbed iron during installation
	30.	Fell from height during reinforced installation
Reinforced/ molding material erection by Tower crane	31	Reinforced/ stroke by mold material during Tower Crane erection process.
	32	Dislocated material drop down
	33	Tower Crane material hit
Beam, column, shear wall, and stairs casting	34	Fall hazard due to vibration/ concrete check
	35	Stroke/ hit by concrete pump piping
	36	Stroke/ splashed by concrete material
	37	Cement material fell/ splashed
	38	Eye/ respiratory disorder during blower area cleaning.

Table 3. Additional variables from interview results.

Work description	Risk variables	
Excavation and Pile	1	Underground electrical shock during excavation
Foundation raft ironing	2	Slipped into foundation raft ironing
Scaffolding installation	3	Fell scaffolding material from height during installation
Upper structure reinforced	4	Fire on work area due to iron welding or cutting
	5	Electrical shocked during iron welder or cutter operation
Reinforced/molding material erection by Tower crane	6	Capsized, tumbled, broken sling crane fell
Beam, column, shear wall, and stairs casting	7	Collapse floor during floor/ shaft plate casting

3 Results and discussion

3.1 Risk identification

Identification results on variables derived from previous research literary studies, occupational accident data, and interview results with QSHE presented 38 occupational accident risk variables. The variables were classified from work based on excavation and piling to the casting of beams, column, *shear wall*, and stairs casting. Risk identification results were presented in Table 2. In addition to those variables mentioned in Table 2, there were another 7 specified additional variables at the preliminary questionnaire distribution of the respondents presented in Table 3.

Statistically, the validity test was performed by SPSS method of product moment pearson correlation. A variable was considered as valid if the r computation is larger than r table values. The validity test results were presented in Table 4.

Table 4. Preliminary questionnaire validating results.

	Risk Variables	r computation	r table	Remarks
1	Accident during heavy equipment mobilization	0.7212	0.5494	valid
2	Hit by excavator during excavation	0.6026	0.5494	valid
3	Crashed by dump truck	0.0639	0.5494	invalid
4	Slipped on graving	0.6246	0.5494	valid
5	Buried by landslide	0.6246	0.5494	valid
6	Dust inhalation from excavation and piling process	-0.9016	0.5494	invalid
7	Stroke by pole during lifting	0.6246	0.5494	valid
8	Slipped on graving due to land condition	0.7493	0.5494	valid
9	Vibration influence due to erection work	0.4620	0.5494	invalid
10	Hearing disorder	0.6491	0.5494	valid
11	Blistered hand due to iron direct contact	0.7212	0.5494	valid
12	Wedged during iron lifting	0.6246	0.5494	valid
13	Stubbed during transportation	0.6930	0.5494	valid
14	Slipped during installation	0.7212	0.5494	valid
15	Mixer, concrete pump movement hazard	0.0451	0.5494	invalid
16	Hit by concrete pump pipe	0.6026	0.5494	valid
17	Stroke/ splashed by concrete material	0.7212	0.5494	valid
18	Dust and cement material inhalation	-0.6946	0.5494	invalid
19	Stroke by mold material (from the same height)	0.6246	0.5494	valid
20	Slipped during installation	0.7493	0.5494	valid
21	Hit/ stabbed during installation/ dismantling	0.7212	0.5494	valid
22	Fell (person) during dismantling at height	0.6246	0.5494	valid
23	Injured hand during polywood installation	0.6930	0.5494	valid

Risk Variables		r computation	r table	Remarks
24	Fell from height during table foam installation	0.7493	0.5494	valid
25	Dust splash on eyes during polywood cutting	0.9442	0.5494	valid
26	Blistered hand due to iron direct contact	0.7212	0.5494	valid
27	Splashed during iron cutting	0.7212	0.5494	valid
28	Wedged during iron lifting/ putting	0.6930	0.5494	valid
29	Slipped/stubbed iron during installation	0.6246	0.5494	valid
30	Fell from height during reinforced installation	0.6930	0.5494	valid
31	Reinforced/stroke by mold material during Tower Crane erection process.	0.7493	0.5494	valid
32	Dislocated material drop down	0.6246	0.5494	valid
33	Tower Crane material hit	0.7212	0.5494	valid
34	Fall hazard for vibration/ concrete check	0.6930	0.5494	valid
35	Stroke/hit by concrete pump piping	0.7493	0.5494	valid
36	Stroke/splashed by concrete material	0.6246	0.5494	valid
37	Cement material fell/splashed	0.7493	0.5494	valid
38	Eye/respiratory disorder during blower area cleaning	0.0885	0.5494	invalid

Table 4 contains 32 valid variables and 6 invalid variables since their r computation was less than r table. Those variables were number of 3,6,9,15,18 and 38 in which should be eliminated for having no correlation to the item total scores. The reliability test found 32 reliable validated variables with Cronbach's Alpha value of 0,965, thus Cronbach's Alpha was larger than r table values.

3.2 Risk assessment under FMEA method

Risk assessment under the FMEA method comprised of 32 valid variables, derived from validity and reliability tests, added with seven additional interview result variables. Thus there were a total of 39 assessment variables. The risk assessment results were presented in Table 5.

The severity, occurrence, and detection average values for each variable applied the following formula:

$$\text{Average} = \frac{\text{Total S/O/D values of all respondents}}{\text{Total respondents}} \quad (1)$$

The FMEA method assessment from 36 risk variables resulted in 6 Critical and High-risk variables measured from their severity and Occurrence levels through the Criticality

matrix FMEA Diagram. Accident risk variable with the highest RPN values was fell from a height during reinforced installation with 350.96 RPN. While the lowest RPN value variable was of an accident during heavy equipment mobilization of 20.18. The highest risk rank was presented in Table 6.

Table 5. Discover the RPN value.

Risk variables		S	O	D	RPN	Rank
1	Accident during heavy equipment mobilization	3.03	3.16	2.11	20.18	39
2	Hit by excavator during excavation	7.14	1.97	3.22	45.28	29
3	Slipped on graving	8.22	3.03	6.81	169.39	7
4	Underground electrical shock during excavation	4.97	2.14	4.22	44.77	30
5	Buried by landslide	7.22	4.00	6.81	196.59	6
6	Stroke by pole during lifting	5.14	2.16	4.16	46.21	28
7	Slipped on graving due to land condition	4.05	4.05	3.22	52.86	20
8	Hearing disorder	2.97	6.73	1.49	29.74	35
9	Blistered hand due to iron direct contact	3.16	6.95	2.30	50.46	25
10	Wedged during iron lifting	4.22	5.70	2.14	51.34	23
11	Slipped into foundation raft ironing	4.24	3.84	4.11	66.90	15
12	Stubbed during transportation	4.16	4.11	3.19	54.53	17
13	Slipped during installation	3.11	4.27	4.11	54.52	18
14	Hit by concrete pump pipe	4.97	3.27	3.22	52.31	21
15	Stroke/ splashed by concrete material	5.08	3.16	3.19	51.24	24
16	Stroke feet due to scaffolding material installation	3.16	4.27	5.08	68.61	13
17	Slipped during installation	3.68	5.32	3.24	63.47	16
18	Hit/ stabbed during installation/ dismantling	4.14	3.92	3.32	53.87	19
19	Scaffolding material fell (from height)	7.41	6.41	6.24	296.15	3
20	Fell (person) during dismantling at height	8.54	4.46	7.19	273.81	5
21	Injured hand during polywood installation	3.24	4.14	3.14	42.05	31
22	Fell from height during table foam installation	8.86	5.41	6.30	301.76	2
23	Dust splash on eyes during polywood cutting	2.54	5.16	2.14	28.00	36

Risk variables		S	O	D	RPN	Rank
24	Blistered hand due to iron direct contact	2.32	5.22	2.22	26.87	38
25	Splashed during iron cutting	3.11	7.32	2.16	49.22	26
26	Wedged during iron lifting/ putting	3.03	6.97	3.24	68.46	14
27	Slipped/ stubbed iron during installation	3.05	5.86	2.89	51.80	22
28	Fire on work area due to iron welding or cutting	5.19	1.86	4.86	47.08	27
29	Electrical shocked during iron welder or cutter operation	7.30	1.73	3.22	40.60	32
30	Fell from height during reinforced installation	9.08	4.24	9.11	350.96	1
31	Reinforced/ stroke by mold material during Tower Crane erection process.	8.97	4.05	8.14	295.93	4
32	Dislocated material drop down	7.19	3.05	3.27	71.80	12
33	Capsized, tumbled, broken sling crane fell	8.27	1.51	6.86	85.93	11
34	Tower crane material hit	7.14	2.35	5.16	86.61	10
35	Fall hazard for vibration/ concrete bucket check	8.22	2.19	6.14	110.35	8
36	Collapse floor during floor/ shaft plate casting	8.86	1.57	6.27	87.13	9
37	Stroke/ hit by concrete pump piping	5.08	1.78	4.30	38.95	33
38	Stroke/ splashed by concrete material	5.16	2.22	2.97	34.01	34
39	Cement material inhalation/ attachment	4.22	3.89	1.70	27.94	37

Table 6. Types of dominant risk variables.

No	Risk variables	S	O	D	RPN	Risk type
1	Fell from height during reinforced installation	9.08	4.24	9.11	350.96	critical
2	Fell from height during table foam installation	8.86	5.41	6.30	301.76	high
3	Fell scaffolding material from height during installation	7.41	6.41	6.24	296.15	High
4	Fell (person) during dismantling at height	8.54	4.46	7.19	273.81	High
5	Tower crane material hit	8.97	4.05	8.14	295.93	High
6	Buried by landslide	7.22	4.00	6.81	196.59	High

Types of occupational accident risks were noticed through critically matrix diagram by pulling the straight line between the Severity and Occurrence values, the meeting point of such lines presented the risk levels of each variable. For example: Variable: Fell from height during reinforced installation, Severity: 9.08, Occurrence: 4.24, Risk: Critical risk.

Fig. 2. Critically matrix diagram [9].

The results of risk value computation using FMEA method is a worker at height accident, while tower crane material transportation, excavation, and piling accidents were included in the recordable or highrisk incidents. The dominant risk causal analysis and mitigation should be performed to those high accident risk values.

3.3 Dominant risk causal and mitigation

Six variable dominant risks with the highest RPN values are classified to 3 occupational accident types, i.e. work-at-height, stroke by mold material during Tower Crane erection process, and landslide during excavation and piling processes.

Three accident types were observed for their dominant causal factors and mitigation performance. Occupational accident factors shall be described with the fishbone diagram used to identify any possible problem causals:

1) Work-at-height accident. Work-at-height accident causal illustrated by fishbone diagram in Fig. 3. The most dominant accident causal on work-at-height is the worker factor. It became the dominant factor based on accident data on 20 October 2017, where falling from height was caused by not applying *safety body harness*. Risk controls were presented in Table 7.

2) Stroke by reinforced or mold material during Tower Crane (TC) erection. The causal of stroke by reinforced or mold material during tower crane erection process was illustrated by fishbone diagram in Fig. 4. The dominant causal for stroke by falling material from tower crane refers to the operational method factor. It became the dominant factor based on accident data on 12 October, and 12 December 2017, where material fell incident during their lifting by tower crane was caused by excessive load, and inappropriate hook installation.

3). Buried by landslide during Excavation. The causals of buried by landslide during excavation were totally illustrated by fishbone diagram in Fig. 5. The environment was the dominant causal factors for landslide accident during excavation and piling based on accidents record in 23rd September 2017, and 22nd January 2018, where the worker fell during the excavation because of muddy and slippery earth factors. Applicable risk controls were presented in Table 8.

Fig. 3. Fishbone diagram on height-risk accident.

Fig. 4. Fishbone diagram of TC material fell risk.

Table 7. Height accident control.

Accident sub factor	Risk control
Wear no PPE (<i>Personal Protective Equipment</i>), such as safety belt or safety body harness	PPE penalty discipline to those personnel not applying complete PPE, especially for those work-at-heights with very high accident risks. Any works at above 1.8 meter height shall use safety body harness, furnished with two hooks of up or down lanyard. Penalty is imposed in case of worker failure to comply with the given admonition by deducting the relevant worker salary.
Less concentration at work	Warn or admonish the relevant worker, and let them in rest (in case of sick) for resuming their concentration.
Fatigue or health decrease	Free drug program for health service at safety corner or health clinic
Unsafe or neck action	More briefing and approach to comply with the safe procedure, such as person to person approach by QSHE
Lack of safety team control	Add safety patrol team for PPE compliance and occupational safety monitoring
Lack of SHE (<i>Safety and Health Environment</i>) training	SHE safety training, and meeting organization
Lack of safety induction and talk	More frequent safety induction and talk organization

Fig. 5. Fishbone diagram of buried by landslide risk.

Table 8. Landslide accident control.

Accident sub factor	Risk control
No hazard precaution sign	
Foggy or rainy weather to cause unstable earth	Warn or admonish the relevant worker, and let them in rest (in case of sick) for resuming their concentration.
Noise disturbing worker concentration	Wear ear plug, and always establish conducive atmosphere at each work.
flooded and slippery excavation	Drain water flooded in the excavation with water pump, and continue the work if the area returned to be conducive
No safety screen, safety net, and railing	Add safety net along the excavation work area to restrict unauthorized person access
No earth retaining wall	Construct earth retaining wall for any relative longer excavation works, for example SPT and GWT construction.

4 Conclusions

Based on the study, it can be concluded as follows. There were 18 worker or human resource risk variables, 9 operational method variables, 12 equipment variables. The highest variable RPN values were fell from a height during reinforced installation of 350.96, whereas the lowest variable RPN values were an accident during heavy equipment mobilization of 20.18. SOD multiplication presented six variables with the highest RPN values and included in high and critical range risks to allow the analysis of dominant causal risk and risk control. Accident dominant factors for work-at-height, material transportation with tower crane, buried by a landslide during excavation and piling were caused by human or worker, operational method. And environmental factors, respectively. Applicable human resources mitigation is the penalty procedure imposed on indiscipline workers with their PPE utilization. Mitigation to apply is to observe and check the hook lanyard on the material before the tower crane lifts it, and also to lift the non-excessive load. Environmental mitigation including to postpone any works in case of inappropriate weather condition. Drain water flooded, or water was entering in the excavation with the water pump.

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