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:

\[ (RPN) = \text{Severity} \times \text{Occurrence} \times \text{Detection} \]  

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

![Fig. 1. Critically matrix diagram [9].](image)

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                                |
| Table foam 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

| 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:

\[
\text{Average} = \frac{\text{Total S/O/D values of all respondents}}{\text{Total respondents}}
\]  

(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].](image)

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 (Personal Protective Equipment), 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 (Safety and Health Environment) training | SHE safety training, and meeting organization |
| Lack of safety induction and talk | More frequent safety induction and talk organization |

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**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   | Warn or admonish the relevant worker, and let them in rest (in case of sick)  |
| earth                                       | 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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