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Crane Safety Analysis and Recommendation Report

September 2009

This Report is published by the Workplace Safety and Health Council, the Ministry of Manpower and the National Crane Safety Taskforce.

EXECUTIVE SUMMARY

Background

1. In 2008, there were 162 crane-related fatalities, injuries and dangerous occurrences, a 27% increase from 128 cases in 2007. While most of the cases involve less serious non-fatal injuries, crane incidents can potentially lead to massive and severe damage to both physical properties and human lives.

Objective

2. The primary objectives for this report are to:

   a) Identify the major contributing factors for the collapse of cranes

      40 investigated cases[1] of past crane incidents were analysed using the 5M model (i.e. *Man*, *Machine*, *Medium*, *Management* & *Mission*) and several major reasons for the collapse of cranes were identified.

   b) Make recommendations to improve safety of crane operations

      Recommendations and suitable changes/improvements to improve safety of crane operations were made from lessons learnt through the 40 cases.

Findings of the Crane Safety Analysis and Recommendation Report

Summary of Analysis

3. Using the 5M model, *Man*, *Medium*, *Machine* and *Management* were found to have contributed to the collapse of cranes.

4. Among the 40 cases studied, *Man* was identified as a contributing factor for 23 cases. The main concern in this area is the violation of safety rules and regulations by individual workers. This includes bypassing limit switches, ignoring warning alarms as well as failing to check load charts and comply with safe work procedures. Other concerns include unintentional human errors and the lack of knowledge / information on the weight of the load being lifted.

5. *Machine* was a factor in 14 of the cases where machine components failed to function properly. The most common component failures are wire ropes and limit switches. Two reasons identified were the lack of maintenance and the improper use of cranes (e.g. using cranes of wrong capacity).

6. *Medium*, such as ground stability, was a factor in 9 cases. This includes grounds that were too weak or too inclined to support crane operations safely.

[1] Report were provided by Ministry of Manpower

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Ground stability can also be affected by changes in weather (such as heavy rainfall) and by other ongoing works such as excavation in its vicinity. Safety measures such as the adequate use of steel plates and constant monitoring of ground conditions were found lacking in these cases.

7. Finally, *Management* was identified in 25 out of the 40 cases studied. The various ways in which *Management* contributed to these crane collapses include the lack of site assessment, inadequate supervision (refers mainly to lifting supervisor), lack of established and implemented safe work procedures, as well as the lack of worker training.

8. This Report also identified *Management* as a key factor affecting safe operation of cranes. Besides contributing directly to the largest number of cases, it also played an influential role in the other 3 factors. It had direct control over the amount of supervision and training provided for the workers, which affected the *Man* factor. In addition, the responsibility of having regular maintenance for the crane and conducting site assessments (which greatly influenced the *Machine* and *Medium* factors respectively) lies on *Management*. Thus *Management* plays an important role in keeping our cranes safe.

Improvement areas identified

9. Based on the analysis of the contributing factors, several improvement areas were identified in this Report.

10. To address the tendencies for *Man* to engage in unsafe acts, it is important to have proper supervision. and to conduct behaviour audit checks to identify and tackle these unsafe behaviours before they lead to an incident. Crane operators must be properly informed of the load's weight and the crane's capacity before commencing any lifting operations. All personnel should be adequately trained and briefed before work. An efficient fatigue management system must also be in place.

11. The failure in *Machine* components highlights the need to ensure that all cranes are properly and regularly maintained. Record of the crane's maintenance history must be kept for reference, when needed. The industry must also make routine checks on the functionality of the crane prior to any lifting operation with particular attention for safety devices such as limit switches and warning alarms.

12. On the issue of *Medium*, it is important to conduct a proper site assessment to ensure that the ground can safely support the required crane operation before work commence. An assessment should also be carried out after any change in weather condition. If the ground condition is deemed to be unsafe or unsuitable for crane operation, *Management* must locate an alternative suitable site or undertake sufficient safety measures such as placement of adequate steel plates over the soft ground.

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13. *Management* must ensure that risk assessment is conducted prior to developing any safety measures. This would identify all potential hazards (e.g. soft ground condition) and methods to eliminate or reduce them. These safe work procedures must be developed by competent personnel. These procedures are to be communicated to and adhered by personnel involved in the crane operation. *Management* must also ensure there is adequate supervision during the crane operation and that all personnel are properly trained.

Recommendations by National Crane Safety Taskforce

14. Based on this Report, the National Crane Safety Taskforce, the Workplace Safety and Health Council (WSHC) and the Ministry of Manpower (MOM) have made recommendations to address issues related to *Man, Machine, Medium* and *Management.* The recommendations are broadly classified in three areas – training, outreach and reviewing Codes of Practice.

15. On *training*, the Taskforce will work with WSHC and MOM to improve the current training content of various mandatory courses for lifting operations. These courses will be reviewed in consultation with the industry, where appropriate. To improve the quality of delivery of the training courses on lifting operation, MOM will also strengthen the surveillance on its Accredited Training Providers (ATPs). There is also a proposal to leverage on the national WSQ framework for consistency in training provision and competency of the trainees.

16. On enhancing *outreach* efforts, the Taskforce will work with WSHC and MOM to establish appropriate joint programmes to engage top management, upstream crane manufacturers and downstream crane operators. A risk register for lifting operation will also be developed. Platforms to send crane safety messages will include newsletters for stakeholders and forums.

17. On *review of Codes of Practice*, the Taskforce, with WSHC and MOM, will participate in the review of relevant Codes of Practice, such as the CP62:1995 Code of Practice for the Safe Use of Tower Cranes. In addition, a fact sheet on Maintenance Programme is also being planned.

Conclusion

18. This Report marks the start of the Taskforce's work to improve the safety of crane operations. The Taskforce will further develop its recommendations and an implementation plan. It will also review relevant legislations and explore new technology to enhance safe lifting. The Taskforce will provide updates on its plans and progress in early 2010.

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1. Introduction

1.1 Background

As illustrated in Figure 1 below, the total number of injuries and dangerous occurrences involving crane increased from 128 in 2007 to 162 in 2008, an increase of almost 27%.

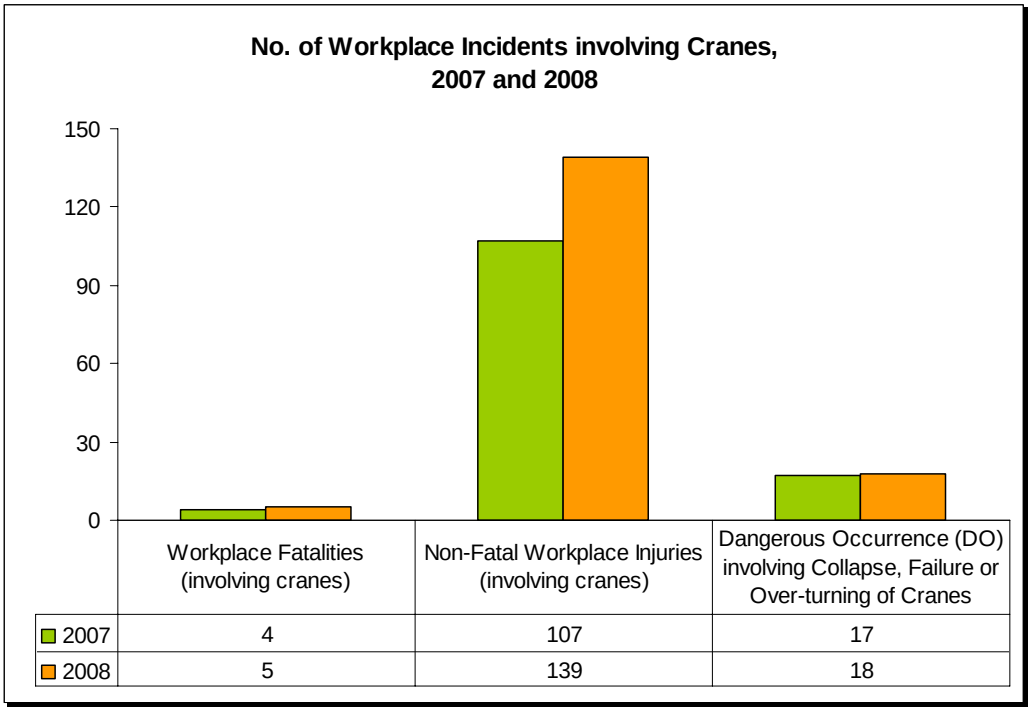


Figure 1: Number of workplace incidents involving cranes for 2007 and 2008

Even though most of the increase came from non-fatal injury cases, it is important to note that crane incidents can potentially cause massive and severe damage to both physical property and human lives. In addition, the use of cranes is extensive across many workplaces, with more than 17000 cranes registered.

Hence, the increase is a matter of concern and there is a need to analyse crane incidents and recommend appropriate prevention measures.

1.2 Present Legal Requirements

The following legal requirements relating to operations of cranes are currently in place:

1) Workplace Safety and Health Act (Chapter 354A)
2) Workplace Safety and Health (General Provisions) Regulations
3) Workplace Safety and Health (Construction) Regulations
4) Workplace Safety and Health (Shipbuilding and Ship-repairing) Regulations
5) Factories (Operations of Cranes) Regulations (will be replaced by Workplace Safety and Health (Operation of Cranes) Regulations)

Relevant codes of practice are as follow:

1) Singapore Standard SS 536:2008 Code of Practice for the Safe Use of Mobile Crane
2) Singapore Standard CP 62:1995 Code of Practice for Safe Use of Tower Crane
3) Singapore Standard SS 497:2002 Design, Safe Use and Maintenance of Overhead Travelling Crane

1.3 Objectives of This Crane Safety Analysis and Recommendation Report

The objectives of this Crane Safety Analysis and Recommendation Report are:

1) Identify the major contributing factors for collapse of cranes

   In-depth study on investigated cases related to collapse of cranes to identify the major contributing factors for collapse of cranes.

2) Make recommendations to improve safety of crane operations

   The final part of this analysis report will focus on recommendations and proposal of suitable changes/improvements to prevent the next collapse of crane.

2. Research and Analysis

2.1 Definitions

The following definitions will apply in the context of this Crane Safety Analysis and Recommendation Report:

2.1.1 Cranes

The crane in this Crane Safety Analysis and Recommendation Report refers to, but not limited to, the following:

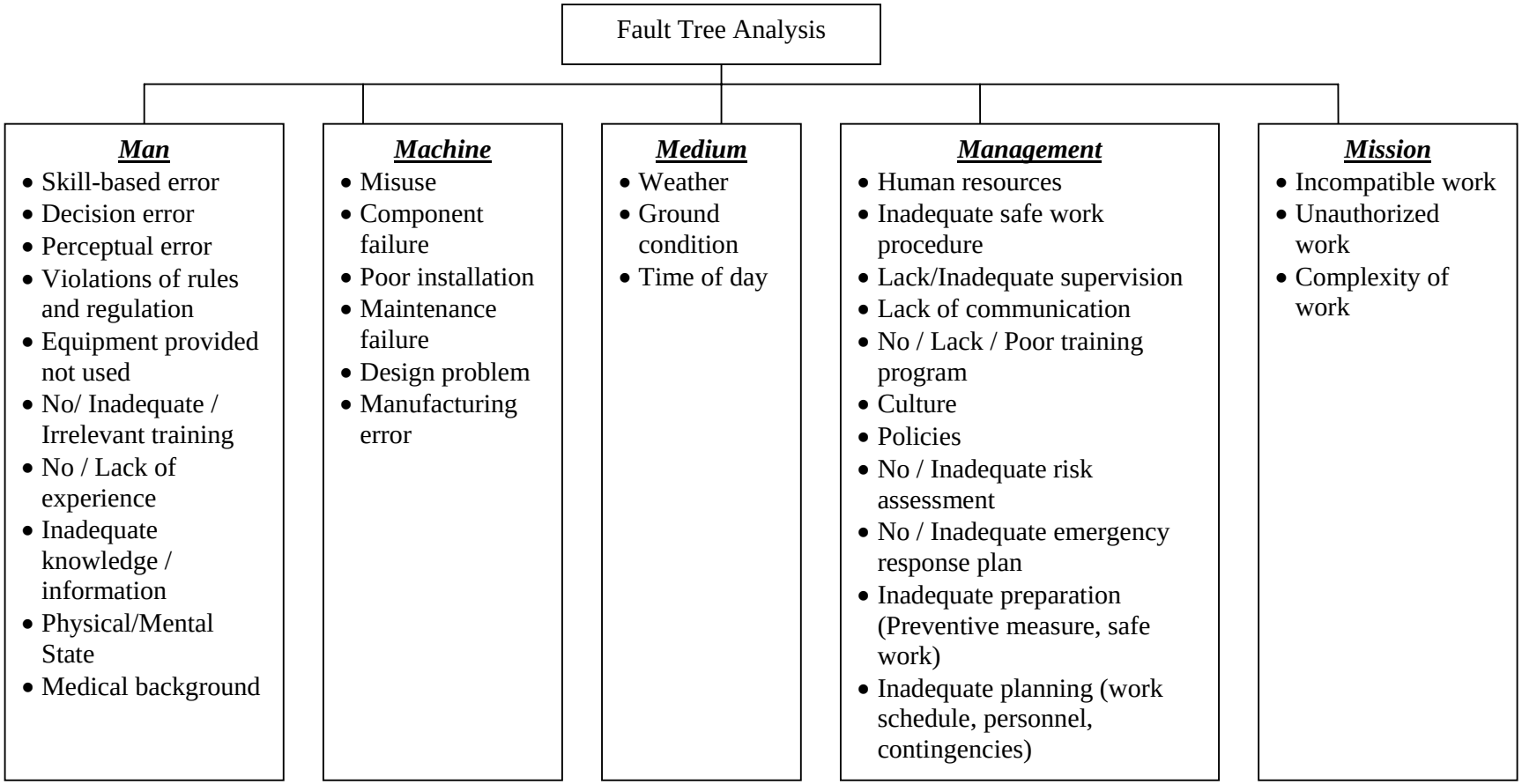
- Crawler crane
- Floor crane
- Mobile crane
- Overhead crane
- Tower crane
- Truck mounted crane

2.2.2 Collapse of cranes

Collapse of cranes in this Crane Safety Analysis and Recommendation Report refers to the collapse or failure of crane, derrick, winch, hoist, piling frame except chain/rope sling. In addition, collapse of the boom and toppling of the crane are also included in this report.

2.2 Fault Tree Analysis

The following fault tree analysis was utilized to identify the causal factors for the collapse of the cranes.



* Factors listed under each branch are the possible causes for the collapse of cranes

2.3 Contributing Factors Leading to Collapse of Cranes at Workplace

In the analysis of factors leading to the collapse of cranes, 40 investigation reports[2] of past crane collapse cases from 2003 to 2007 were analysed.

Figure 2 presents the distribution of contributing factors that led to the collapse of cranes.

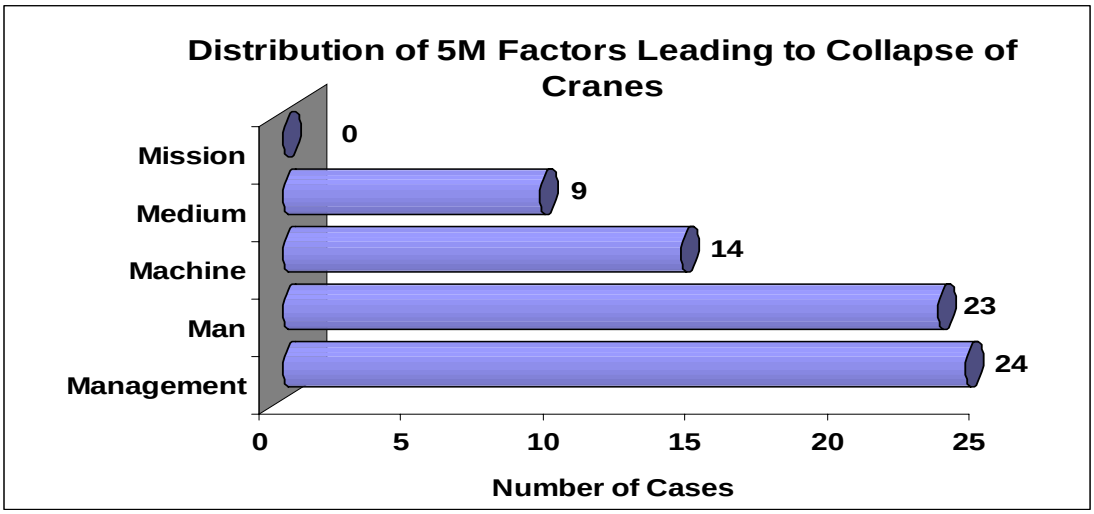


Figure 2: Distribution of 5M factors leading to collapse of cranes
***There may be more than one contributing factor in each case**

As seen in Figure 2, the significant contributing factors leading to the collapse of cranes were *Management* and *Man*, while *Machine* and *Medium* were less significant. It was also noted that no incident occurred due to *Mission* as a contributing factor. Hence the analysis would delve into the four factors highlighted.

[2] Reports were provided by the Ministry of Manpower.

2.4 Analysis of Identified Contributing Factors

2.4.1 *Man*

In the analysis of 23 cases of crane collapse involving *Man* (usually the crane operator), three main factors were identified using the fault tree analysis described in Section 2.2. They include inadequate knowledge / information, violation of rules and regulations and human errors as shown in Figure 3.

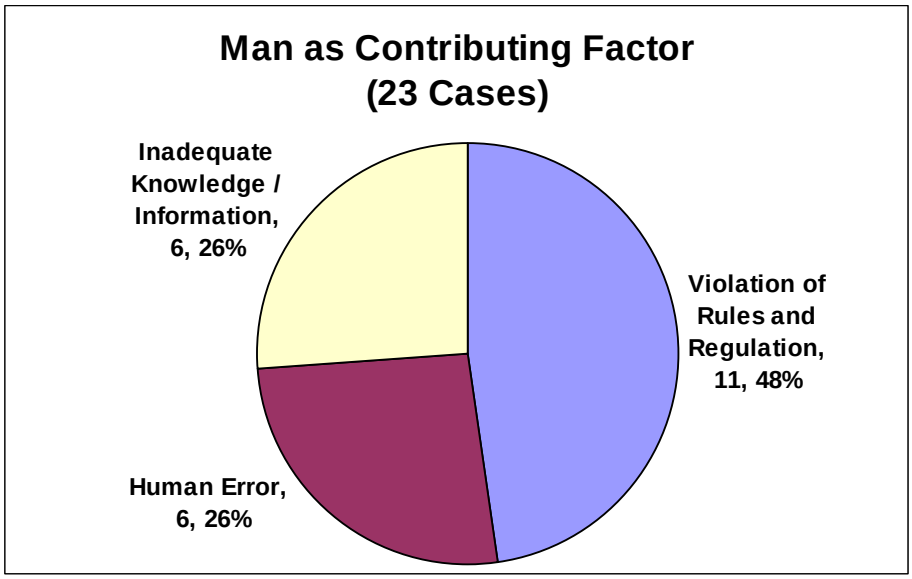


Figure 3: Reasons to why *Man* resulted in the collapse of cranes

Inadequate knowledge / information was a factor in 26% of the 23 cases. These can often be attributed to inadequate training (e.g. lifting personnel do not have the required competencies) or inadequate briefing conducted prior to commencement of work (e.g. operators being uninformed of weight of the load being lifted).

Human error constituted another 26% of the 23 cases and mostly resulted in over hoisting of the crane's boom. There were many instances of perception error where the operator misjudged the maximum allowable angle for the boom to be luffed. Other cases involved operators in poor mental and physical conditions due to fatigue.

Violation of safety rules and regulations accounted for almost half of the 23 cases. This includes bypassing of limit switches, ignoring warning alarms, failing to check allowable load charts and not complying with safe work procedures.

Further analysis into the above three factors showed that overloading was a key problem. 14 out of the 23 *Man*-related cases were due to cranes being overloaded. Please refer to Figure 4.

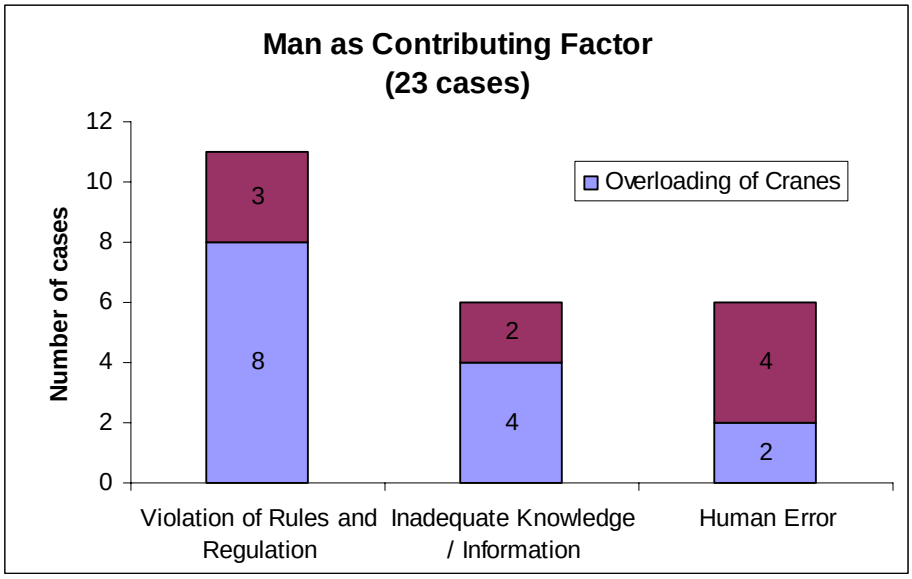


Figure 4: Overloading in *Man* factor leading to collapse of cranes

Figure 5: Collapse of crane due to overloading

Reasons to why *Man* caused the collapse of cranes include:

- Violation of Rules and Regulation
- Inadequate Knowledge / Information
- Human Error

These commonly lead to overloading of cranes, resulting to their eventual collapse as reflected in the 14 cases of overloading among the 23 cases with *Man* as contributing factor.

2.4.2 *Machine*

Machine contributed to the collapse of cranes through component failures. Components which had failed include warning alarms, brake system, wire ropes, limit switches and structures. Figure 6 below shows the distribution of different component failures for the 14 cases involving *Machine* failure.

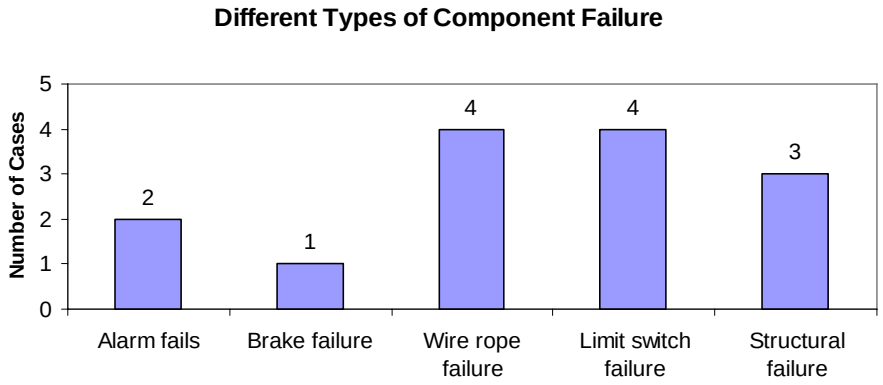


Figure 6: Different Types of Component Failure

From Figure 6, it could be seen that the components which failed more frequently were wire ropes and limit switches. Hence, more attention should be given to upkeep the condition of these components.

A common reason for component failure was the lack of maintenance. Out of the 14 cases of machine failure, half of them were maintenance-related. This further emphasized the importance of ensuring thorough and regular maintenance for cranes, with proper maintenance record for every crane.

Besides having proper maintenance, failure of machine can be avoided if operators adhered to the proper use of cranes. This can be illustrated by one of the cases studied, which involved failure of wire rope. In this particular case, a crane with incorrect capacity was used to extract a casing imbedded in the ground (Figure 7). During the lifting operation, the friction between the imbedded casing and the earth subjected the wire rope to a load greater than its capacity and resulted in the crane's collapse. This incident could have been avoided if a crane with a larger load capacity was utilised instead.

Figure 7: Improper use of crane

Component failures (*Machine*) identified in the collapse of cranes include:

- Alarm failure
- Brake failure
- Wire Rope failure (high frequency)
- Limit Switch failure (high frequency)
- Structural failure

Lack of maintenance and improper usage of cranes were the main contributors of these component failures.

2.4.3 *Medium*

Medium of the workplace was the contributing factor for 9 of the 40 cases studied. A breakdown of these 9 cases is shown in Figure 8 below.

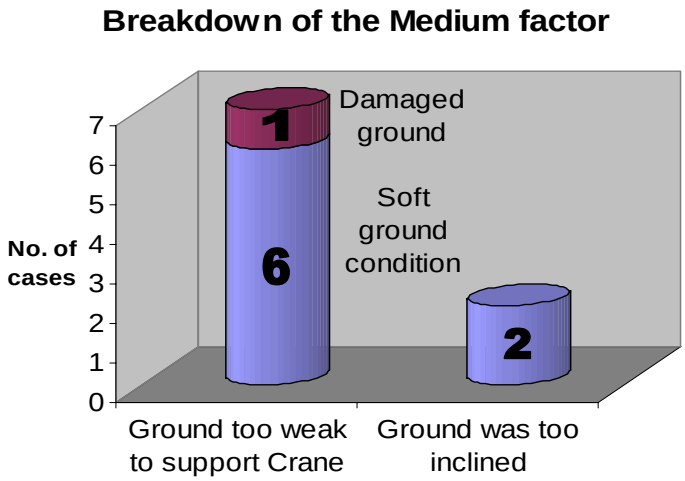


Figure 8: Break down of the 9 incident cases where *Medium* is a contributing factor

Weak/soft grounds and excessively inclined worksite were the reasons attributed to *Medium* in the collapse of cranes – see Figure 9. Figure 10 shows the inadequate use of steel plates for crane operations on weak/soft ground.

Figure 9: Collapse of crane due to soft ground condition

Figure 10: Collapse of crane due to inadequate steel plates coupled with soft ground condition

Medium as a contributing factor may suggest that the work site is unsuitable for work. However, with proper implementation of safety measures and work procedures, these incidents can be avoided. Proper ground assessments must be conducted prior to the setting up of the crane and the start of lifting operation. Besides the actual ground condition, it is also important to check for other works nearby. For example, excavating works near the lifting site may compromise the stability of the ground.

Half of the incidents (3 out of 6 cases) attributed to weak ground conditions were caused by softening of ground due to wet weather. Thus, it is also important to have additional ground assessment whenever there is a change of weather.

Medium contributed to 9 out of the 40 cases in this study. Unsuitable ground conditions (soft/weak or inclined ground) could not safely support crane operations.

The incidents mentioned in this section can be avoided by:

a) Selection of proper work site through adequate ground assessment prior to start of work or after a change in weather condition.
b) Putting in place adequate and appropriate measures if the ground was assessed to be unsuitable.

2.4.4 *Management*

Management [3] was the largest contributing factor for the collapse of cranes, accounting for 25 of the 40 investigated cases. Please see Figure 11 for a break down of the areas where *Management* contributed to the collapse of cranes.

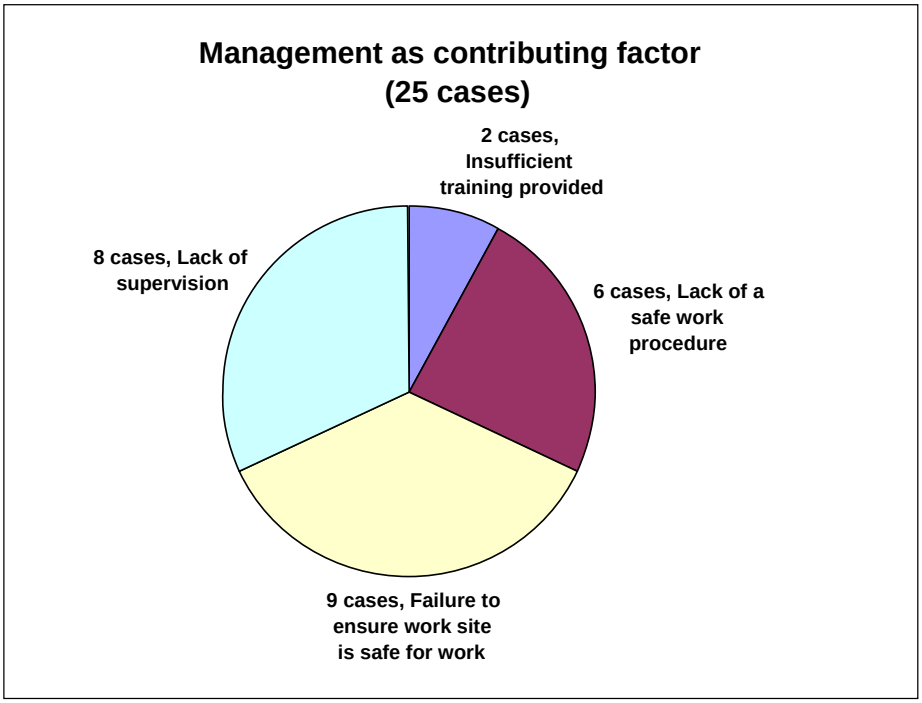


Figure 11: Reasons *Management* contributed to the collapse of cranes

2.4.4.1 *Management (supervisor)*

Under *Management (supervisor)*, the most common deficiency that resulted in the collapse of cranes was its failure to ensure safe worksite for workers. The lack of proper supervision by appointed supervisors, including lifting supervisors, constituted the second highest reason for the collapse of cranes. Supervisors who perform their role well can prevent crane incidents. For example, they can ask for proper site assessment to identify and eliminate potential hazards.

Lack of supervision also provides opportunities for errant crane operators to take hazardous short-cuts and violate rules and regulations. An alert supervisor can halt crane operations for necessary rectification if he observes an abnormality.

[3] *Management* in this section also includes personnel with supervisory responsibility (e.g. lifting/site supervisors). The term *Management (supervisor)* is used to specifically denote this group of personnel.

2.4.4.2 *Management*

Another major contributor for the collapse of cranes was the lack of safe work procedures. This is the procedure that ensures a particular work can be carried out safely without compromising the safety and health of the personnel involved. Examples of these lapses include the lack of lifting procedures, inadequate planning prior to commencing work and inadequate/lack of risk assessment leading to poor work procedures.

Last but not least, there was also a lack of adequate training provided by the *Management* to the relevant lifting personnel. By not having the necessary knowledge and training, the lifting personnel will not be competent enough to carry out lifting operations safely and should not be involved in or carry out any lifting operation.

Reasons to why *Management / Management (supervisor)* caused the collapse of cranes include:

- Inadequate site assessment
- Inadequate supervision
- Lack of safe work procedure
- Inadequate provision of training

3. Summary of Analysis

Management, *Man*, *Medium* and *Machine* had contributed significantly to the collapse of cranes. While *Man*, *Medium* and *Machine* were often the direct reasons for these collapses, *Management* played an even more important, albeit indirect role.

3.1 *Man*

Man contributed to the collapse of cranes mainly through violation of safety rules. Some operators did not have relevant knowledge on lifting operations or information on the load being lifted and capacity of crane assigned. Human errors/misjudgements by operators when they over-hoisted the boom also led to cranes collapsing. This can be caused by either insufficient training or poor mental or physical conditions of the operators due to fatigue.

3.2 *Machine*

Failure of *Machine* refers to any failure in the component(s) of the crane. Wire ropes and limit switches were the common failures. These often resulted from poor maintenance or improper usage of crane. Component failures compromise the overall physical integrity of the crane, increasing the likelihood of a catastrophic collapse.

3.3 *Medium*

The *Medium* where the work is carried out has a significant impact on its operations. The risk of a crane collapse escalates significantly if any dangerous *Medium* conditions, such as unsuitable grounds are left unchecked. Unsuitable ground conditions include inclined or soft ground condition, which may be further affected by changes of weather. Proper ground assessment must be carried out prior to commencement of work and after a wet weather condition. Adequate measures must also be put in place if the site is found to be unsafe.

3.4 *Management*

Although *Man*, *Machine* and *Medium* may contribute directly to the collapse of cranes, they are frequently a manifestation of the fourth and the most important factor – *Management*. As *Management* is frequently not perceived as the direct cause in the collapse of crane, its role may not be obvious. However, *Management* was often found to be the main driving force behind the incidents analysed in this report.

Management (supervisor) often do not conduct proper site assessment and put in place sufficient safety measures to overcome any unsafe ground conditions identified. In addition, lack of supervision by the *Management (supervisor)* could also result in violation of safety rules. It is the *Management's* responsibility to put in place adequate safe work procedures (e.g. lifting procedures) and to ensure that these procedures are communicated to and adhered by the lifting crew. Last but not least, it is also the *Management*'s responsibility to provide adequate training for workers and ensure that they are competent before they are allowed to be involved in the lifting operation.

4. Improvement areas identified

4.1 *Man*

- *Man* (mainly crane operator) should not violate rules and regulation (e.g. bypassing limit switches, ignoring warning alarms and not complying with safe work procedure). The tendencies for *Man* to engage in these unsafe acts can be effective reduced via proper supervision as well as conduct of behaviour audit checks to identify and tackle these unsafe behaviours before they lead to an incident.

- *Man* (mainly crane operator) should not use safety devices, such as warning alarm, to "weigh" the load being lifted. The operator must be informed of the weight of the load.

- *Man* (mainly crane operator) should, through the use of the crane's load chart, ascertain that the weight of the load being lifted is within the crane safe load capacity before commencing any lifting operations. Operators must never lift a load of unknown weight.

- *Man* should be adequately trained and briefed to ensure their competency in carrying out crane operations safely. This could be achieved through provision of effective and relevant training to the lifting crew and conduct of safety briefings on the lifting operation prior to start of work.

- An efficient fatigue management system must be in place to ensure that crane personnel (particularly operators) are mentally and physically fit for work.

4.2 *Machine*

- All cranes are to be properly and regularly maintained. Record of the crane's maintenance history should also be meticulously kept and made available for reference whenever needed.

- Routine check on functionality of the crane should be carried out prior to any lifting operation with particular attention for safety devices such as limit switches and warning alarms. This routine check can be facilitated and its thoroughness ensured through the use of a checklist.

4.3 *Medium*

- Prior to carrying out any crane operation, proper site assessment must be done to ensure that the ground can safely support the required operation.

- Soft ground condition can be an inherent nature of the worksite or a result of wet weather conditions. Hence, site assessments should also be carried out after any change in weather condition.

- If condition of *Medium* is deemed to be unsafe or unsuitable for crane operation, *Management* must either:

    a) locate an alternative site which is suitable for the operation; or
    b) undertake sufficient safety measures (e.g. placement of adequate steel plates over the soft ground) to ensure that the safety of the crane operation will not be compromised

4.4 *Management*

- Risk assessment should be conducted prior to the development of safe work procedures. This would identify all potential hazards (e.g. soft ground condition) and methods to eliminate or reduce them can then be incorporated into the safe work procedure. For example, properly and adequately placed steel plates could be used to mitigate soft ground conditions.

- Safe work procedures, especially for lifting process, should be developed by competent personnel. These procedures are to be communicated to and adhered by personnel involved in the crane operation.

- Important points to take note of when devising safe work procedures include:

    - The need to determine weight of the load and to ensure suitability of the crane before lifting commence.
    - During lifting, safety devices should never be overrode (e.g. safety alarms, limit switches) unless in an emergency situation.
    - Weather can affect the crane operation and should be taken into consideration. This includes carrying out ground assessments after wet weather condition.

5. Recommendations by National Crane Safety Taskforce

To enhance safe operation of cranes, the National Crane Safety Taskforce, with the Workplace Safety and Health (WSH) Council and the Ministry of Manpower (MOM), has made several recommendations. They will embark on several joint initiatives to improve crane safety, some of which are described below:

5.1 Enhancement of Training

The Taskforce, WSH Council and MOM will embark on a joint effort to improve the current training curricula of various mandatory courses for lifting operations, particularly those for lifting supervisors, crane operators, riggers and signalman. These courses will be thoroughly reviewed, with the participation and consultation with the industry, where appropriate. The course content on risk assessment and the responsibility of various personnel will be enhanced.

There is also a need to improve the quality of delivery of the training courses on lifting operation, to ensure uniformity of competency of the lifting personnel. MOM will strengthen the surveillance on its Accredited Training Providers (ATPs). Actions will be taken against errant ATPs. There will be closer auditing and enforcement on the quality of trainers, relevance of practical training equipment, appropriate mode of course delivery, and good standards of test and examination. There is also a proposal to leverage on the national WSQ framework for consistency in training provision and competency of the trainees.

5.2 Enhancement of Outreach Efforts

The Taskforce, with WSH Council and MOM, will establish appropriate joint programmes to enhance outreach efforts to top management, upstream crane manufacturers and the downstream crane operators.

A risk register for lifting operation will also be developed. It will incorporate crane safety messages, case studies, and newsletters for stakeholders. The current engagement platforms such as ProBE and crane seminars will also be enhanced.

5.3 Review of Codes of Practice

The Taskforce, with WSH Council and MOM, will participate in the review the relevant Codes of Practice, in particular CP62:1995 Code of Practice for the Safe Use of Tower Cranes (led by SPRING). In addition, a fact sheet on Maintenance Programme is also being planned.

6. Conclusion

This Crane Safety Analysis and Recommendation Report highlighted how different factors could lead to the collapse of cranes and provided some learning points to reinforce safety for our crane operations.

Recommendations have been made to improve crane safety based on these learning points, with the initial plans outlined in Section 5 of this report. The National Crane Safety Taskforce will further develop its recommendations and implementation plan. It will also review relevant legislations and explore new technology to enhance safe lifting. The Taskforce will provide updates on its plans and progress in early 2010.