Countermeasure for Construction Machinery Produced using 5Why Technique

Dong Gil SHIN[#1], Seung Il LEE[#2], Ki Sang SON[*3]
[#] General Manager Q-HSE Management Div. (Strategy and Planning) ,SAMSUNG C&T, Korea
[1] clvud@samsung.com
[#] Seoul National University of Science & Technology, Seoul, Korea
[2] qqqtema@gmail.com
[*] Seoul National University of Science & Technology, Seoul, Korea
[3] ksson@seoultech.ac.kr

***Abstract*-A variety of perspectives and opinions on the causes of construction machinery-related accidents were collected through a questionnaire survey and direct interviews with management supervisors, operators, etc. The accident causes will be analyzed using 5Whys technique for major construction machinery disaster case. Improvement ideas will be suggested with an aspect of technical training, management system in the study. In the case of tower cranes, some of the risk factors are being neglected in formal inspections. The reliability of the maintenance performed by rental companies is low. Moreover, in the case of big cranes, unsatisfactory installation and dismantling teams with insufficient expertise can be assigned to sites. There is no process for checking this onsite and management supervisors may just neglect the safety supervision of the installation/dismantling work due to insufficient experience. Excavator accidents cannot be eradicated, e.g. with buckets falling due to the lack of fixing of the bucket's safety device during operation. Crashing and jamming accidents involving workers and excavators have occurred due to the lack of placement of full-time guiders and the lack of excavator control around the sites.**

Keywords-Construction Machinery, Countermeasures, History Record, Height Operation, 5Why Technique

I. INTRODUCTION

In 2013, the Industrial Accident Statistics of the Korean domestic construction industry reported the total number of disaster victims as 22,801, including 516 deaths. 98 of the casualties (which represented a relatively high proportion of 19%) worked with construction machinery. Construction unions affiliated to the KCTU (the Korean Confederation of Trade Unions) indicated that construction machinery accidents occurred daily and were more serious than anticipated. Around 2,000 persons are involved in work accidents related to construction machinery each year, and it is considered that around 130 persons a year die from construction machinery, directly and indirectly [1].

Thus, the increasing number of construction machinery accidents on construction sites is related to the lack of awareness of construction machinery accidents and of management alternatives in the construction industry.

Due to the lack of expertise related to this type of machinery, there is a lack of suitable measures beyond merely technical ones. Therefore, similar accidents occur every year.

This study analyzes the existing accident causes and suggests essential accident prevention measures and other approaches to solve this problem.

The reoccurrence of the same or similar accidents on sites has not been effectively prevented. There is a need to find the essential causes of accidents related to machinery operation and to take preventive measures. However, for short-time use, people only take superficial measures. Measures are only taken for administrative reasons, without a consideration of certain essential factors. Eventually, this leads to the same accidents happening over and over again.

Having carried out practical safety management tasks in the construction industry for a long time, the authors of this study set out to apply the 5 Whys technique to conduct a root cause analysis [3] focusing on construction machinery and based on related accidents. Once the root causes of the accidents are identified, practical preventive measures can be suggested.

This study aims to suggest ways to prevent accidents related to the operation of machinery on construction sites. Tower cranes, excavators, mobile cranes, dump trucks, vehicle-mounted equipment operating at a height, and aerial work platforms have recently become a social issue as they have been causing serious accidents.

Frequent accidents have been occurring from the operation of the above equipment on sites.

II. METHOD

A. Introduction to Accident Cause Analysis Using 5 Whys Technique

1) Definition of 5 Whys technique

This technique was applied to the case of the Toyota, Sakichi Toyoda car in the automobile industry. **To solve a quality problem occurring in the car production process, the 5 Whys technique was applied** by just repeating "Why" five times not only to solve the problem but also to clarify the essence of the problem [2].

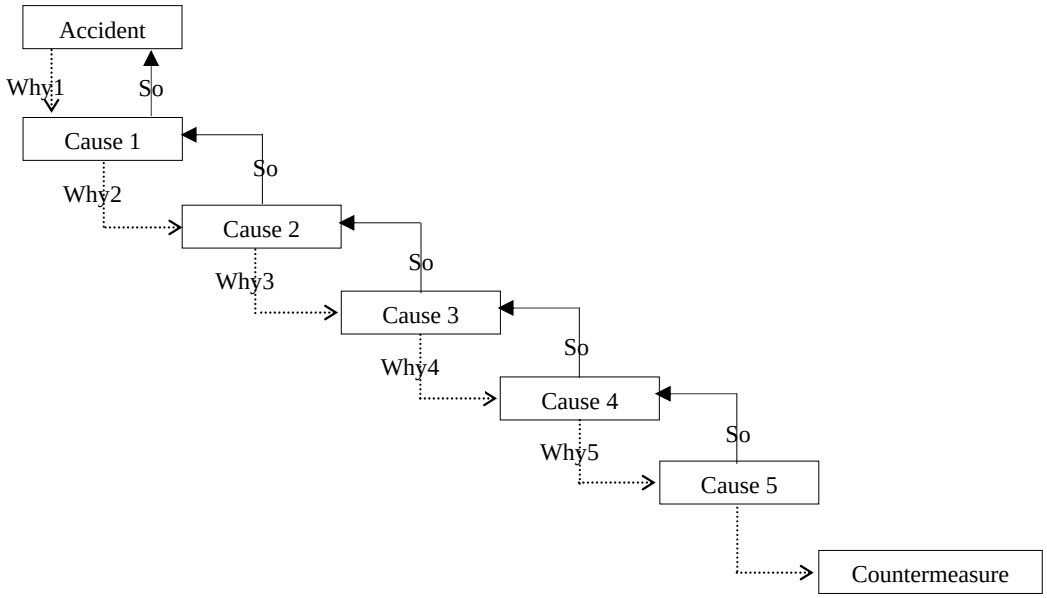

Fig.1. Whys Progress and Verification Procedure

There are some differences between a quality problem and the safety problem examined in this study to suggest a solution method and seek root causes. The 5 Whys technique needs to be used as a tool to find the root causes of main construction machinery accidents.

2) Applying the 5 Whys technique

Before the inspector asks about the root cause, there is sometimes a trend that stops an analysis in some symptom. For this, the inspector or manager needs to give each other mutual support and to pay continuous attention in order to analyze the problem successfully. A policy has to be drawn to guarantee that no penalties will come with the result. Depending on the inspector's knowledge level, we can limit the number of steps needed to identify the root cause. We have to seek to improve the level through repetitive case studies and by enforcing special training for the inspectors.

In the case of repeated analyses of the same problem with the 5 Whys by different people, another cause may be found. A different result may be obtained depending on the point of view, tendency, or situation. Therefore, the cause-and-effect relationship should be checked for each step of the Whys. A process is needed to double-check the final root cause. Namely, begin with the countermeasure and check the step-by-step cause-and-effect relationships up to the accident [3].

B. Application Process of 5 Whys technique

1) Stage-by-stage safety accident occurrence (domino theory of Heinrich) and relation to the 5 Whys

It shows the accident occurrence process according to Heinrich's domino theory. The analysis method illustrated here is closely related to the 5 Whys. Namely, the 5 Whys seek a precedent factor for an indirect cause (4M) in relation to the direct cause of the accident, which can be diagrammatized. It takes the form of a diagram in which the 5 Whys can help to identify the behind-the-scenes factors for the unsafe actions & conditions of the 4M (Machine, Media, Man, Management). The root cause should be checked for each step of the questioning process.

2) Application process of 5 whys technique

2-1). Definition of accident (Problem)

As the first step in the 5 Whys technique, we need to gather details about the features of the problem, including its size, location, and time of occurrence. A simple and clear definition of the problem should be formulated. Considering the dump truck case, “The dump truck did not start.” is the definition of the accident (problem).

2-2). Step Why 1

This step is used to find the direct cause of the unsafe action and condition that caused the problem or accident. Namely, various verification checks for the direct causes of the inability to start the dump truck, such as "The car battery was worn out.”, should be made to find why the truck did not start. Changing the battery can be a countermeasure at this step, but the truck might turn off soon again as this is not the root cause. it shows the logic for this.

2-3). Steps Why 2 ~ 5

This process aims to find the root cause through more detailed questions and answers. In this process, similarly to step Why 1, the procedure is checked through hypothesis checking. Each cause prior to the Why 5 step is checked, and the procedure can be concluded at this step once the suggested countermeasure appears to be suitable.

If a countermeasure is produced for a root cause, then it should be checked for reasonability. New evaluation standards for feasible countermeasures should be designed if the produced countermeasure does not prevent accidents or reduce their effects. After verifying it, it must be clearly decided with the staff group’s agreement who will push this countermeasure forward and when.

If the problem is related to two or more root causes, then each root cause needs to be identified in order to prepare optimal countermeasures, and a priority order must be decided for the application of the countermeasures.

III. RESULTS

A. Tower crane

1). Conducting an operational performance inspection to iron out danger factors

There is no legal obligation to inspect cranes before operating them on sites. Rental companies do not really conduct proper inspections. They merely fill out check lists for themselves, and do not manage the records properly. The danger factors arising from this neglect eventually lead to accidents, as no checks of the main structural parts are conducted to verify whether the welding parts present any defects such as cracks, overlaps or undercuts.

Moreover, the machinery should be autonomously checked for performance by the construction company and the rental company during the operation and after installation, and legally, a test should be made every 6 months. However, generally the machinery is not satisfactorily checked for the operation of a safety device or any defect on the main structure.

2). Low level of tower crane maintenance reliability

Rental companies must continue to operate a maintenance system for the parts-changing period according to the method recorded in the operation manual of the tower crane produced by the manufacturer. However, there is insufficient maintenance reliability in the industry. This causes severe potential hazards and breakdowns due to the application of breakdown maintenance instead of preventive maintenance. Table I presents a review of the status of maintenance management in domestic rental companies. It was verified that the maintenance conditions for the facilities of the majority of rental companies are not satisfactory.

Moreover, although two cranes may be of the same type and may have been manufactured in the same year, the aging condition is not easily determined. It is difficult to check the safety conditions without appropriate record management of the use history.

TABLE I. Maintenance status of rental companies' records for actual tower crane conditions

division	T Co.	S Co.	K Co.	A Co.	G Co.
Maintenance facility	297㎡	370㎡	-	-	680㎡
Maintenance personnel	2person	7person	-	1person	4person
Maintenance range	small maintenance	medium maintenance	-	small maintenance	small maintenance
Maintenance use history	management	management	-	-	management
Car number	45EA	101EA	60EA	65EA	31EA

3). Poor installation/disassembly work teams' professionalism and problem of career management

Domestic installation-disassembly work teams comprise around 80 teams and 400 workers. This represents insufficient manpower to cover all of Korea. Therefore, workers are assigned to sites without proper checks of their skills, experience, or any age-related problems.

4). Carelessness of installation-disassembly safety supervision

It is thought that construction management supervisors' competencies in terms of installation-disassembly work are insufficient. No practical safety management guidelines matched with the work attribution have been produced. The danger factor in the work process varies with the work and the site conditions. As part of the planning and checking of construction sites, the work environment should be reviewed before initiating the work. Moreover, a quick-starting/quick-finishing work process can increase the risks of accidents or hazards on sites.

B. Excavator

1). Badly fixed safety device

For operators' work convenience, it is thought that safety pins are sometimes not connected to the oil pressure coupler which is fixing the bucket of the excavator. There is a high risk of worker injury due to a sudden fall of the excavator's bucket during work. There is a quasi-lack of safety training for operators and no checks by management supervisors.

2). Poor worker control in operating radius and no assignment of full-time guider

There is almost no worker control zone in the excavator-operating radius to prevent contact between workers and excavator. Accidents such as jams of crashes have occurred close to workers when the excavators went back or rotated without the arrangement of a guider. There are more potential hazards that may occur when the excavator moves backwards.

3). Used for different purposes

Excavators are widely used for excavation work on construction sites. But they are also used for other purposes, such as placing small-size concrete, installing boundary stones, conveying material or shifting pipes, planting trees, and so on. There are no legal safety standards for these subsidiary uses of excavators, and a high proportion of accidents can occur due to poor management and supervision on sites.

C. Mobile Crane

1). Poor work planning prior to investigation, and work departing from original planning

Cranes can be overturned during operation due to ground unsettlement or support collapse as a result of poor advance investigation of the ground conditions. The crane capacity can be a reason for overturning when lifting a heavy load. Specialists should conduct thorough advance checks of the capacity for any inadequate items. It is believed that there is not only a lack of professionalism among management supervisors, but also that management supervisors' awareness of workers' safety is inappropriate.

2). Signal system not established and insufficient manpower for full-time signal man

Article 40 of the Occupational Safety and Health Guidelines provides that "The owner shall make a signal system for the operation of the crane, and operators shall have to follow the signal". Nevertheless, there is a high potential for hazards from inconsistent signaling due to incompetent full-time signal men, or from the non-establishment of signal systems on sites. In particular, there is no training course for signal men, so they have no choice but to make up their own signal system at work.

3). Inadequate use of lifting tool

A lifting tool is a subsidiary tool used to convey work more easily and more safely and to connect the lifting material to the rope sling, chain sling, ring, hook, shackle, and so on. The lifting tool is a tool for rigging work.

It is an important component of a safe lift load by a crane and a proper lifting tool should be selected in advance according to the shape and weight of the load. The safety conditions need to be checked at all times before and during the work. When the lifting tool is selected in advance, proper checks are not carried out with consideration of safety factors. This leads to numerous accidents, such as slings breaking in the lifting process.

4). Removal of protective device

As per the above-mentioned compulsory items to apply according to the Occupational Safety and Health Guidelines rules about protective devices or cranes, protective devices comprise the following: “overload limiter, overwrap limiter, emergency stop equipment, break equipment, safety valve, hook removal equipment, slope-fixing device, stick device from storm and rotation-preventing part” .

Nevertheless, accidents continue to occur on sites despite their being equipped with many kinds of prevention devices. This is due to the removal or deteriorated conditions of those devices resulting from the absence of safety awareness and working standards on sites. Operators’ poor management and the lack of professionalism of management supervisors can cause accidents even when the protective items have been found to be in inadequate condition by a specialized organization.

5). Performance inspection test

When mobile cranes are imported, management supervisors should check the functional abnormalities of the cranes and verify that the work plan is consistent with previous work.

If an inadequacy is identified, the crane operation should be stopped. If an operator or supervisor with a lack of management expertise or insufficient formal implementation conducts his work on sites without inspections, then a functional problem can occur during operation of the equipment. Regular inspections and appropriate safety checks should be performed at any time.

6). Maintenance reliability problem

According to the Construction Machinery Management Act, construction machinery should be inspected every 1-3 year cycle, periodically after registration, and when 20 years have elapsed. The first year cycle requires regular inspection but the aging condition of the equipment cannot be checked objectively with a visual inspection only.

In the case of mobile cranes and tower cranes, there are some differences to a degree. But there is low maintenance reliability in the case of small rental companies, as their history records are not properly maintained.

IV. ANALYSIS

A. The Technical Aspect

1). Maintenance requirements for construction machinery and obligation to keep records

The replacement of parts of tower cranes by the rental company in accordance with the operating manual issued by the crane manufacturer should be performed and recorded, and should be conducted periodically.

Before operating or installing equipment on a site, maintenance should be conducted for the main length of use, and it should be carried out more than one month prior in the case of oil, electricity or hydraulic equipment, etc.

For the maintenance of rented equipment, the safety and reliability of the machine should be ensured according to the historical management data. The historical management data of rental companies should be improved continuously in accordance with the Construction Machinery Management Act.

2). Perform effective inspection to get rid of dangerous factors

Before installing tower cranes on sites, the technical experts working for the contractor should check them before importing them to the site to allow for aggressive preventive measures to be taken to eliminate the risk of accidents caused by the improper use of equipment according to an internal work process. The maintenance records of the rental company should naturally be incorporated into the process.

In particular, contractors should ensure safety through non-destructive testing for major structural overhaul and weld, bolt, mast connection pins by magnetic particle inspection (MT) and ultrasonic testing (UT).

Using construction equipment, the tests should be made by experts outside the construction company or by an independent third party to conduct regular safety checks of the operating state, the main structural part, the abnormality of the electrical devices, and the records of use of the rental company. Maintenance should be performed after establishing a management system.

3). Issue guidelines for installation/disassembly time for each type of tower crane

The guidelines for the standard installation/disassembly time should be reviewed if needed. To this end, the tower crane specialists of rental companies, installation/disassembly teams, construction firms etc should set a standard operation time by collecting advice and presenting recommendations for the guidelines. These needs to be publicized and the participants to be paid proper wages accordingly.

4). Tighten inspection management and ensure professionalism of installing/disassembling tower crane work

To prevent accidents caused by unskilled, insufficiently experienced workers in the installation/disassembly team, the construction company should enforce a process check by type of installation expertise, so that each operation is in accordance with the internal standards.

It is also suggested that the supervision of the installation/disassembly work be enforced by a third-party supervisor in order to benefit from the experience of full-time engineers.

In addition, it is not only a problem of years in relation to the strength of the actual equipment, but strengthening of the management should also be considered to make for a reasonable use history.

5). Develop sensors to prevent jamming

The Construction Machinery Management Act was amended in 2015. Since January, 27 kinds of production, assembly or construction machines can be imported to Korea. The legal safety standards for the prevention of jamming accidents have been reinforced. A safety device allowing operators to check their rear by using a "rear view mirror" should be installed in an enclosed cab.

B. The Training Aspect

1). Enhance management level of supervisor skills through construction machinery operation training

The training center of the Korea Occupational Health and Safety Agency has operated some courses about construction machinery safety, such as for cranes, lifts, and gondolas. Those courses have contributed to giving workers the skills to ensure safety on construction sites. The training allows them to recognize hazard factors by themselves, as a parallel theoretical and practical skill about machinery safety developed through training. In the future, this type of training should be provided to more beneficiaries.

A new statutory safety training should be designed to increase the experience of management supervisors, so that they may enhance their professional skills.

2). Practical maintenance training for workers installing tower cranes

Currently, tower crane installation workers carry out their job after receiving special on-site training for 2 hours before every installation. An initial maintenance training course is provided at a professional training center under the Korea Occupational Safety and Health Agency. The safety manager organizing on-site training focuses on delivering common safety standards based on unsatisfactory experiences.

Every worker does his work on construction sites after only 2 hours of training. This is not sufficient to conduct practical work safety, particularly when undertaking rapidly–finishing work (quick start/quick finish work) in the winter time. This rapid work can make workers omit the work processes. Hence, more serious accidents might occur due to unsafe behavior. One of the solutions is to train the workers to have more professionalism. A specialized training course for installation workers is provided by training centers as a reward for contractors who pay training fees, allowing them to send in their workers every three years.

C. The Management Aspect

1). Pre-investigate mobile cranes, improve effectiveness, and design work plan

The results of the pre-survey of the workplace should be considered on sites. There should be thorough preparation to reinforce the soil in order to improve the soil capacity to protect the overturning of cranes. The working load of the mobile crane should be less than the bearing capacity of the soil at all times.

In particular, in the case of special work requiring simultaneous lifting with 2 tower cranes, a simulation should be performed in advance and the work should be checked by a specialist.

2). Prepare risk assessment training for the effective operation of construction equipment

Supervisors will conduct a risk assessment on the basis of the work plan for the construction machinery, and must conduct safety training before starting the work to make sure the workers understand the risk factors and safety measures for each work step. Contractors should also prevent accidents by performing regular supervision of the employees.

D. The System Aspect

1). Certify qualifications of signal men, guiders and rigging workers

It is mandatory for signal men, guiders and rigging worker to complete specialized training courses. The training should be conducted by a nationally-approved agency or the Safety and Health Agency. This comes as a complement to the institutional provision of essentials to remove risk factors.

2). Penalize responsible person in the case of disassembly of safety device or protective equipment without permission

Once the site safety inspection of industrial safety inspectors has been completed, active measures should be adopted to impose administrative sanctions, such as a penalty for the person in charge of the construction machinery with a hazardous machine guarding device or safety device.

V. CONCLUSION

Advancements should be made in the complicated processes of the construction industry. Construction machinery is being increasingly used, resulting in accidents with a high proportion (up to around 19% of 516 people) of deaths in 2013.

In this study, many accident cases were analyzed using the 5 Whys technique to derive the root causes of accidents related to construction machinery such as tower cranes, excavators, mobile cranes, dump trucks, and height-operating cars. Using this method, improvement measures to prevent fatal accidents were proposed.

There may be some errors due to attempts to analyze information related to accidents within a limited time. Nevertheless, this study confirmed the applicability of the 5 Whys technique not only for quality issues, but also for investigations of the causes of safety accidents, etc.

The major causes of death from construction machines identified through the 5 Whys technique could be found for taking countermeasures. In the case of height-operating cars (vehicle-mounted type aerial work platforms), the safety against welding accidents in the production process needs to be ensured. It is shown that one of the reasons for accidents is the use of equipment without a safety device attached (or occasionally, a malfunctioning safety device), leaving no overload protection during operation.

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AUTHOR PROFILE

Dong Gil SHIN General Manager Q-HSE Management Div. (Strategy and Planning), SAMSUNG C&T, Korea

Seung Il LEE Seoul National University of Science & Technology, Master course, Seoul, Korea