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The causes of work place accidents and their relation to construction equipment design

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Abstract

Several studies have been conducted in order to identify and analyze the causes of hazards and safety risks at work using different methods of accident investigation. This study aims to analyze a workplace accident on a construction site, in the area of solid waste recycling, in order to identify the causes of the accident and propose solutions to the design of the construction equipment. A technical analysis of the fatal accident was designed based on an on-site inspection of the accident, meetings and testimony gathering, a report on the nature of the event, a probable description of the accident and a proposal for corrective and preventive measures. Amongst the possible causes of this fatal accident are: failure in the design of the mobile crushing equipment, inadequate instructions from the manufacturer regarding the use of the bridge, inappropriate operating procedures, and lack of training on the part of the management team. Finally, corrective and preventive measures were proposed, focusing on the design of the product involved in the accident.

Keywords: Prevention through Design - PtD; Safety at work; Construction

1. Background

Investigations into accidents have shown the importance of measures directed at workplace safety and accident rates in organizations [1]. To prevent accidents, or even reduce their harmful impacts, it is necessary to thoroughly investigate all the possibilities in order to determine their causes and effects, and then to establish effective

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instruments for their prevention and control [2] . In order to prevent fatal accidents and injuries at construction sites, several studies have been conducted in order to identify and analyze the causes of hazards and safety risks through different accident investigation methods [3, 4, 5].

In 2008, Portuguese researchers analyzed 709 serious and fatal accidents in the construction sector in Portugal over a period of three years. From their analytical models, recommendations to improve safety of work on construction sites were formulated, as well as establishing indicators of risks relating to the probability of occurrence of fatal accidents in construction [6].

In the United States, a survey examined 296 fatal accident reports from the Occupational Safety and Health Administration (OSHA), which related to excavation operations from 1997 to 2001. Two analytical models were used. One conisdered the causes which were related to the type of accident and the other considered the causes related to behavioral factors. With this analysis, the authors concluded that the link between the results of both analytical models represented a first step in the identification and analysis of accidents on excavation sites [7].

In South Korea, researchers analyzed 595 accidents at road works on highways between 2007 and 2008. Using an analytical method of research, the authors identified a number of factors involved in the main types of work (drainage, tunnelling, installations, earthwork, paving and structures). They concluded that the identification of these factors may contribute to the recognition and responses to accidents, as well as in reducing the number of road accidents [8].

Accident analysis is gaining more space as a tool for accident prevention given the importance of knowledge of the causal factors of these events for their effective prevention, as well as in risk management [9]. The investigation and analysis of accidents should be seen as a means for improving safety performance in the future , as well as an opportunity for organizational learning [10].

In this sense, OHSAS-18001 recommends the implementation and maintenance of procedures for the registration, investigation and analysis of accidents, in order to identify the need for corrective actions and the opportunity to take preventive measures [11]. Statistical data and analysis of occupational accidents are commonly accepted as important and effective tools for the development of economical and preventive policies [12].

In Brazil, the Ministry of Labor and Employment (MTE), which is the government agency responsible for the analysis of accidents, found that most companies do not identify the real factors related to accidents. To support inspectors, the MTE has compiled a guide to analysise occupational accidents, which is linked to the SIRENA project. The SIRENA - Reference System in Work Accident Analysis presents concepts and methodologies required to understand the causes of adverse events in the workplace [13]. In this guide, the following requirements for investigating accidents are highlighted:

- The health and safety standards;
- The design of machines, equipment and products;
- The company's management system;
- Technological developments;
- Working conditions;
- The reliability of systems.

It is worth noting that accidents are just the tip of the iceberg, and understanding the cause of accidents is of great importance for their prevention. Therefore, it is not enough just to learn from accidents that have already happened, but also to study the incidents and near misses, which are considered to be another source of effective learning and accident prevention [5]. Despite their being more frequent than accidents and provide a great source of information for safety management in construction work, little is known about the characteristics of near misses [14].

Finally, in view of the negative impacts caused by industrial accidents, the investigation of the causes of near misses, incidents and accidents must be interpreted as a collective opportunity for organizational learning [15]. We emphasize, therefore, that safety at work should be seen as an investment, and as 'business' for the organization. From the moment that safety at work cuts financial losses, there will be positive effects on aspects of working conditions, and consequently on the reduction of accident rates, with a reduction of losses in productivity and the workers´ quality of life.

However, the safety of work environments is most effective when implemented early in the product life cycle or process. The most effective control measure, the elimination of the danger, is cheaper and more practical if it is dealt with at the design stage, than when the dangers constitute a real risk to customers, users, employees and businesses. Benefits include the prevention of injury and illness; improving the usability of products, systems and installations; improved productivity; cost reduction; improvement of forecasting and management of production and operating costs over the product life cycle; and compliance with [16] legislation. The economic benefits of Prevention though Design - PtD also include the reduction of the costs of workers´ injuries, the reduction of the likelihood of embargoes and bans and the elimination of the need to improvise, all of which can lead to significant costs in the long term.

A survey conducted in Australia found a range of project issues related to fatal accidents, with the most common being: problems with moving parts on protective structures or those associated with seat belts, inadequate guardrails, lack of residual current circuit breakers, inadequate protection against falls, failure of hydraulic lifting systems on vehicles and moveable equipment, and inadequate protection mechanisms on mobile units and vehicles [17]. In this study, it was noted that problems wtih machine design, installation and equipment contributed significantly to the occurrence of injuries in occupational accidents.

Within this context, this paper aims to analyze a workplace accident in civil construction work, in the area of solid waste recycling (the collection, transport and crushing of demolished material), in order to identify the causes of the accident and propose solutions for the design of construction equipment.

2. Methodology

The design of the technical analysis of the fatal accident in the study was based on the following methodological steps:

Inspection of the scene: From the on-site inspection of the accident, the location and the equipment involved in the accident were identified. The day after the fatal accident, photographic records and observations were carried out at the construction site, with due attention being paid to the area of the recycling of solid waste, specifically to the area of the collection, transportation and crushing of the demolished material.

Meetings and testimony gathering: There were meetings at the company's office in order to gain more knowledge of the statements and information already collected. In addition, we recorded the statements of the employees participating in the same task as the accident victim at the time of the accident.

Structuring the report of the incident and a probable description of the accident: Based on the investigation undertaken at the meetings and testimony gatherings, a report of the accident and a probable description of the accident were formulated, thereby leading to the probable causes of the accident.

Proposition for corrective and preventive measures: From an understanding of the causes of the accident, corrective and preventive measures and recommendations were proposed, with an emphasis on the design of the machine involved in the accident.

3. Results

The accident analysis results were formulated into the following parts: characterization of the construction site; description of the accident site and the equipment involved in the accident; report of the accident; and, a likely description of the accident. Then the recommendations and solutions were presented, with an emphasis on the design of the equipment involved in the accident.

3.1. Characterization of the construction site

The construction site under study is the construction of a shopping center located in Recife, Pernambuco, in Brazil, undertaken from July 2010 to November 2012. This was a complex work, with activities covering a building area of 295,000 m², in addition to works underaken on two fly-overs, the revitalization of the banks of a river and

landscaping. It had a peak of 6924 employees and a sum of 409 companies providing services. It is noteworthy that the developer is the construction company responsible for contracting the services of these companies.

In addition to the safety engineer, safety specialists, occupational physicians, nurses, the construction site had a management system for health and safety at the site. Throughout the project implementation phase, there were two fatal accidents in the outsourced services companies. These companies had their safety and occupational health services, and received assistance from the contracting company when needed. The accident under study relates to an event occurring in October 2010, during the foundation phase of the construction.

Together with the foundation services, the foundation phase involved demolition and waste recycling activities, since the work undertook an environmental commitment to recycle all of the solid waste from the demolition of the previous building, which was a drinks´ factory consisting of sheds.

Fig. 1 shows the area for the recycling of solid waste, specifically the area of crushing demolished material, as well as part of the old factory sheds before demolition. Fig. 2 and 3 illustrate activities related to the manual and mechanized excavation; use of continuous flight augers CFA; leveling of cuttings, use of jackhammers; and the concreting of blocks for capping the piles with the use of a pumped concrete mixer truck.

Fig. 1. (a) area for the recycling of solid waste; (b) sheds of the old factory before demolition.

Fig. 2. (a) continuous flight augers; (b) erecting piles.

Fig. 3. (a) concrete blocks for crowning the piles; (b) concreted crowning block to connect the stakes to the pillar.

These activities involve different professionals such as carpenters, iron workers, blacksmiths, jackhammer operators, bricklayers, surveyors, pile driver operators and concrete mixer truck operators. In turn, these activities and functions are associated with accident risks, such as burials, falls, mechanical shocks and being run over. The use of jackhammers for leveling the stakes stands out because of the noise and vibration generated in the worker's body, which can cause occupational illnesses in the medium and / or long term.

3.2. Description of the site and equipment involved in the accident

The accident occurred in an area of a subcontracted third party, for the collection, transport and crushing of the material demolished at the site in Recife, Brazil, during the foundation stage of construction. This third party worked on undertaking the demolition and recycling services of the demolished material in the construction work under study. It was using the mobile crushing equipment ICON UMB1010 - VR, to remove debris and for crushing the demolished materials (Fig.4). The equipment consists of two parts. The top is for the buckets, motors and crushers used for the collection, transportation and crushing of the material. Whereas the bottom consists of a platform, which transports and fixes the unit.

Despite the supporting metal parts for fixing the unit having a hydraulic system, the connected equipment causes strong and intense vibration, causing wear on the supporting metal parts. As reported by the commercial manager of the third-party company, to solve the problem, the company's operational team used three metal trestles to support the truck, giving it greater stability and preventing the rapid wear of the original pieces of support equipment (Fig.5).

Fig. 4. mobile equipment for removal and crushing**.**

Fig. 5. metal parts for fixing the mobile equipment.

The use of trestles to support and fix the mobile unit was also suggested by the manufacturer of the equipment, in order to extend the life of the chassis suspension, improve equipment operational safety and minimize vibration. The manufacturer stated that construction trestles consisted of beams in "I" formation, in 250 x 120 mm steel, supported on steel plates with sufficient height so that the tires become suspended above the ground.

3.3. Report on the accident

On the day of the accident, the contractor requested that the commercial manager of third party move the crusher from where it was because the place would be used as a work access. Therefore, on the same day, the commercial manager arranged for the removal of the crusher from where it was located to the nearest place to the rest of the material being recycled.

It was more than a month before the accident, and the crusher had been positioned and there was no problem in mounting it. A technical manufacturer had supervised the placement of the trestles under the crusher, so that employees of the outsourced company could learn how it should be done, although there was no formal training by the manufacturer. As directed by the manufacturer, three iron trestles were built by the employees of the third party in order to support the unit, and thereby improve the safety of equipment´s operation.

Based on this experience, the commercial manager asked the same employees who positioned the crusher for the first time, to do it again, which they did. However, the victim, crouching and forcibly resting one foot against one of the trestles and leaning on the other trestle, had an accident. The loose trestle fell on him as he was resting on one of trestles with one foot, and holding onto the other with his hands, which is the one which fell on him.

The other workers had also been crouching down whilst helping the man erect the trestles. The procedure was performed according to the practice performed previously. However, the employee who had the accident put to a lot of force on the trestle that was already under the crusher and dislodged the trestle he was supporting with his hands, and then this fell on him.

3.4. Likely description of the accident

On the day of the accident, about 11am, an employee had an accident with one of the unit´s support trestles, which fell on his face, causing his face to be crushed. Subsequent death occurred the next day in a public hospital in Recife , Brazil.

The team, consisting of four employees responsible for the transport and fixing of the mobile unit, was working under the truck when the accident occurred. It is worth mentioning that the allocation and adjustment of the trestles under the unit, weighing around 300 kg, is performed manually by a team consisting of four workers. However, one

of the trestles had a broken support, as can be seen in Fig.6. In this case, the commercial manager of the outsourced company reported that this support would have been soldered at the location.

The employees were adjusting the tresle with the broken support for subsequent welding, when the victim, crouching and pressing one foot on one of the trestles, lost his balance and fell backwards. When he fell, in order to keep his balance and prevent his fall, 'pulled' at the other metal trestle, which was loose and very close (Fig.6). This, weighing about 300 kg, fell on top of him, crushing his face.

Finally, the victim was rescued and immediately taken to the public hospital by the ambulance on the construction site. This was under the guidance of the workplace medic, who was present at the time of the accident, and was accompanied by the workplace medical repsonder. Then the whole area of the accident was isolated, and the Regional Labour Superintendent (SRT), the Civil Police and the Workers' Union were notified of the accident.

4. Proposals for corrective and preventive measures

It is concluded that the probable causes of this fatal accident were:

- a failure in the operation of the mobile crushing equipment when it is operated with excessive vibrations. The equipment must be stable;
- inadequate guidelines on the part of the manufacturer regarding the use of the trestle. The trestle is only an accessory , or simply, a piece of support equipment;
- a failure in the design of the trestle, which was unstable. The trestle should have all four supports on the ground;
- the trestle had a broken support;
- inappropriate Operating Procedure;
- a lack of training on the part of the management team.

Therefore, some corrective and preventive measures are:

- designing rigid supports for the unit;
- designing trestles as part of the equipment, which would mean not having to improvise and the not having to handle the trestles;
- development of specific operating procedures for this activity;
- teaching / strengthening the skills of the management team. Despite giving technical training on environmental and operational issues of crushing waste, the management team of the outsourced company demonstrated a deficiency in technical knowledge of health and safety at work.

Fig. 6. (a) improvised support for the truck; (b) the metal piece that fell on the employee.

5. Conclusions

The causes of an accident at work can be numerous, but are mostly due to a lack or deficiency of planning and organization of production, unsafe conditions in the workplace and human factors, which may have psychological origins or reflect social problems and cultural and / or organizational training. Since human behavior relates to subjective factors, it makes the task of researching them more difficult since the problems and / or psychosocial disorders may be, or not, directly related to work activity. Due to this diversity of variables that can be linked to an accident, the investigation of an accident becomes complex, and it must be based on a large amount of information accumulated by the company.

This study showed that workplace accidents are caused by organizational factors at work, reflecting the lack of and / or inadequacies and / or failures in the construction site management, operational procedures and designs. With regards to the accident under study, a number of safety measures relating to the managerial nature of work, operations, education and design were proposed.

In the case of failures and / or omissions in the planning project with regards to aspects of safety, research and studies around the world contain data which relate the causes of industrial accidents to planning projects, as well as proposing guidelines and methods so that designers can include safety at work in their projects. It is found that, on average, 6.9% of serious and fatal accidents in the construction industry could have been prevented if measures had been taken in equipment design [18].

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