Utilization and Effectiveness of Harnesses and Lifelines in Grain Entrapment Incidents: Preliminary Analysis

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ABSTRACT. *No previous studies have been found that document the level of use or validate the effectiveness of safety harnesses and lifelines in the prevention of or extrication from grain entrapments or engulfments. This article addresses that void via analysis of the data contained in the Purdue Agricultural Confined Space Incident Database. A total of 1,147 cases involving entrapments or engulfments in grain masses were mined for terms that might indicate the use of a safety harness, lifeline, fall restraint system, rope, or outside observer. Case information ranged from brief news accounts to comprehensive investigation results. The review turned up 38 incidents (<5%) in which these safety devices were identified as having been used by either workers or rescuers during access to a storage structure. In 26 of the 38 cases (68%) where safety devices were identified, the entrapment or engulfment resulted in a fatality. The two most common reasons cited for failure of these devices were (1) that the lifeline or rope was too long (17 incidents) and (2) that the worker had removed the harness with the attached lifeline while in the structure (6 incidents). It was also determined that these devices, if used improperly, can lead to secondary injuries of the victim. The preliminary evidence suggests that use of these devices alone does not ensure the user's safety and may even provide a false sense of security if used without proper training. It was further found that an approved body harness and safety line provided little or no protection from either entrapment or falls if used in the presence of vertically crusted grain surfaces, without proper anchors, or not in conjunction with outside observers. The presented results are important for safety professionals to consider as they endeavor to reduce the risk of grain entrapment and engulfment incidents through training, education, selection of personal protective equipment, etc., and should contribute to the development of new structural standards for grain bins. It is the intent of this article to elucidate the importance of training and proper use of these safety devices.*

Keywords. *Agriculture, Confined space, Engulfment, Fall, Grain storage facility, Lifeline, Rope, Safety rope.*

Entrapments and engulfments are among the most common hazards associated with grain storage facilities. Since the 1970s, nearly 1,150 incidents have been documented and entered into the Purdue Agricultural Confined Space Incident Database (PACSID; Riedel and Field, 2013; Issa et al., 2015, 2016). To address this problem, the commercial grain storage and handling industry and OSHA have developed a variety of

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intervention strategies, workplace safety practices, and regulations. Among these is the almost universally held position that entry into grain storage structures should include the use of safety harnesses and lifelines. In fact, OSHA Standard 29 CFR 1910.272 mandates that any worker entering a non-exempt (i.e., commercial) grain storage facility must wear a full-body harness with a lifeline (OSHA, 2002). However, while some 8,500 such grain storage and handling operations fall under the 29 CFR 1910.272 rules, more than 260,000 facilities are exempt from compliance due to their status as "agriculture," "farm," "feedlot," or "seed processing" (NASS, 2016). The vast majority of entrapment and engulfment incidents occurs at these exempt facilities (Issa et al., 2016).

Although harnesses and lifelines have been deemed essential personal protection equipment by the grain industry and are required by OSHA for non-exempt facilities, their contribution to reducing the frequency or severity of grain entrapments or engulfments, especially at exempt facilities, has never been adequately documented. This concern about their effectiveness is related to the fact that they must be used in conjunction with a suitable anchor point within the storage structure and with a trained observer outside the structure. The vast majority of the 750,000 or so steel grain bins in the U.S., most of which are found on exempt facilities, do not have anchor points that meet the minimum load capacity for use in securing a lifeline, as specified by 29 CFR 1910.272 (Bauer, 2014). The load capacity of a typical bin roof will not support a top-access retrieval system. As for outside observers, most grain bins in use today do not provide an observer station, as specified in the current OSHA regulations.

In summary, the overwhelming majority of persons most likely to be exposed to the hazards of grain entrapment are not required to adhere to the basic preventive measures contained in 29 CFR 1910.272. There is little incentive to purchase or be trained in the proper use of fall protection, safety, or rescue equipment. Thus, it is unclear if harnesses with lifelines would have prevented a significant number of the documented entrapments and engulfments.

Focus of this Study

This article focuses on a preliminary analysis of the use and demonstrated efficacy of safety equipment, particularly harnesses and ropes, in grain entrapment and engulfment prevention and rescue efforts. A literature review of the pertinent research methods is followed by a summary of the findings, an analysis of those findings, and a review of six cases illustrating the wide range of possible scenarios in the application of safety equipment, and a discussion on why the use of such equipment remains problematic.

Review of the Literature

Types of Grain Entrapment

Before attempting to determine the effectiveness of harnesses and lifelines, it is necessary to understand the various circumstances in which these safety devices might be used. Field et al. (2014a) identified and described the following seven categories of grain entrapment:

Flowing-Grain Entrapment: This type of incident generally starts when a worker enters the top of a storage structure during unloading, while the in-floor auger is running, to clear a plugged outlet or break up clumps of grain. As the structure empties, a rapidly moving column of grain forms over the floor outlet, and the victim is quickly drawn into the flowing grain toward the center and down to the floor directly over the outlet, often plugging the flow. Once trapped, escape is nearly impossible, and the victim is usually found in the center and in an upright position. Flowing-grain entrapments in gravity-flow grain transport vehicles, which often involve children, are included in this category.

Bridging Entrapment: This type of incident is usually the result of either improper drying or rewetting of the grain, which allows moisture to build up on the grain surface, eventually creating a hard crust on top of the grain mass due to spoilage. Later, when the grain is augered out at the bottom of the bin, the crust maintains its shape and forms a bridge that conceals the cavity underneath. After entering the bin to break up the crusted surface, a worker breaks through the surface while walking on it and is quickly covered by the grain flowing into the cavity. If the unloading equipment is still running, the worker is pulled even deeper into the grain. The victim is generally found directly over the outlet in the bin floor.

Avalanche Entrapment: This type of incident occurs when spoiled grain forms free-standing columns or clings to the bins walls. The likely cause of that spoilage is water leaking through the bin roof, moisture accumulating on the walls due to condensation or weather conditions, or rain or snow entering through improperly positioned vents. Unlike dry grain that piles at an angle of repose 25° to 30°, caked grain can stand almost vertically. When a worker enters the base of the structure and tries to break up the crusted material, it can collapse, entrapping and often crushing the worker with both free-flowing grain and large chunks of caked grain. The chunks that fall from the walls can weigh hundreds or even thousands of pounds.

Vacuum Machine-Related Entrapment: This type of incident can occur when a vacuum machine and hose are used to remove grain from the storage structure or grain pile instead of the in-floor auger (Field et al., 2014b). Such machines have become widely used to remove residual grain or when heavy crusting clogs the auger wells. The entrapment usually involves a worker standing on the grain surface while operating the machine (a practice clearly discouraged by warnings placed on the machine by the manufacturer). As the grain is removed from beneath the worker's feet, the worker is drawn deeper into the grain. Entrapment can occur in a matter seconds with vacuum machines that remove 1,000 to 2,000 bushels of grain per hour.

Covered Entrapment: This type of incident occurs when a worker is inside an empty or partially empty structure or grain transport vehicle and another worker, unaware of that fact, begins loading grain into the structure or vehicle. This incident frequently involves youth playing in the space.

Structural Collapse or Unintentional Release Entrapment: Workers have become entrapped or engulfed when grain or feed was released unexpectedly from an access point, such as an inspection opening on a hopper-bottom bin, or due to structural failure. When suddenly released from a large structure, the force of the grain can quickly engulf anyone who happens to be in close proximity.

Open-Pile Entrapment: Entrapments or engulfments in free-standing piles of grain are rare but have resulted in some of the most difficult rescues due to the large amount of grain involved and the tendencies for these piles to shift. While walking on the surface of the pile, a worker can cause an avalanche of grain from above, which is impossible to stop until it reaches its natural angle of repose (usually 25° to 30°, depending on the type of grain and moisture content).

The effectiveness of safety harnesses and lifelines depends on the type of entrapment. In the case of flowing-grain entrapment, a harness and lifeline when used alone (i.e., taut lines not maintained or no outside observer) offers little protection. In addition, the lack of an adequate anchor point and the inability to shut off the unloading system greatly reduces the probability of survival. In the case of bridging entrapment, a harness and lifeline could be an effective safety device; however, again, this is highly dependent on the tautness of the lifeline and the availability of adequate anchor points. In avalanche, covered, structural collapse, and open-pile entrapments, a harness and lifeline would provide no benefit, except perhaps in locating the buried victim. Lastly, the efficacy of harness systems when using grain vacuum machines is not well documented in the literature, although we believe they would be of little value because the operator in many cases does not have direct access to the controls of the vacuum machine.

Because the effectiveness of safety harnesses and lifelines is dependent on the type of entrapment, finding the distribution of each of these incident types is important for understanding the effectiveness of these devices in preventing entrapments.

Fall-Safety Equipment

OSHA (2015) has identified four classes of fall-safety equipment according to their intended function:

- Class 1 includes body belts that are intended primarily for positioning and reducing the risk of falls (e.g., from a slippery surface). They should never be used where a risk of free-fall exists.
- Class 2 includes chest harnesses that are intended primarily to retrieve a person. They can be used for a limited fall hazard (e.g., from a sloped roof) as long as it is not a vertical free-fall.
- Class 3 includes full-body harnesses that are intended primarily for use where there is potential for a free-fall (e.g., from a bin roof).
- Class 4 includes suspension belts and chairs that are intended only to suspend a worker (e.g., in the air to dislodge a crusted column of grain).

Only classes 3 and 4 are allowable for grain bin entry at OSHA non-exempt facilities under the provisions of 29 CFR 1910.272. However, it is common to find equipment from all four classes (and even makeshift solutions) at smaller commercial grain and feed operations and on farms, which are usually exempt from 29 CFR 1910.272 compliance (Bauer, 2014). It is important to note again that grain storage structures (both non-exempt and exempt) have generally not been designed to support the use of harnesses and lifelines for fall protection or confined space entry (Bauer, 2014).

Designed Purposes

Fall-safety equipment is designed for four different purposes: fall arrest, positioning, suspension, and retrieval. Fall arrest equipment, which generally includes a full-body harness, a shock-absorbing lanyard or self-retracting lifeline, and an anchor point, activates after a fall occurs; its function is to dissipate the forces associated with the fall. Positioning equipment allows a worker full use of both hands and only activates when the worker leans back; it might not be designed for fall arrest. Suspension equipment actively supports the worker and allows full use of both hands; it is not a fall arrest system. Retrieval equipment addresses the after-effects of a fall, including extricating or lifting a person to safety (OSHA, 2015). For grain entrapment prevention, fall-safety equipment is generally either fall arrest equipment or positioning equipment.

Harness and Lifeline as a Retrieval System

In addition to the intended role of harnesses and lifelines in injury prevention, there have been documented attempts to use these devices to extricate victims from a grain mass (Roberts, 2008). To determine the total force necessary to extricate an entrapped person, Schwab et al. (1985), Roberts et al. (2015), and Issa and Field (2017) conducted studies with mannequins in full-body harnesses that were pulled vertically upward. They found that extricating a victim entrapped to the chest or armpit level required at least twice and in some cases up to four times as much force as the victim's body weight, e.g., 400 lb or more to extricate a 200 lb victim. These results led to the recommendation to avoid pulling an entrapped victim forcibly out of a grain mass due to the risk of secondary injury (Baker et al., 1999; Drake et al., 2010; Field et al., 2014c). For example, Bahlmann et al. (2002) reported a case in which the victim experienced such unbearable pain in an attempt to extricate him using a rope tied under his arms that the effort had to be stopped. Similarly, Roberts (2008) reported a case in which the victim may have died as the result of injuries sustained during a forceful extrication using only a rope. A case study in the PACSID noted permanent injury to a victim's back and lower limbs for the same reason.

Equipment-Related Injuries

A literature search yielded very little with regard to the type and extent of injuries resulting from the use of safety harnesses, lanyards, lifelines, or other fall-safety equipment in grain storage and handling situations. One of the documented injuries associated with the use of a harness and lifeline was suspension trauma, also known as harness-induced pathology (Lee and Porter, 2007). A healthy adult suspended in a vertical position for as little as 5 min with no body movement can lose consciousness and, if not placed in a horizontal position, may die. The reason is that blood quickly pools in the legs due to lack of muscle movement, reducing the blood supply to the heart. Harness straps around the thighs or groin area further cut off blood flow (Weems and Bishop, 2003; Pasquier et al., 2011).

Outside Observer Station

Without the presence of an outside observer, harnesses and lifelines will be less effective in preventing an entrapment. Most grain storage structures, especially steel bins, do not have a station from which an observer can supervise a worker inside the structure nor adequately respond in the event of an entrapment. The forces exerted on a victim being drawn into grain greatly exceed the strength of a person standing on a ladder or steep roof surface (Schwab et al., 1985; Issa and Field, 2017). Incidents have been documented in which the observer lacked the strength to keep a lifeline-secured worker from sinking into the grain (Roberts, 2008). In addition, in cases where unloading was taking place, observers often lacked ready access to the unloading controls. In numerous cases, an observer watched as the victim became entrapped or engulfed and did not have access to the controls to stop the flowing grain, or had insufficient time to reach the controls or alert co-workers to shut off the grain flow (Roberts, 2008).

Research Methodology

The PACSID was developed to assist in storing, adding, querying, and analyzing incidents related to agricultural confined spaces. Each entered case contains all the parameters that were reported (e.g., date, time, state, worker name and age, farm type, incident type, agent of injury or fatality, and incident narrative) and is searchable by any of these parameters. A complete list of all inputs that the database supports and a description of each parameter can be found in Riedel (2011).

For this study, the PACSID was mined for all grain storage structure entrapment incidents that indicated involvement of fall-safety equipment (i.e., terms such as "chest harness," "full-body harness," "lifeline," "rope," "tool belt," "beltline," etc.) In addition, any narrative recorded for each case was analyzed, and the following data were extracted from the narrative: type of entrapment, cause of entrapment, presence of observers or other workers, use of safety equipment, use of lockout or tagout procedures, use of respirators or dust masks, and vertical rescue attempts.

Research Findings

Number of Qualifying Entrapment Incidents

At the time it was queried for this study, the PACSID contained 1,147 reported entrapment incidents at grain storage facilities. Of that number, 822 provided enough information in their narrative sections to determine the type of entrapment. The remaining 325 incidents contained either no narratives or narratives so sparse (e.g., "suffocation in bin," "fell into bin") that they were deemed insufficient to identify the type of incident or determine the use of safety equipment. In addition to the 1,147 grain entrapment incidents, 196 falls from bins, silos, and other confined spaces were reported in the database.

Incidents and Fatalities by Entrapment Type

Of the 822 cases in which the type of entrapment could be identified (table 1), 783 occurred inside a confined space, such as a bin, silo, or other grain storage structure. The other 39 incidents occurred outside a confined space. Of the 783 confined-space incidents, 577 (74%) were flowing-grain entrapments, 72 (9%) were caused by an avalanche, 56 (7%) were due to bridging, 52 (7%) were entrapments in which the victim was covered by flowing grain, and 26 (3%) involved the use of grain vacuum equipment. Of the 39 incidents that occurred outside a confined space, 29 (74%) were related to structural collapse or unintentional release of grain, and 10 (26%) were related to open piles.

Of the 1,147 total entrapment cases in the PACSID, 775 (68%) resulted in a fatality. Of, the 822 cases for which the type of entrapment was known, 544 (66%) were fatal. In comparison the fatality percentage for each grain entrapment type varied from a low of 61% for avalanche entrapments to a high of 90% for structural collapse or unintentional release entrapments. Of the 1,147 entrapment cases, 349 occurred in OSHA non-exempt facilities, 397 occurred in OSHA exempt facilities, and for 401 cases the status was unknown.

Table 1. Number and percentage of incidents and fatal incidents within each entrapment category.

Type of Entrapment	No. of Cases	% of Cases	No. of Fatalities	% of Cases that were Fatal
Inside a confined space				
Flowing grain	577	70%	362	63%
Avalanche	72	9%	44	61%
Bridging	56	7%	39	70%
Covered	52	6%	43	83%
Vacuum machine	26	3%	22	85%
Outside a confined space				
Structural collapse or unintended release	29	4%	26	90%
Open pile	10	1%	8	80%
Total[a]	822	100%	544	66%
Grand total[b]	1,147	-	775	68%

[a] Total = sum of all cases in which entrapment type was known.
[b] Grand total = sum of all cases found in the PACSID.

Reasons Given for Entering the Structure

The reason for entry by the worker into a grain storage structure was known in 702 of the total 822 cases. The four most recorded reasons were as follows:

- Dealing with out-of-condition grain (includes unplugging in-floor auger) (317 cases).
- Co-worker falling into grain (93 cases).
- Cleaning out or scooping up residual grain (86 cases).
- Playing or sitting on the grain in a storage structure or transport vehicle (91 cases).

These four reasons accounted for 82% of all recorded reasons for entry. Highest among the other 18% were repairs, observation, rescue, and installing equipment. In 39 (6%) of the 702 cases, the entrapment occurred outside a structure in an open pile or was due to structural collapse. (For the fell-into-the-grain category, in many cases it was not clear if the worker fell into the structure and became entrapped or was already inside the structure and fell into flowing grain.)

Use of Fall-Safety Devices and Other Safety Measures

Of the 822 qualifying cases, there were 18 in which the narrative specifically mentioned that the worker was wearing a harness or using a boatswain's chair, 7 cases reported that the worker was attached to a safety rope, safety line, lifeline, or lanyard (although it was unclear if those devices were attached to a harness or directly to the person), and 13 cases mentioned that the worker held or had tied around his waist a rope or chain. Thus, a total of 38 cases (out of 822; <5%) reported that the worker used (or attempted to use) personal protective equipment designed to prevent an entrapment or fall. This compares to incidents for which other entrapment-preventive practices were documented in the narratives:

- Another worker was nearby or was in the structure (244 cases).
- The victim had access to a communication device (e.g., phone or radio) (9 cases).
- The victim was wearing a mask or ventilator (6 cases).
- The auger or equipment was turned off during the incident (5 cases). No narrative specifically mentioned the use of lockout or tagout procedures.

These findings are not a reliable indication of the adoption rate or effectiveness of safety harnesses. However, the relatively small number of incidents involving harnesses along with other safety equipment is of concern, especially given the generally observed low adoption rates.

Fatalities

Of the 38 harness or rope cases identified, 26 (68%) resulted in a fatality, the same as the fatality percentage for all documented cases. In contrast, the 244 incidents in which an observer or multiple workers were present had a 51% fatality rate. Table 2 shows that in 17 of the 26 fatality cases (plus six of the non-fatal cases), the safety rope was too long. In six cases, the victim had disconnected the harness while working, and in two cases (plus three of the non-fatal cases), the worker was holding the rope only with his hands, not having affixed it to his body or to the harness. In two cases, the workers used the safety equipment and were successfully rescued. Regarding the OSHA classification, 20 cases occurred in OSHA non-exempt facilities, seven cases occurred in OSHA exempt facilities, and for 11 cases the OSHA status was unknown. In addition, the types of entrapment for these cases were 29 flowing-grain cases, five unknown cases, three bridging cases, and one avalanche case.

Table 2. Entrapment issues experienced by workers using safety devices on entering a confined space.

Issue	Fatal	Non-Fatal	Total
Safety line or rope too long	17	6	23
Worker disconnected harness	6	0	6
Rope only held by hand	2	3	5
Equipment malfunction	1	1	2
Safety equipment used properly	0	2	2
Total	26	12	38

Use of Harnesses or Rope as Rescue Device

There were 21 incidents that involved safety harnesses and/or ropes in attempts to rescue the entrapped workers. The following was gleaned from the PACSID relative to the use of harnesses and/or ropes as rescue devices in those 21 incidents:

- Used successfully to extricate the victim (9 cases).
- Used only to stabilize the victim or prevent further submersion (4 cases).
- Used only to recover the victim's body (3 cases).
- The use of a harness and rope or lifeline failed or resulted in injuries (5 cases).

Devices that were specifically identified included harnesses (10 cases), ropes (10 cases), and a tool belt serving as a makeshift harness (1 case).

Example Case Studies

The following six case studies illustrate issues related to workers' use of safety harnesses and/or lifelines to protect themselves while inside grain storage structures. All cases were obtained from the PACSID database:

Case 1 illustrates that a harness and lifeline system, by itself, does not ensure safety.

Case 3 illustrates why adequate anchor points must be used with harnesses and lifelines.

Cases 2, 4, and 5 are examples of safety harnesses and lines being used unsuccessfully as extrication tools.

Case 6 illustrates the ineffectiveness of a self-retracting lifeline in maintaining taut lines.

Case 1 (1993, OSHA non-exempt facility)

Upon entering a steel bin containing some 80,000 bushels of corn, a worker in search of a missing co-worker could see the engulfed victim's taut safety line but not the victim. After trying unsuccessfully to pull on the lifeline, the worker sought help from first responders. It appeared to investigators that the victim had been standing over a grain pocket that collapsed. When the body was recovered, one of the victim's hands was gripping the rope while the other hand was above his head, indicating that he was drawn into the grain with substantial force. The rope was not attached to the victim nor to his safety harness. The preliminary cause of death was ruled asphyxiation.

Case 2 (2000, international case)

The victim had become buried in the grain up to his armpits. At the time of attempted rescue, he was conscious and experiencing no pain. The rescuers (firefighters) initially tried to free him by shoveling the grain away from him, which proved unsuccessful because it immediately flowed back in as they shoveled. They next placed a harness with a rope attached around his upper body to attempt extrication. As they pulled, the victim experienced chest pains and breathing problems. Although analgesic drugs were provided to reduce the pain, the pulling force caused such unbearable pain that the rescue attempt could not be continued. Eventually, the rescuers placed a cylinder around the victim, removed the grain between his body and the cylinder wall, and then pulled him out. Once extricated, his chest pain immediately ceased (Bahlmann et al., 2002).

Case 3 (2003, OSHA exempt facility)

Before entering a 10,000-bushel bin three-quarters full of corn to unclog the in-floor auger, the victim (a farm operator in his fifties) had tied a rope around his waist and attached the other end to the inside bin wall ladder to serve as an anchor. When the unloading system was energized and the grain flow resumed, he became engulfed. The ladder could not withstand the force pulling the victim into the grain and broke loose from the wall. Even though the victim had a radio, he was unable to use it, most likely due to the speed of the entrapment. When co-workers (none of whom had been acting as outside observers) did not hear from him for a while, they investigated to find that he was buried in the grain. Rescuers cut a hole in the bin wall and recovered the deceased victim 75 min later, with the rope still attached to his waist.

Case 4 (2003, OSHA non-exempt facility)

A worker became entrapped inside a 60-foot-tall silo that was about one-third full of soybeans. The first responders initially placed a harness, with a rope attached, under his shoulders to attempt to pull him out, but that did not work due to the pressure of the grain. They then built a box around the victim to keep the grain from packing against his body. Some 9 h later, the victim was successfully extricated. The rescuers believed that he might have been standing on the auger motor, which kept him from sinking deeper. A co-worker who was in the silo when the victim became trapped had been able to free himself.

Case 5 (2012, OSHA non-exempt facility)

Two workers and the victim (all males) had entered an 80-foot-tall concrete silo to set up a sweep auger and remove the residual wheat. A light and the auger (16 feet long, including the motor) were lowered by cable from the top of the silo, after which the three workers entered through a side door and climbed down an inside ladder to the surface of the grain. As the victim, who was walking on the grain, detached the suspended auger, the conveyor belt underneath was unexpectedly turned on, and the victim sank into the grain up to his mouth. Once the conveyor was shut down, a worker shoveled grain from around the victim's mouth and down to chest level. Two other workers then entered the bin, and together all three tried to pull the victim out by his arms, but they ceased when the victim said he felt his shoulder and back pop. After nearly an hour, 911 was called, and firefighters soon arrived. By then, the victim was complaining of pain in his legs and difficulty breathing. The responders sank sheets of plywood into the grain around the victim, vacuumed out the grain down to knee level, and then placed a harness and lifeline on the victim and, without warning, tried to pull him out. He immediately reported feeling as if his spine had popped. The responders adjusted the harness and pulled him again, successfully. The victim survived the incident but suffered long-term psychological damage (e.g., anxiety) and weakness in his legs. He initially needed a wheelchair for mobility and later a cane (Issa, 2016).

Case 6 (2013, OSHA non-exempt facility)

Three workers were assigned to clean out a hopper of broken corn and corn screenings. Their team leader first had them open the bottom hatch (controlled electronically) to empty the screenings. When the flow had slowed, they were instructed to hit the hopper with a hammer to free the residual material. When the flow became extremely slow, the team leader sent a worker up to the top of the hopper to prepare for entry. The worker was equipped with a harness attached to a self-retracting lifeline. Unobserved, he entered the hopper with a pole to break up the plugged material. The two workers at the bottom of the hopper noticed the pole coming down through the bottom hatch. They contacted the team leader, who went up and found the victim's taut line entering the hopper. First responders were immediately called, and they worked to remove the screenings from the bottom hatch until they could pull the victim out. The victim was declared dead at the scene, and an autopsy revealed that he had asphyxiated through aspiration, having been buried under 8 to 12 feet of material for 1 to 2 h. The self-retracting lifeline that the victim used did not activate and did not brake to prevent or minimize engulfment.

Discussion

Analysis of the Findings

The data indicate that the majority of grain entrapment cases occurred without the use of safety equipment. A harness or rope was involved in 38 entrapment cases, in comparison with 21 cases for all other types of safety equipment (e.g., logout or tagout procedures, communication devices, masks or ventilators). The percentage of workers using ropes at exempt facilities was not significantly different from the use of ropes at the non-exempt facilities. In addition, the use of harnesses and lifelines did not affect the fatality percentage in comparison to the overall database. This suggests that such devices are ineffective if they are not used in conjunction with comprehensive entry procedures, including an outside observer. When used incorrectly, or when used only to provide an unfounded sense of security, the risk of entrapment is unchanged.

The lack of compliance with safe work practices and regulatory requirements may increase the risk of entrapment. For instance:

- The most frequently documented cause of death for victims who used some form of lifeline or rope (with or without a harness) was that the lifeline was too long (23 cases) to prevent the victim from being drawn into the grain before it became taut, thus providing no protection from entrapment.
- Victims entered a structure with a rope that was either handheld or tied around their waist (5 cases), rather than secured to an approved, properly worn harness.
- Not realizing the substantial force encountered when entrapment occurs, victims anchored their lifelines to an inside or outside ladder or a roof beam, which were not designed as OSHA Standard 29 CFR 1926.502(d) personal fall arrest systems. The failure of these improvised anchors led to the victim's complete engulfment. In one case, the force of being engulfed was great enough to pull a steel ladder free from the bin wall.
- The practice of using an outside observer who could intervene in the event of entrapment was very limited, especially at OSHA exempt facilities. Such a practice was identified in only 28% of the cases for which sufficient information was available. These cases had a 51% fatality rate, in comparison to the overall 68% fatality rate.
- Use of lockout or tagout procedures was almost non-existent at exempt facilities. Their use or non-use was reported for only five cases.

Effectiveness of a Fall-Prevention System

The current fall-prevention system promoted in the grain industry consists of a harness, a lifeline, two anchor points (one in the center of the bin and one at the access point), and an observer station with an observer who maintains taut lines (Bauer, 2014; GHSC, 2014). While the recommended system appears to be effective in flowing grain and bridging entrapment incidents, the following realities likely jeopardize that effectiveness: (1) the vast majority of grain bin roofs neither have nor are able to support adequate anchor points; (2) it is doubtful that most exempt facilities would voluntarily assign extra workers to act as observers; and (3) the cost of adding observer stations or anchor points would reduce the likelihood of exempt facilities installing them. As the data have confirmed, partial implementation of a fall-prevention system does not protect workers.

In addition to the above concerns, the danger of falling from the structure exists when a worker climbs up to the access points on the roof. This risk is documented by about 200 cases in the PACSID (Issa et al., 2015, 2016, 2017). Currently, there is no significant effort to address this issue. If harnesses are required when using roof access points under OSHA standards for non-exempt facilities, how do facilities differentiate between equipment required for fall-arrest and equipment required for grain entrapment prevention?

Comparison to the Construction Industry

The entrapment prevention and fall-safety equipment used in grain storage facilities appears to be based on equipment designed for the construction industry. This is primarily due to the large number of fall-related fatalities in the construction industry. For instance, during the 1980s, almost 50% of all occupation-related fall fatalities occurred in construction, compared to just 10% in agriculture (Cattledge et al., 1996). Similarly, from 1992 to 1995, a total of 566 fall fatalities were recorded in construction (Janicak, 1998); in that same period, only 78 grain entrapment fatalities were recorded in the PACSID.

This is an important issue, as adoption of fall-prevention equipment designed primarily for construction workers does not necessarily translate into increased safety for workers at grain storage facilities. In fact, rope lanyards and self-retracting lifelines, while a necessity in the construction industry, can be dangerous in the grain industry. A self-retracting lifeline allows a construction worker flexibility and, in a free-fall incident, its brake system works to stop the fall. However, in a grain entrapment, the speed of entrapment is relatively slow compared to a free-fall, and the brake system will likely not be activated, resulting in the victim becoming fully engulfed (as in case study 6).

In the grain industry, rope length is critical for surviving an entrapment. Every extra foot of rope means that the worker will be buried a foot deeper in the grain mass. If the rope is attached to a harness at chest level, which is usually the case, that extra foot is enough to allow the worker to be completely engulfed. For example, if a worker entering a 30-foot-tall grain bin from the top access point attaches his lifeline to an anchor next to the hatch and then descends only 5 feet, he would need a lifeline that is 30.4 feet long to access the other end of the bin (A in fig. 1). In an entrapment, he could be pulled down as far as 14 feet into the grain in the center of the bin before the line became taut. If the anchor point was located in the center of the bin, he could still be pulled down as far as 11 feet into the grain (B in fig. 1). In some non-exempt facilities, systems have been installed to provide a secure lifeline; however, such systems are not widely used in exempt facilities, which are most vulnerable to engulfment incidents. The use of fall-safety equipment in the grain industry, including its high potential for misuse, is an issue that deserves further attention.

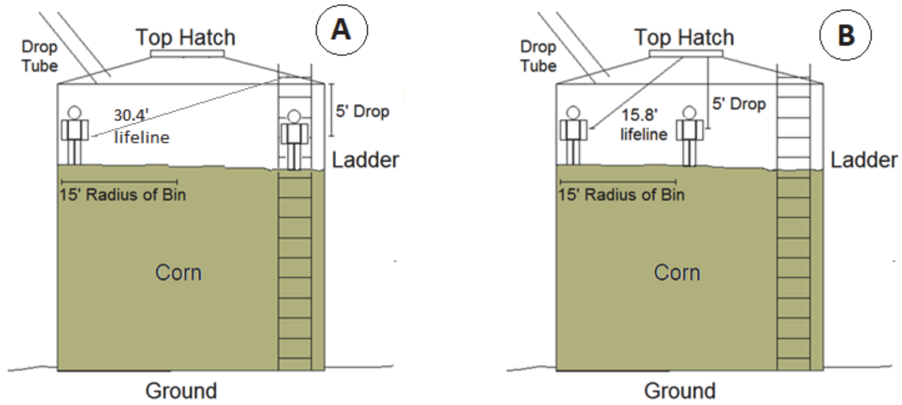

Figure 1. Examples of how a lifeline attached to an anchor point at the top hatch (A) or in the center of the bin (B), to provide access to the bin perimeter, would not protect a worker from grain entrapment.

Study Limitations

The conclusions drawn from analysis of the findings and from the case studies are based on the data documented in the PACSID. As a database of incidents, the PACSID does not document situations in which a safety harness and lifeline system was effective in preventing a grain entrapment unless reported in the sources reviewed, which is extremely rare. The lack of comprehensive data, generally due to the lack of reporting requirements, is a limiting factor. However, this study provides a first step in determining the effectiveness of bin entry safety equipment. Further studies on the adoption rate of harnesses and other safety equipment will provide greater insight on the information presented in this article.

Conclusions and Recommendations

The data available in the PACSID suggest that safety harnesses, lifelines, and appropriate confined-space entry procedures for grain storage and handling structures may be sparsely or improperly used. A survey of the adoption rate of harnesses and lifelines is recommended to determine the acceptance of this equipment. Although this equipment (if properly used) is considered important for preventing falls in grain facilities, it cannot be ascertained from the PACSID data that requiring this equipment for workers who enter grain structures results in a substantial decrease in the number of incidents, due to the potential for misuse (e.g., excessively long lifelines, improper anchor points, and the use of ropes instead of harnesses or lifelines).

To adequately address this issue, the following recommendations should be considered for maintaining a safe workplace and preventing injuries and illnesses:

1. Substantiate other best safety practices associated with confined-space entry as a means of reducing the frequency and severity of grain entrapments. Such practices should include the following:
   - Never enter a grain storage structure while grain is being unloaded either by gravity or by under-floor conveyors.
   - Use lockout and tagout procedures whenever a worker enters a structure to prevent unintentional energizing of equipment.
   - Never enter a storage structure when the grain surface appears to be crusted.

- Never enter a structure with vertically crusted grain above the level of the worker.
- Use an external observer who has both line-of-sight and communication-device contact with the worker inside.
- Relocate the unloading controls for quick access by observers.

2. Research the use of various types of safety equipment and their effectiveness in preventing grain entrapments. Consider reviewing and updating (as warranted) the regulations and standards that address the use of harnesses and lifelines in grain storage structures. For instance, efforts were recently made to clarify the regulations relative to exposure to sweep augers inside these structures (OSHA, 2013). Similar research should be done to develop new evidence-based regulations or to clarify current regulations regarding the use of safety harnesses and lifelines in these applications.
3. Develop an effective educational program to teach farmers and other agricultural workers at OSHA exempt facilities the importance of safety equipment and the proper techniques for using safety harnesses, lifelines, and other confined-space equipment and procedures. Special attention should be given to the problems associated with fall-protection devices, including expandable lanyards, excessively long lifelines, the need for observers, and air quality monitoring.
4. Because most fatalities in grain entrapments are caused by asphyxiation (Issa et al., 2017), other safety measures should also be considered, such as those that are required for toxic environments and devices designed to protect the airway. Consideration should be given to safety devices that may prevent full engulfment, such as the expandable vests that are used to prevent engulfment in snow avalanches.

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