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An analysis of injuries to front-end loader operators during ingress and egress

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A B S T R A C T

Slips, trips, and falls from mobile mining equipment have been documented for decades. However, little research has been conducted to determine the events precipitating these incidents during ingress or egress. This study examined slips, trips, and falls sustained during ingress or egress from front-end loaders to determine the frequencies of factors that may contribute to injuries. Non-fatal injuries, when getting on or off of front-end wheel loaders specifically, were identified, coded, and analyzed from the Mine Safety and Health Administration's accidents, injuries, and illnesses database. Overall trends, events that precipitated the injury, injuries sustained, contributing factors, location of the individual, and equipment characteristics were analyzed. More incidents occurred during egress (63%); and egress is believed to be more hazardous than ingress. Foot slips were the most common event that precipitated the incident and the leading cause of these was contaminants on the equipment. Misstep, loss of footing, and step on/in related incidents were more common during egress and are likely due to the operator's reduced visibility when descending a ladder facing the equipment, limiting their ability to detect hazards. Egress also makes an operator less capable of avoiding unsafe ground conditions as indicated by the significant number of step on/in injuries occurring on the ground during egress. Most of the front-end loaders associated with the incidents were found to have bottom rungs with flexible rails, which may also increase fall risk during egress due to inconsistent rung heights and lengthy transition areas from the ground, through the flexible-railed rungs, to the rungs with rigid rails. Recommendations are provided to reduce the risk for slips, trips, and falls from mobile mining equipment.

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1. Introduction

Slips, trips, and falls (STF) are the second leading cause of non-fatal injuries in the mining industry (Mine Safety and Health Administration, 1995–2015). Many factors contribute to these injuries including the environment, the task being performed, the equipment being used, and personal factors. In mining, slips and falls do not occur solely on walking surfaces during travel but are also prevalent when getting on and off of equipment. From 1995 to 2015, most non-fatal slips and falls that occurred on equipment at surface mining facilities were associated with mobile equipment (bulldozer, front-end loader, tractor and truck) (n = 2322) (Mine Safety and Health Administration, 1995–2015). Issues associated with ingress and egress systems on large mining equipment were identified as early as 1978 (Conway and Cross, 1978). A more recent National Institute for Occupational Safety and Health (NIOSH) analysis of falls from mobile mining equipment found that nearly half of the injuries occurred during ingress/egress, with nearly two-thirds during egress (Moore et al., 2009). Injuries to mobile equipment operators were further examined in an analysis of non-fatal injuries to haul truck operators over a 5-year period (Santos et al., 2010). Of the 359 injuries associated with slips or falls on haul trucks, 46% occurred during egress and 23% occurred during ingress (Santos et al., 2010). These numbers are consistent with those from other industries, such as trucking, where there were three times as many egress injuries as compared to ingress injuries (Lin and Harvey Cohen, 1997). As these statistics show, mobile mining equipment may create a significant injury risk for operators during ingress and egress.

Previous research has also identified key elements of the access system that are critical for safe ingress and egress. Design guidelines have been recommended for the cab, ladders and ladder rungs, steps, and handrails leading into the cab (Bottoms, 1983;

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Bottoms et al., 1979; Gavan et al., 1980). Even with established guidelines, there may be issues with compliance with the current guidelines and standards. Guidelines may not be specific enough for ingress and egress systems of elevated vehicles such as mobile mining equipment (Hirth and Khalil, 2004). Simulation research has also been carried out to investigate ingress and egress from heavy earth moving equipment, however the focus has been on obstacle avoidance during ingress and egress to the cab, with little attention placed on the stairs or ladders needed to reach the cab (Kwon, 2011). The height of mobile mining equipment and the distance from the ground to the cab put mine workers at unique risks during ingress and egress.

Mobile mining equipment ingress/egress systems utilize ladders, stairs, or combinations of both. Of these systems, ladders pose the greatest risk for severe injury (Cohen and Lin, 1991). Falls from ladders often result from the user losing contact with the hand and/or foot that provides supporting contact on the ladder. Typically, falls from ladders initiate as a result of a misstep, a slip, or a balance perturbation and also commonly occur during transitions to and from the ladder (Shepherd et al., 2006). Personal factors and individual climbing styles may influence fall risks (Cohen and Lin, 1991; Pliner et al., 2014; Pliner et al., 2017; Shepherd et al., 2006). In addition, the ladder design and the condition it is in are also significant factors to prevent falls (Cohen and Lin, 1991; Shepherd et al., 2006). Subjective evaluations of cabin comfort on wheel loaders and excavators also indicate that overall ratings of comfort can be improved by improving the design of the ingress and egress system (Kuijt-Evers et al., 2003).

Ladders require physical exertion to ascend and descend and may have design attributes that increase fall risk. Vertical ladders increase the potential for a foot or hand slip as compared to inclined ladders (tilted forward at less than 90° to the horizontal) due to an increased horizontal force at the feet and the total hand force for vertical ladders (Bloswick and Chaffin, 1990). Ladders with restricted toe clearance may also increase fall risks (Pliner et al., 2014). Laterally tilted (to the side) ladders are more difficult to climb than vertical ladders due to changes in the hand and foot load cycle times (Armstrong et al., 2009). Handrail placement is also a concern for mobile equipment ladders because the hands must constantly exert force (Armstrong et al., 2009). The location and spacing of handrails must allow the user to maintain three points of contact for the full length of the ladder and into the cab. Bottom rungs that are high off of the ground increase the stresses on the upper body during ingress and egress and increase the ground reaction forces when stepping off of the ladder, making ingress and egress more strenuous (Gavan et al., 1980). Fig. 1 provides three examples of ingress/egress systems commonly used on mobile mining equipment. Due to the harsh mining terrain with rough or uneven ground conditions, fixed ladder rails that extend below the frame of the truck would be at high risk for being damaged or ripped off. To combat this risk and provide a lower rung with a suitable height for use, bottom rungs with flexible rails are used. These flexible rails utilize wound wire cables, chains, or rubber to attach the rung to the ladder system. This creates a rung that is capable of deflecting when encountering rough terrain while remaining securely attached to the ladder system. The flexibility of the rails, however, may create additional risks (Gavan et al., 1980).

Environmental conditions may play a role in STF from mobile equipment ladders. While most of the body weight is supported by the feet during ingress and egress from the ladder, the hands play a crucial role in fall prevention. A slip or misstep will likely result in a fall from a ladder if the hands are unable to maintain contact with the ladder (Pliner et al., 2014). When exposed to environmental contaminants such as water, mud, or ice, the risk for a slip is increased (Fathallah et al., 2000; Lin and Harvey Cohen, 1997). The condition of the ground is also a concern. The ground reaction forces expected when egressing from mobile mining equipment remain unknown. However, similar research on commercial tractors, trailers, and trucks has reported ground reaction forces exceeding two times body weight when stepping down utilizing the supplied egress systems (Fathallah and Cotnam, 2000). Given this level of force, slippery or uneven ground conditions or debris on the ground could likely result in a fall or other injury.

The high prevalence of slip and fall injuries during ingress and egress (Moore et al., 2009; Santos et al., 2010) highlight the urgent need to determine the causes of these injuries and to elucidate the elements of the ingress/egress system that put mine workers at risk for falls. Accordingly, the goal of this research was to identify the factors that precipitated a non-fatal STF incident during ingress or egress to front-end loader operators, to determine the location of the operator in relation to the front-end loader at the time of the incident, and to document the ingress/egress system characteristics of the front-end loader involved in the incident. These results can be used to ascertain which equipment-related factors may put

Fig. 1. Examples of three ingress/egress systems. From left to right: cable-sided first rung with a vertical ladder, rubber-sided first rung with a vertical ladder, and combination stairway and ladder with two rubber-sided bottom rungs.

mine workers at risk for an STF during ingress or egress from front-end loaders.

2. Methods

2.1. Dataset

The Mine Safety and Health Administration (MSHA) requires mines to report accidents, injuries, or illnesses that occur, other than first-aid, using the MSHA 7000-1 form under part 50 of the U.S. Code of Federal Regulations. This dataset is published annually by MSHA, and NIOSH provides the dataset in an SPSS (IBM SPSS Inc., Chicago, IL) format, which can be found at https://www.cdc.gov/niosh/mining/data/default.html. Twenty years of MSHA accident, injury, and illness data, from 1996 to 2015, was selected for this analysis; as the general design of front-end loaders and their ingress and egress systems have not changed much in this period.

The initial dataset was comprised of only non-fatal injuries reported to MSHA (n = 242,526)—i.e., fatalities were excluded. The dataset was reduced based on mine worker activity at the time of the incident (coded by MSHA) to extract injuries related to “getting on/off equipment, machines, etc.” (n = 17,169). Getting on/off equipment was the 5th highest category of worker activities at the time of injury. The dataset was further reduced based on the mining machine/equipment involved (coded by MSHA) to include only “front end loader, tractor-shovel, payloader, highlift, skip loader” (n = 2358), which was the largest single category. The manufacturer and model of the equipment were determined from the equipment model number field or information provided in the narrative text field of the incident report. This information was used to extract only those injury reports associated with front-end loaders (hereafter referred to as ‘loaders’). Equipment with unknown model numbers that did not match manufactured equipment and entries with missing data or inadequate detail to identify the exact loader were eliminated. The final dataset contained 1457 reports. Table 1 provides a summary of case selection from the MSHA accident, injury, and illness dataset.

2.2. Data coding

The dataset was further coded based on the narrative text available to identify details of the incident and to classify equipment characteristics as specified below.

2.2.1. Incident details

In general, specific details of the incident cannot be found in the pre-coded fields of the MSHA dataset. Hence, the narrative texts supplied with the incident reports were used to extract incident details. Coding was carried out in two stages. The first stage involved preliminary coding of 150 narratives to develop and finalize the coding scheme. The coding scheme was modified from the scheme used by Moore et al. (2009) in their analysis of fall from equipment injuries. Once the coding scheme was finalized, the entire dataset was coded based on the categories described in detail below. In both the preliminary and final coding, each record was coded by two researchers independently. Any discrepancies in the coding were resolved through discussion and input from a third researcher.

The narrative text was coded to identify if the incident occurred during ingress or egress from the equipment, maintenance, or during some other activity. If the direction of travel (ingress vs. egress) was specified, it was also coded. Ingress and egress was defined as traveling from the ground to the cab and vice versa, respectively. Maintenance included cleaning windows, other routine or unscheduled maintenance, or gaining access to other parts of the equipment other than the cab such as the engine compartment, radiator, or fluid/fuel lines.

The locations of the feet at the time of the incident were coded when indicated in the narrative. The locations of the feet were coded as ladder/stair, ground, platform/cab, tire/fender, and other. When information was available on the specific rung or step of the ladder or stair, respectively, it was also coded. For this variable, the data was coded to refer to the location where the operator was moving to at the time of the incident. If the individual missed the bottom step, the location was coded as the bottom step because the hazard actually occurred at the level of the bottom step. If the individual slipped on the platform, the location was coded as the platform. If the narrative clearly stated that there was an object in the hand, it was also coded.

The event that precipitated the incident was categorized as fall, foot slip, trip or foot caught, hand slip, misstep or loss of footing, step on or in, jump, loss of balance, and other. Fall was a generic category, where the exact event that precipitated the fall was unknown and the narrative text clearly stated that the individual fell. The foot slip category included those cases where it was indicated that the individual slipped. Typically, a slip occurs after making contact with the walking surface, unlike a misstep or loss of footing where full contact was not made. Foot slip was further broken down as foot slip with recovery, if the narrative indicated that the individual recovered or caught themselves before falling; foot slip with fall, if the narrative indicated that the individual fell; and a generic foot slip, if it was unclear whether there was a fall or some sort of a recovery. A similar breakdown was used for the trip or foot caught, hand slip, misstep or loss of footing, and loss of balance categories. Preliminary coding indicated that there were a number of incidents where the only detail on the event that predicated the injury was that the individual sustained a sprain or strain, twisted or pulled a joint or muscle, heard a pop, or had pain. These events were coded as idiopathic because no other details on the actual event that precipitated the incident were present so it was unclear what caused or contributed to the injury.

Factors that may have contributed to the incident (contributing factors) were coded as contaminant on equipment, ground condition, equipment failure, unexpected movement, or other. Ground condition was only included if the incident occurred at ground level. In addition, the specific contaminant on the surface or other conditions that could be a secondary contributing factor were coded as water, ice/snow, mud/slick ground surface, rock, hole, uneven surface, other inclement weather (including wind), or other. In some cases, the narrative text did not clearly indicate if a contaminant was on the surface that the feet were in contact with, but instead indicated that the equipment was wet, it had just rained, or the steps were muddy. In these cases, the surface contaminant or condition was specifically mentioned in the

Table 1
Selection criteria from the full injury dataset to the final dataset used for analysis.

Selection criteria	Sample size	Percent of larger sample
Non-fatal injuries from 1996 to 2015	242,526	–
When getting on or off equipment or machinery (5th highest category)	17,169	7.08%
When operating front end loader, tractor-shovel, payloader, highlift, or skip loader (highest category)	2358	13.73%
Front-end wheel loaders only where equipment details could be identified and coded	1457	61.79%
Coded as ingress/egress	1291	88.6%
- Egress	924	–
- Ingress	367	–

narrative text, so it was coded as a secondary contributing factor. In other cases, more than one contributing factor and secondary contributing factor were specified in the narrative text. These incidents were then coded to have multiple contributing factors. For all variables, when the information in the narrative text was inadequate to code the variable, it was coded as unknown. In addition, specific information for variables coded as "other" was provided by the coders.

2.2.2. Equipment characteristics

Information on the exact manufacturer and model of the equipment was identified from either the equipment model number field in the MSHA dataset or based on information provided in the narrative text. For each model identified, an image search was conducted using either the manufacturer's website or the Google search engine (Google Inc., Mountain View, CA) to locate a clear picture of the primary ingress/egress system. In some cases, a single picture was inadequate to extract all the required equipment details due to poor photography angles or blurry images. In those cases, additional pictures were identified and coding was carried out using multiple images of the same make and model. Two researchers independently coded the features of the ingress/egress system and any discrepancies in the coding were resolved through discussion and input from a third researcher.

The size, design, and construction of the loader ingress/egress systems can be very different based on equipment manufacturer and model, and therefore generic equipment characteristics were coded. The type of ingress/egress system was coded as having a vertical ladder, inclined ladder, stairs, or combination (equipment that has both a ladder and stairs). The number of stairs and ladder rungs (not including the final platform) were counted. The number of rungs with flexible rails (if any) and the construction of these flexible rails (cable, rubber, chain, or other) were also coded. Finally, the location of the first designated handhold during ingress into the equipment from the ground was coded. The sides of the ladder (rails) or rungs were not counted as designated handholds; instead a designed handhold was defined as a rod/bar/attachment designed and located specifically for an individual to grasp during ingress or egress. In a few cases, the sides of the ladder that return to the equipment for mounting were flared, protruded out, or were curved to serve as a handhold and these were coded as designated handholds.

2.3. Analysis

The coded incident details and equipment details were merged with the variables present within the MSHA accident, injury, and illness dataset for further analysis. The resulting dataset was analyzed utilizing descriptive statistics in SPSS (IBM, version 19) for frequencies of factors that may contribute to injuries during ingress and egress from loaders via a ladder. Associations between variables were determined using a Chi-square test with an alpha level of 0.05.

3. Results

3.1. Overall trends and demographics

Of the 1457 incidents in the final dataset, 924 (63.4%) occurred during egress, 367 (25.2%) occurred during ingress, 70 (4.8%) occurred during maintenance activities, and the remaining 96 (6.6%) were either unknown or occurred during other tasks. Further analysis and discussion has been limited to the 1291 incidents associated with ingress and egress.

There was a steady significant reduction in the number of incidents associated with ingress ($\beta = -0.908$, $t(18) = -5.86$, $p < 0.001$; $R^2 = 0.656$) and egress ($\beta = -2.35$, $t(18) = -7.175$, $p < 0.001$; $R^2 = 0.741$) for loaders between 1996 and 2015 (Fig. 2). Throughout this time, egress injuries were consistently more prevalent than ingress injuries. Most ingress and egress incidents occurred when mining stone (n = 461, 35.7%), coal (n = 359, 27.8%), and sand and gravel (n = 292, 22.6%) at surface mines (strip and open pit mines including associated shops and yards) (n = 878, 68%) and mill or preparation plants (mill, preparation plants or breaker operations associated with one specific mine and the associated shops and yards) (n = 279, 21.6%).

Males accounted for 99% (n = 1273) of those injured. The mean age was 43.39 (SD = 12.07) years with a range of 18–84 years. Mean total mining experience was 12.5 (SD = 11.2) years with a range of 0–55 years. Three main job types/occupations (from the MSHA dataset) accounted for approximately 65% of the incidents. Front-end loader/high lift operator accounted for the highest percentage of incidents 46% (n = 595), followed by bulldozer/tractor operators at 10% (n = 126), and mechanics/repairman/helper at 9% (n = 112).

3.2. Events that precipitated the incidents

Foot slips accounted for nearly 38% (n = 490) of the reported events that precipitated an incident during ingress or egress. Misstep or loss of footing was the only other category that accounted for more than 10% where the exact event was known (10%, n = 130). A large proportion of the events were coded under the generic 'fall' category (n = 96, 7%), as there was inadequate detail to decipher the exact event; or were coded as idiopathic (n = 260, 20.1%), as the only information presented was that the individual sustained a sprain or strain, twisted or pulled a joint or muscle, heard a pop, or had pain. There was a significant association ($\chi2 = 108.278$ (10, 1291), $p < 0.001$) between the event and the direction of travel (ingress vs egress). In general, there were more injuries during egress as compared to ingress, except when coded as hand slip and other (Table 2). Step on/in, jump, trip, and misstep/loss of footing contributed to an exceptionally high proportion of injuries (greater than 80%) during egress as compared to ingress. For incidents where it could be identified if the individual fell or recovered, most cases led to a fall (Fig. 3). Recovery, usually in the form of the individuals 'catching themselves' was not reported as often. In addition, there were quite a few cases where there was no clear indication if the individuals fell or were able to recover.

3.3. Types of injury

Over half of the injuries associated with ingress or egress resulted in strains and sprains (56%). Other common injuries included fractures/chips (15%) and contusion/bruise (10%). The most commonly affected body parts were the back (19%), knees (17%), ankles (11%), shoulders (11%), and multiple body parts (8%). Of the strains and sprains, most occurred in the back (23%), knees (22%), ankles (18%), and shoulders (15%). Of the fractures/chips, most occurred at the wrist (15%), feet (not ankles or toes) (12%), ankles (10%), chest (9%), back (7%), and fingers (17%). Of the contusions/bruises, most occurred at the knees (21%), back (16%), multiple body parts (11%), chest (9%), and elbow (9%). When there was a recovery, there was a trend to have more upper extremity injuries, especially of the shoulder, as compared to falls that led to lower extremity and back injuries. Fig. 4 shows an example of body parts affected for slip events when a recovery occurred versus when a fall occurred.

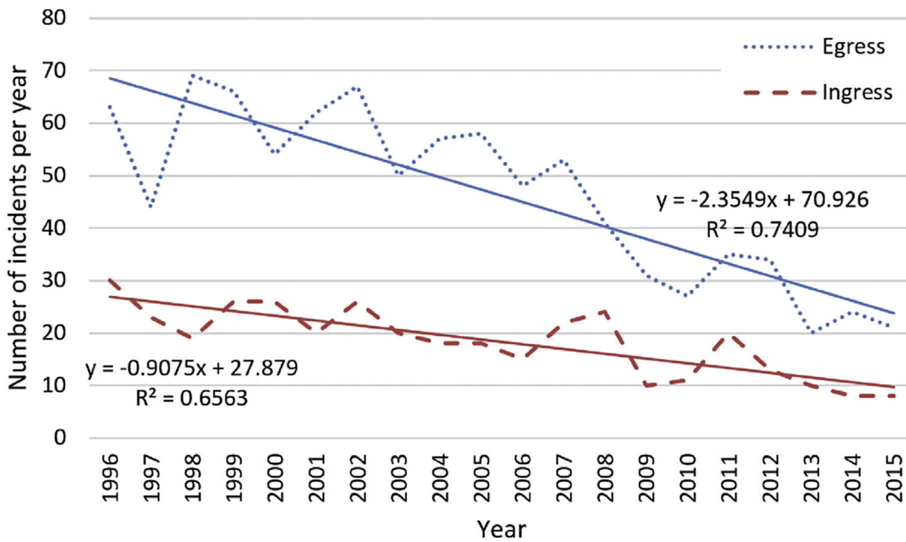

Fig. 2. Trend in incidents related to ingress and egress over the 20-year analysis period.

Table 2
Events that precipitated incidents based on direction of travel.

Event	Egress	Ingress	Total
Foot slip	338	152	490
Idiopathic	179	81	260
Misstep/loss of footing	112	18	130
Fall	76	20	96
Step on/in	91	2	93
Hand slip	16	26	42
Trip	29	4	33
Loss of balance	12	7	19
Jump	13	1	14
Other	46	50	96
Unknown	12	6	18
Total	924	347	1291

3.4. Contributing factors

Nearly three quarters of the incident narratives (73%) did not provide adequate detail to decipher if there were any contributing factors. However, some information was gleaned from the remaining 352 narratives. For slips, contaminants on equipment (n = 74) was the most reported contributing factor with the most common contaminants being water (n = 33), ice/snow (n = 23), mud (n = 20), and grease or oil (n = 6). Ground conditions (n = 20) was the second most reported contributing factor for slips, with the most common condition being ice/snow (n = 9), mud (n = 4), rocks (n = 4), and uneven surface (n = 3). The other major contributing factors when slips were the event that precipitated the injury were muddy boots (n = 13) and hurrying (n = 5).

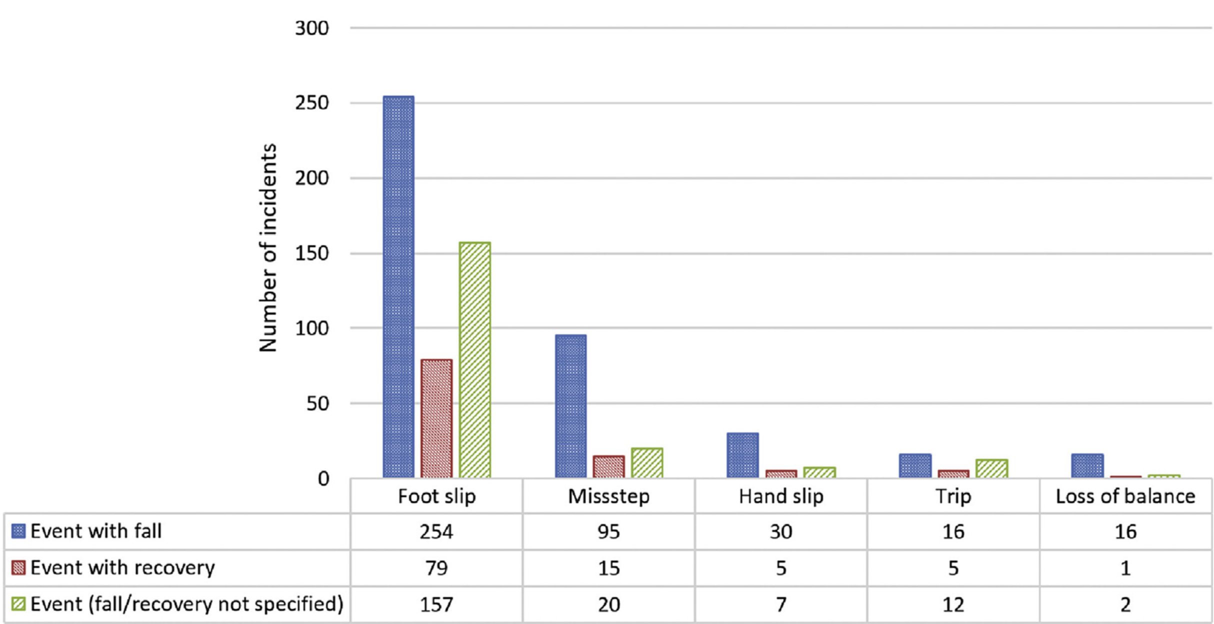

Fig. 3. Breakdown of the event that precipitated the injury if fall or recovery was clearly specified in the narrative.

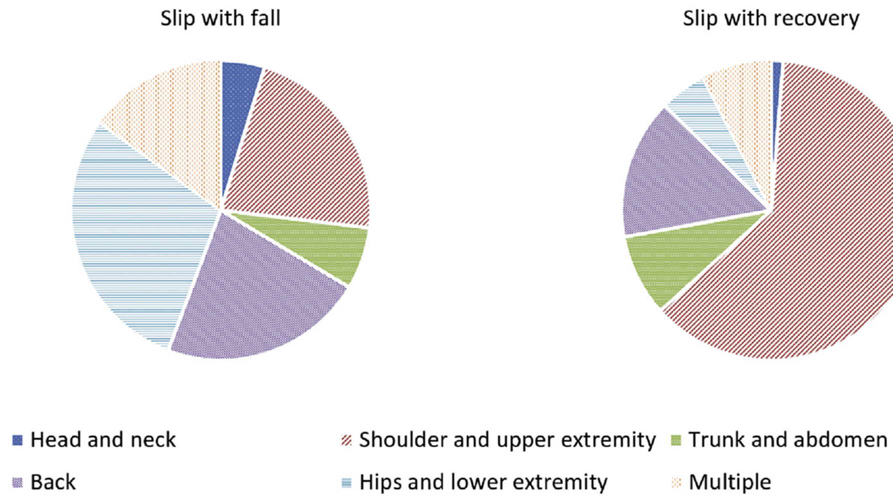

Fig. 4. Injured body parts for slips that resulted in falls as compared to slips where the individual recovered.

When step on/in was the event that precipitated the injury, ground conditions (n = 87) were exclusively the contributing factor. Rocks (n = 47), uneven surface (n = 20), holes (n = 10), and other materials such as hoses/pipes and wooden blocks/crib blocks on the surface (n = 9) were the most common ground conditions. When the event precipitating the injury was coded under the generic 'fall' category, equipment failure was the largest single contributing factor (n = 14), although information on the type of failure was lacking. When the event that precipitated the injury was classified as 'other' and the contributing factor was known (n = 32), there were 13 instances where the contributing factor was unexpected movement caused by the wind blowing the cab door, and 7 instances where equipment failure contributed to the event even though information on the type of failure was lacking.

3.5. Locations of the feet at the time of injury

In approximately 70% of the cases in the final dataset, there was adequate information to decipher the locations of the feet at the time of the incident. When the locations of feet were known, 74% of incidents occurred on the ladder/stair, 20% occurred on the ground, 4% occurred on the cab/platform, and 3% occurred on the tire/fender or some other location. In 166 cases, the bottom rung/step was explicitly identified as the location of the feet (141 for egress and 25 for ingress). In 34 cases, the top rung/step was explicitly identified as the location of the feet, and in 35 cases the 2nd step was identified as the location of the feet; however, it was not often clear if the rungs/steps were counted from the top or bottom. A further analysis of the locations revealed a significant association between the locations of the feet at the time of the incident and the directions of travel ($\chi2 = 101.197(7, 1291)$, $p < 0.001$). When the incident occurred while the feet were on the ground, the individual was almost always egressing (97%). Similarly, when the feet were on the bottom step/rung, the individual was usually egressing (86%). In all other cases, approximately 64% of the cases were during egress and the remainder during ingress. Table 3 shows the locations of the feet based on the event that precipitated the injury broken down by ingress and egress. When on the bottom rung/step, foot slips and missteps/loss of footing were the most common events that predicated the injury. When on the ground, step on/in was often the event that predicated the injury.

3.6. Equipment characteristics

Most ingress/egress injuries occurred on equipment with vertical ladders (78%, n = 1011). Inclined ladders and combination systems accounted for 11% each (n = 138) (Table 4). Only 3 loaders had stairs only. All vertical and inclined ladders had at least 1 rung with rigid rails. Vertical ladders most commonly had (mode) 3 rungs. In comparison, inclined ladders had a modal value of 4 rungs. Most of the vertical ladders (57%, n = 575) and inclined ladders (84%, n = 116) had at least 1 bottom rung with flexible rails, with most (86% and 82% for vertical and inclined ladders, respectively) having only 1 bottom rung with flexible rails. Combination ladders most commonly had (mode) 6 stairs, 2 rungs with rigid rails, and 2 bottom rungs with flexible rails. For equipment that had a bottom rung with flexible rails, rubber sided was the most common (66.45%, n = 537), followed by cable sided (33%, n = 267). Most vertical ladders (64%) had the first handhold at or above the 3rd, 4th, or 5th rung (n = 226, n = 187, n = 229 respectively). In addition, in 18.9% (n = 191) of the cases, the first handhold was at or above the first platform. In comparison, 65.9% (n = 91) of inclined ladders had the first handhold at or above the 3rd rung, with 12% (n = 17) above the 4th rung and 19.5% (n = 27) above the platform. For combination ladders, the first handhold was most often above the 2nd or 3rd rung (49.3%, n = 68; and 44.2%, n = 61 respectively). For ingress/egress systems with stairs, the first handhold was located at or above the platform. There were no significant findings when comparing ingress to egress, the various events that predicated the injury, or the location of the feet based on the equipment characteristics, as data for each characteristic followed the global trends described previously.

4. Discussion

The objective of this research was to identify the cause of nonfatal injuries sustained during ingress and egress from front-end loaders of known makes and models, to determine the location where the injury occurred, and to document characteristics of equipment associated with the injuries. Our findings indicated that 63.4% of the injuries occurred during egress, 25.2% occurred during ingress, and the remainder (11.4%) were either unknown or during maintenance or other activities. These findings are a slightly different from those of Moore et al. (2009), who reported that approximately 75% of the incidents occurred during egress, and

Table 3
Events that precipitated injury by locations of feet at the time of the incident for ingress and egress (*: 2nd from the top or bottom of the ladder is not known).

Location of feet	Ladder/stair								Platform/cab		Ground		Other		Unknown	
	Other/rung/ step unknown		Bottom rung/ step		Top rung/step		2nd rung/step*									
Event	Egress	Ingress	Egress	Ingress	Egress	Ingress	Egress	Ingress	Egress	Ingress	Egress	Ingress	Egress	Ingress	Egress	Ingress
Foot slip	146	86	43	10	10	8	13	6	9	2	21	2	6	4	90	34
Idiopathic	23	26	13	5	0	3	0	1	1	3	53	1	2	1	87	41
Misstep/loss of footing	30	8	57	4	8	0	7	1	1	1	3	0	0	0	6	4
Fall	26	9	13	1	1	0	1	1	3	0	3	1	0	1	29	7
Step on/in	1	0	0	0	0	0	0	0	0	1	86	1	4	0	0	0
Hand slip	8	15	1	2	1	0	0	1	0	0	0	0	0	0	6	8
Trip	12	1	6	0	0	1	1	0	4	1	3	0	0	0	3	1
Loss of balance	3	1	1	1	0	0	2	1	1	1	0	0	0	0	5	3
Jump	2	0	1	0	1	0	0	0	0	0	2	0	1	0	6	1
Other	11	19	3	2	1	0	0	0	3	6		0	1	0	27	23
Unknown	1	3	3	0	0	0	0	0	0	0	1	0	1	1	6	2
Total	**263**	**168**	**141**	**25**	**22**	**12**	**24**	**11**	**22**	**15**	**172**	**5**	**15**	**7**	**265**	**124**

Table 4
The number and percentage of cases associated with equipment characteristics. #: Percent represents percent of overall sample (n = 1291). ~: Percent represents percent of total cases. *: Percent represents percent of all cases with bottom rungs made with flexible rails.

Type of ingress/egress system	Vertical ladder		Inclined ladder		Combination		Stairs	
	n	%	n	%	n	%	n	%
Total#	1011	78.4	138	10.7	138	10.7	3	0.2
Rigid rails~	1011	100	138	100	95	68.8	–	–
Flexible rails~	575	56.9	116	84.1	118	85.5	–	–
Rubber sided*	314	54.6	109	94.0	114	96.6	–	–
Cable sided*	260	45.2	3	2.6	4	3.4	–	–
Chain*	1	0.2	4	3.4	–	–	–	–
Stairs~	–	–	–	–	133	96.3%	3	1

those of Santos et al. (2010), who indicated 46% during egress and 23% during ingress for haulage trucks. These differences can be attributed to our analysis focusing on front-end loaders as compared to all mobile equipment in Moore et al. (2009) and haul trucks in Santos et al. (2010).

There is a lack of empirical evidence to explain the higher proportion of injuries sustained during egress as compared to ingress from loaders; however, there are several probable explanations. The simplest explanation could be the force of gravity. As the individual is already descending the ladder, gravity is accelerating the body downward and it would be harder to recover from any unexpected perturbation or event without an incident. Also, when descending a ladder, there is a greater reliance on proprioception for foot placement and to sense the presence of the ladder rung beneath one's feet, which could be diminished due to age or type of footwear (Robbins et al., 1995). This may have contributed to the increased prevalence of misstep or loss of footing injuries during egress as compared to ingress. When facing the ladder during descent, it is also difficult to see where the feet are landing or placed. This poses a challenge to judging distance to the subsequent rung and the ground, or identifying contaminants on the ladder rung or ground conditions such as rough, uneven, or slippery conditions that may lead to a fall. Numerous slips and step-on/in injuries with contaminants as contributing factors were identified in this study, indicating unsafe ladder and ground conditions and parking locations. Contaminants can pose a significant threat during egress, as it may be a challenge to identify the hazard and there may not be an easy way to mitigate or avoid the hazard while on the equipment. For large front-end loaders, there may be an option to eliminate the hazards associated with egress using ladders, by providing an elevated platform with stairs so egress occurs directly onto the platform which is level with the operator's cab. Unsafe ground conditions can be minimized by providing designated parking areas where ground conditions are regularly monitored and maintained free of rocks, holes, ruts, other objects, or contaminants. Although engineering controls are preferable (National Institute for Occupational Safety and Health, 2016), hazard recognition by the operator is critical and can be facilitated by increased illumination on and around the ingress/egress system and on the ground. Finally, to prevent slips due to contaminants on the shoes, shoe cleaning stations can be provided both in the parking area and on the equipment to mitigate accumulation of mud, dirt, and other debris on the sole of the shoes.

Falls from ladders commonly occur during transitions to and from the ladder and have been investigated previously for commercial equipment and ladders (Fathallah and Cotnam, 2000; Shepherd et al., 2006). Although transitions were not explicitly mentioned in the narratives examined, the location of the feet at the time of the incident provides some evidence that transitions may be critical during ingress and egress. The ground, the bottom rung, the top rung, and the second rung were explicitly indicated approximately 18% of the time. In addition, 63% of ingress/egress systems associated with injuries in this analysis had a bottom rung with flexible rails. Hence, the transitional areas may span a large portion of the ladder for loaders in the mining industry, extending from the ground, through the flexible-railed bottom rung/s, to the first rigid-railed rung. Although equipment with flexible rails have their benefits, the risk to the operators have not been adequately investigated. How individuals modify their climbing styles when transitioning from the ground to the bottom rung with flexible rails then to the rung with rigid rails and vice versa is largely unknown and warrants further investigation. In addition, inconsistent rung spacing and high bottom rungs may also influence the transition. Most ladder standards, including those for mobile and fixed machines, recommend consistent spacing between rungs (ISO 2867:2011(E) 9.4, SAE.J185 1988 3.8, ISO14122-4-2014 4.4.1.1, OHSHA CFR 29 §1910.23(b)(1), OSHA CFR 29 §1926.1053(a)(2), ANSI-ASC A14.3–2008 5.1.1, ASAE S412.1 MAR1990 (R2014) 3.2.1). However, inconsistent rung spacing is commonly observed on mobile mining equipment, especially at the transition from the ground, through the rung/s with flexible rails, to the rungs with fixed rails. The inconsistent rung heights between the ground, bottom rungs with flexible rails, and rungs with rigid rails and the larger transition area may play a role in the high prevalence of egress-related slips, missteps, and loss of footing injuries on mobile mining equipment. Ensuring consistent rung heights from the ground level through the cab may prevent injuries from occurring in these transitional areas.

To prevent injuries associated with ingress and egress it is advantageous to prevent the event that precipitated the incident; however, once the event has occurred, recovery is one way to prevent a fall or potentially reduce the severity of the incident. Pliner et al. (2017) identify that when the body is moving downward, it requires more effort to change the momentum, thus reducing an individual's ability to recover from a fall during egress as compared to ingress. Our analysis supports this thesis as most events led to a fall and most occurred during egress. Ensuring that adequate handholds are provided for the length of the ladder into the cab may increase the potential for recovery. Additional research to improve the location and design of handholds can improve the likelihood of recovery during egress and prevent falls.

Equipment failure and unexpected movement was the leading contributing factor when the exact event that precipitated a fall was categorized as other or unknown. Mitigating these factors through regular and thorough inspection and maintenance could prevent injuries. The unexpected movement of the door due to wind was identified in several cases and may be mitigated through the use of chain stops or dampers. Regular and thorough inspection, maintenance, and repair can also eliminate excessive movement of the bottom rungs with flexible rails and ensure all parts of the ladder are in good working condition.

4.1. Limitations

There are some limitations to this study. The numbers and percentages presented for the equipment characteristics may not be indicative of the types of equipment used in the mining industry. It was not possible to calculate rates, as information on the number and type of loaders used at mines was not available. However, reporting the absolute number of incidents for each type of equipment can help ascertain the need to improve safety associated with ingress and egress. The injury coding was reliant on provided narratives that often had limited descriptions of the contributing factors. However, the injury reports are the best publically available source for detailed information on non-fatal incidents in the mining industry. Improved reporting of the event and contributing factors in the future may help researchers and mining companies to identify the root cause of non-fatal incidents and control risks.

5. Recommendations

To prevent injury during ingress or egress, operators must prevent the event that precipitated the incident. Based on this analysis, ingress and egress safety could be improved through design, maintenance, and housekeeping of ladders and parking areas. Recommendations are provided to mitigate the causes and contributing factors to the injuries examined in this research. Suggested improvements include:

- Ensure consistent rung heights from the ground level through the cab.
- Provide adequate lighting to improve detection of hazardous ground or ladder conditions.
- Provide designated parking areas free of hazardous ground conditions such as uneven terrain, rocks, or slippery surfaces.
- Construct ingress/egress platforms with stairs that allow operators to access the cab of the equipment directly, to eliminate the use of ladders when possible.
- Ensure that adequate handholds are provided for the length of the ladder into the cab.
- Regularly and thoroughly inspect ingress and egress systems to identify and prevent any potential failures and ensure all rungs are securely attached to the ladder system to prevent unexpected movement or excessive flexibility.

Disclaimer

The findings and conclusions in this manuscript are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health (NIOSH). Mention of any company or product does not constitute endorsement by NIOSH.

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