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Evaluation of Occupational Safety in the Operation and Maintenance Activities of Dams

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ABSTRACT

The accidents occurred during the operation/maintenance activities of US dams between 1984-2018 were analyzed from the OSHA database and 88 cases were selected. The objective of our study is to identify and investigate potential hazards and risk sources responsible for and affecting OHS performance in the operation/maintenance activities. Furthermore, the factors responsible for injuries and fatalities happened during these activities are determined. It is found out that 5.2% of precaution negligence was related to the facility and wrong design and poor maintenance were the main negligence factors. The important point to be noted is that these negligence factors result in fatal accidents, albeit few. The results also show that machine safeguarding was not available or provided in most of the cases and 12.7% of those who had occupational accidents did not use appropriate PPE or did not use PPE at all.

Keywords: Construction Safety, Accident Cause, Operation and Maintenance, Dams

1. INTRODUCTION

The construction industry is one of the most hazardous industries in the world because of its diverse and complex nature [1-7]. Moreover, the construction industry ranks higher in fatal occupational injuries than any other sector due to the nature of work [8-12]. So, it mandates that the activities of construction industry have to be studied and further analyzed for reducing accident rates. However, to achieve more efficient results in terms of occupational safety, it is necessary to examine the construction sector which is an integral component of diverse sectors for growth and development. In this study the construction sector is studied by categorizing it based on the end-use of the project such as residential, industrial,

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infrastructure, and road or dam construction. Since the construction processes of diverse sectors are different from each other, these construction branches should be examined separately.

Dams, which are one of the most fundamental infrastructures required by any country, have provided many benefits for human survival and have been utilized thousands of years by mankind [13]. Additionally, dams provide a wide range of economic, environmental, and social benefits, including recreation, flood control, water supply, hydroelectric power, waste management, river navigation, and wildlife habitat [14]. So, dam constructions are done in all ages of mankind, and it is a necessity for humans to survive. According to estimates, over $2 trillion was spent on constructing dams around the world in the 20th century [13]. In addition, most of the dam construction potential has been realized, especially in developed countries (Table 1). Apart from the potential hazards and risks that may arise during dam construction, there are specific risks in terms of occupational safety when the operation and maintenance activities are performed in existing dams, reservoirs, and auxiliary facilities.

There are literatures on "dam safety" that address the problems when demolishing of a dam and/or seek solutions to prevent it [15-19]. However, unfortunately there is almost no literature that deals with the occupational health and safety (OHS) problems in dam constructions. This issue is reflected in the ICOLD bulletin 73 (1989) as "in the majority of dam sites, the risk of fatal accident risk for workers during the construction is higher than the risk of dam break failure" [20].

Based on the various studies [21-24], it is concluded that rate of severe accidents and fatal accidents that occur in dam construction very high and alarming when compared to other construction sites. Hussen et al. (2020) revealed that the annual occupational injury prevalence of the dam construction site was 57.8% [25]. Further, Yılmaz and Başağa (2018) also stated that dam constructions are the second most hazardous construction site where accidents occur at a rate of 19.6% [23]. It is noted that existing research on the subject only focuses more on surveys or observation studies [25-31]. Although it is useful to conduct surveys and use descriptive statistics, using information, such as how the accident occurred and who was involved is not always sufficient to identify the most important contributing factors.

Therefore, analyzing past accident reports to support findings from surveys could be invaluable in accident causation studies. The databases created on the subject were not enough and the work accidents that occurred in the dam sites were not analyzed statistically before. Besides, accidents occur not only during the construction phase but also during operation and maintenance activities of dams. Developed countries have completed constructions of large dams long back, but the operation and maintenance of these dams is continuing and will continue for decades. Nowadays accidents occur during the operation and maintenance activities rather than in construction activities in developed countries. While there are very few studies in the field of OHS in dam construction, there is no study focusing on OHS during the operation and maintenance activities.

The aim of this study is (1) to identify the risk sources that have potential hazards and influence OHS performance, (2) to find the factors responsible for the injuries and fatalities occurred during operation and maintenance activities of dams, reservoirs, and dam auxiliary facilities, and (3) to investigate the frequency distributions of these factors. Subsequently,

these findings will provide guidelines and further necessary safety measures to be adapted to preventing future accidents. Further, it is expected that the findings of the study will guide the employees responsible for operation and maintenance works, guide the occupational safety departments of the dam sites, inform the occupational safety experts about the industry and inspire the researchers.

Table 1 - Number of dams in the topmost 25 countries

	Country	**ICOLD World Register of Dams 2020**	**Percentage of total dams (%)**
1	China	23841	41.7
2	United States of America	9263	16.2
3	India	4408	7.7
4	Japan	3130	5.5
5	Brazil	1365	2.4
6	Korea (Rep. of)	1338	2.3
7	Canada	1150	2.0
8	South Africa	1116	2.0
9	Spain	1064	1.9
10	Turkey	973	1.7
11	France	706	1.2
12	Iran	594	1.0
13	United Kingdom	580	1.0
14	Australia	567	1.0
15	Mexico	543	0.9
16	Italy	541	0.9
17	Germany	371	0.6
18	Norway	347	0.6
19	Albania	308	0.5
20	Zimbabwe	256	0.4
21	Romania	241	0.4
22	Portugal	234	0.4
23	Austria	232	0.4
24	Thailand	220	0.4
25	Sweden	190	0.3
	Others	3621	6.3
	Total	57199	100.0

2. THE OPERATION AND MAINTENANCE ACTIVITIES OF DAMS WITH COMMON POTENTIAL HAZARDS

The operation and maintenance (if necessary, repair) activities of dams is significantly important for efficient operation of a dam and utilities to function effectively throughout their economic life. To evaluate the operation and maintenance of dams, reservoirs, and auxiliary facilities in terms of occupational safety, the various parts of a dam should be considered. While the controls and inspections of these parts are carried out within the scope of the operation and maintenance activities, the topics that need to be evaluated are summarized and presented in the flowchart (Figure 1).

The operation, surveillance, maintenance, and if necessary repair processes can be carried out by automation and require the presence of personnel at the dam site. Moreover, the risk potential for work accidents is higher in maintenance and repair activities since the activities require people to be available and work on sites.

Workers may be exposed to dangers such as collapses, cave-ins, toxic or suffocating gas emissions, gas explosions, dust explosions, component falls, electrocution, and floods. Apart from that, many heavy equipment works simultaneously in dam construction areas may pose problems. The utilization of heavy equipment such as excavator, loader, dump trucks, scrapers and so on comprised of great portion of construction operations in dam projects. Moreover, numerous workers are also present in these areas. Working on or around heavy equipment is high-risk work. If an incident occurs, the result is often a life-altering injury such as a broken bone, head injury, or, in many cases, loss of life. Incidents involving heavy equipment deeply affect not only the person who is injured but also the person operating the equipment or any co-workers nearby [32]. The work environment, which is complicated by the nature of the work, causes various accidents. Heavy equipment striking or slamming pedestrians are the prominent types of accidents. Further, noisy working environment prevents the vehicle sensors from being heard by the workers which result in accidents [24].

3. METHODS

3.1. Data Acquisition

The study specifically focuses on the operation and maintenance of dams, reservoirs, and auxiliary facilities. Because of this reason, data mining should be done to the database consisting of retrospective and comprehensive accident reports. The OSHA report database contains all research details and is very suitable for academic studies. Moreover, there are more than 90,000 dams in the United States according to the American Society of Civil Engineers (Figure 2) spread across the country [33]. OSHA accident reports were selected, because of all these reasons, to examine the accidents that occurred during the operation and maintenance activities of the dams, which are still functioning effectively in the United States.

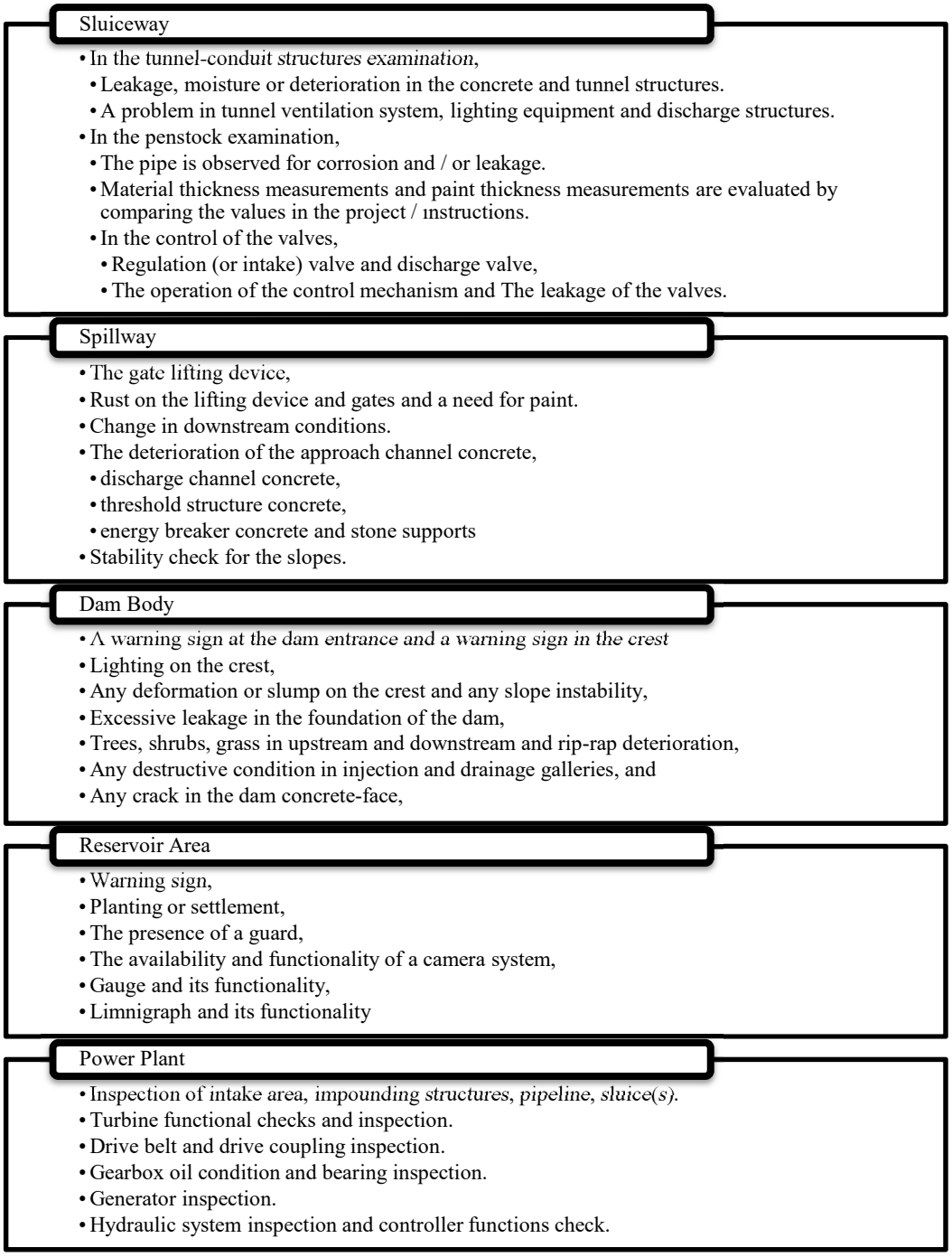

Figure 1 - The operation and maintenance activities.

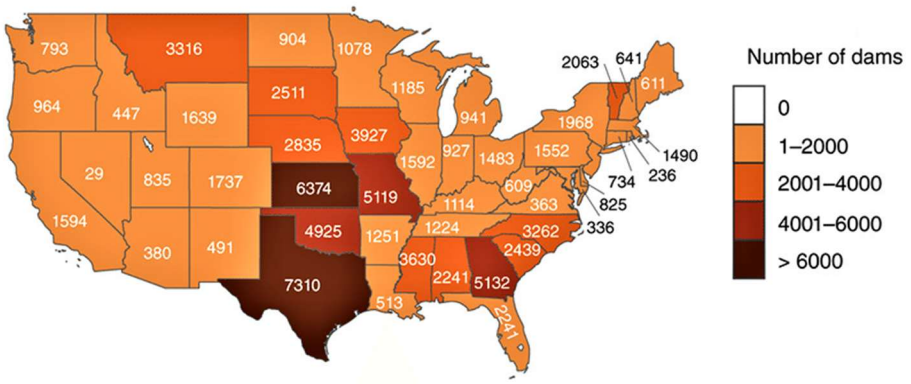

Figure 2 - Distribution of dams in the contiguous US [34].

Further, it should be noted that the Standard Industrial Classification System (SIC), a system for classifying industries by a four-digit code, was used as a limitation of data mining [35]. SIC codes related to construction within the scope of the study were used. Accidents occurring during operation and maintenance works of dams, reservoirs and auxiliary facilities were selected. Extensive elimination of accident cases was performed to achieve accurate and reliable data that is free from bias. Finally, 88 cases were remained that resulted in injuries and fatalities and they were used to create the database of accidents in operation and maintenance works of dams, reservoirs, and auxiliary facilities from 1984 to 2017.

3.2. Causes of Accidents in Operation and Maintenance of Dams, Reservoirs, and Auxiliary Facilities

It is observed that operation and maintenance activities often carried out by employees in areas which are not familiar to them. Even if they do not know the conditions very well or are familiar with environmental conditions, they work in areas where they do not pay much attention to the environmental conditions as their intention is to finish the job as soon as possible. Therefore, statistics and experience show that a large majority of accidents occur during the execution of corrective maintenance activities [36].

All tools, equipment, machinery, and installations need maintenance and repair periodically. Once the dam construction has been completed, regular inspections and maintenance are required to keep it in proper and efficient operating condition. Operation and maintenance activities contain some potential hazards, which necessitate the importance of proper safety and accident prevention throughout this process. According to Karimi et al. (2019) poor maintenance management (25%) tops the ranking of underlying causes of accidents [28]. Fatihkuşan (2011) indicated that 10%–15% of fatal accidents occur in maintenance and repair activities based on EUROSTAT statistics [37]. In European countries, between 10% and 20% of all work accidents and between 10% and 15% of all fatal work accidents can be attributed to maintenance operations [38].

The database used in this study classifies the injuries into fatal and nonfatal. When the accidents occurring in dam maintenance and repair works are investigated, it is found that 68.2% of these accidents result in loss of life (Table 2). Accident characteristics variables (nature of injury, type of injury) reveal plenty of information regarding the incident and injury; in other words, they describe the accident. Therefore, examination of these variables may give important information in learning the root causes of the accident. When the "type of injury" variable was examined, it is found that "drowning" and "falling from height" were the prime causes of accidents with data showing 34.1% and 14.8% frequencies, respectively. According to Hussen et al. (2020) falling from height is the most common type of injury in dam construction [25]. It is also observed from the studies that asphyxia (29.5%) and fractures (13.6%) were the most encountered injuries.

Table 2 - Distribution of accidents characteristics

Variables	Categories	Frequency	Percent	Cumulative Percent
Degree of injury	Fatality	60	68.2	68.2
	Hospitalized injury	28	31.8	100.0
Nature of Injury	Asphyxia	26	29.5	29.5
	Fractures	12	13.6	43.1
	Bruises/Contusions/Abrasions	4	4.5	47.6
	Electrical shock	4	4.5	52.1
	Cuts/Lacerations	3	3.4	55.5
	Burn/Scald (heat)	3	3.4	58.9
	Sprain/Strain	2	2.3	61.3
	Dislocation	2	2.3	63.5
	Concussion	1	1.1	64.6
	Amputation	1	1.1	65.8
	Other	30	34.1	100.0
Type of Injury	Drown	30	34.1	34.1
	Fall from height	13	14.8	48.9
	Struck by falling object /projectile	11	12.5	61.4
	High pressure	8	9.1	70.5
	Caught between	7	8.0	78.5
	Electric shock, other and unknown cause	5	5.7	84.2
	Asphyxiation/Inhalation of toxic vapor	3	3.4	87.6
	Traffic accident	3	3.4	91.0
	Wall collapse	2	2.3	93.3
	Slip	1	1.1	94.3
	Other	5	5.7	100.0

It is found that most victims were operators (13.6%) or special trade construction (8.0%) based on the results. But the occupation of 39.8% of the victims was not reported in the data. Further, it can be observed in Table 3 that people working in the dam site for operation and maintenance show a wide variety of professional fields. It is very important to note that more than half of the workers involved in work-related accidents were non-union workers (54.5%) (Table 3). This shows us an indication that workers who were not members of union were more likely to have accidents or injuries due to lack of safety training [39].

Table 3 - Distribution of worker characteristics

Variables	Categories	Frequency	Percent	Cumulative Percent
Occupation	Occupation not reported	35	39.8	39.8
	Operators	12	13.6	53.4
	Construction trades	7	8.0	61.4
	Electrical power installers and repairers	7	8.0	69.3
	Construction laborer	6	6.8	76.1
	Labors except construction	6	6.8	83.0
	Structural metal workers	2	2.3	85.2
	Plumbers, pipefitters, and steamfitters	2	2.3	87.5
	Farm worker	2	2.3	89.8
	Timber cutting and logging occupations	2	2.3	92.0
	Welders and cutters	1	1.1	93.2
	Carpenter	1	1.1	94.3
	Supervisors, brick masons, stonemasons, tile setters	1	1.1	95.5
	Painters, construction, and maintenance	1	1.1	96.6
	Firefighting occupations	1	1.1	97.7
	Forestry workers except logging	1	1.1	98.9
	Guards and police excluding public service	1	1.1	100.0
Union Status	Union	40	45.5	45.5
	Non-union	48	54.5	100.0
Ownership	Private	68	77.3	77.3
	Local Government	20	22.7	100.0

Initial violations and penalties of the selected cases are also presented to emphasize post-accidental responsibilities of the companies. Totally 165 violations were seen in four main categories, namely, serious, wilful, repeat, and other. Serious category could be assigned

when companies had the potential to foresee a risk but did not protect or poorly protected the workers. When examined the data set, it is observed that serious violation has the highest frequency. The companies getting penalties in the serious category will be summoned most frequently by the OSHA and carry the highest fees [40]. Further, wilful violations include an intentional violation of OSHA rules by the employer or blatantly/deliberately disregard of the safety rules will result in highest penalties. Violations in the repeat category associated to a condition in which an OSHA regulation was infringed, and a company has been issued a citation within the last 3 years (unless that citation is currently under appeal). Fortunately, repeat violations are in the minority in the created data set which might be a sign of improved safety rules of the companies (Figure 3).

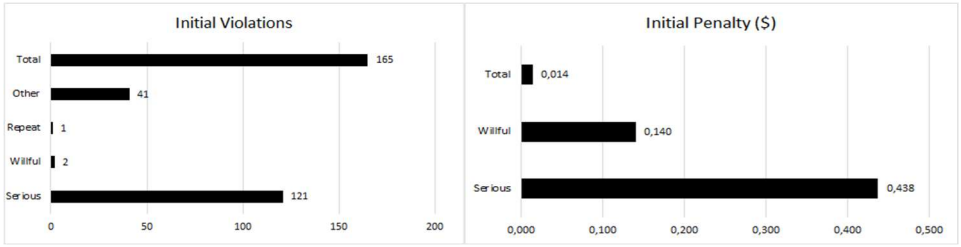

Figure 3 - Initial violation and penalty (M) summaries of selected cases.

4. RESULTS AND DISCUSSION

As mentioned above, 88 work-related injury cases that occurred in operation and maintenance of dams, reservoirs and auxiliary facilities were selected and focused by our studies. Further, the database used in this study has classified the injuries into nonfatal and fatal. The causes of accidents were investigated by categorizing them into four major groups (Table 4).

In the first group, the evaluation was done based on the facility. Based on the results, it is found out that 5.2% of precaution negligence was related to the facility and wrong design and poor maintenance were the main negligence factors. To give an example of this negligence; *"Employee #1 and coworkers were building a work platform made of dirt and held in place by a retaining wall next to the Buffalo Bill Dam. Employee #1 was operating a D Caterpillar when the wall and fill failed, causing him and the Caterpillar to fall into the reservoir. Employee #1 drowned."* Gürcanlı also mentioned that, almost 60% of fatal accidents are related to design decisions made before the work starts [41]. As a matter of fact, it has been stated that the designers' consideration of occupational safety during the planning and design phases of projects will greatly contribute to ensuring construction safety. It is ensured that the field decisions that contractors and builders must take during the implementation phase and that may lead to accidents are prevented on the project [42]. Each building construction project is different and unique, in addition to standard training, informing about the project by the designers ensures that the risks are reduced [43]. The important point to be noted is that these negligence factors result in fatal accidents, albeit few in number (Table 5).

Table 4 - Distribution of accident causes

Cause of accident	Precaution negligence	Number of accidents	Total number of accidents	%
Facility	Wrong design	5	13	
	Poor maintenance	8		5.2
Machine Safeguarding	Not available	17		
	Not appropriate	1	19	7.6
Personal Protective Equipment	Defective	1		
	Not available	18		
	Not appropriate	6	32	12.7
	Not used	8		
	Inadequate protection measure	44		
Training, Supervision, Surveillance	Violate the rules	42		
	Poor inspection	41	187	
	Improper working method	40		74.5
	Inadequate training	20		

Table 5 - Relationship of precaution negligence of facility and degree of injury

			Facility	
			Wrong design	**Poor maintenance**
Degree of Injury (DOI)	Fatal	Count	4	7
		% within DOI	80.0%	87.5%
	Nonfatal	Count	1	1
		% within DOI	20.0%	12.5%
Total		Count	5	8

Machine guarding is a barrier basically guarding or protecting moving parts of the machines that are the most dangerous as well as prevent the workers from getting physical contact with the machines. Table 4 demonstrates the usage of machine safeguards. Investigations revealed that machine safeguarding was not available in most of the cases. In addition, it is found that accidents have occurred in cases where the machine safeguarding was not appropriate, as well as defective, which resulted in loss of life (Table 6). OSHA also, specifically states that machinery workers sustain 18,000 injuries and 800 deaths every year. While injuries can occur from machines in different ways, one of the most common ways is lack of guarding [44].

Table 6 - Relationship of machine safeguarding and degree of injury

			Machine safeguarding		
			Not available	**Not appropriate**	**Defective**
Degree of Injury (DOI)	Fatal	Count	9	1	1
		% within DOI	52.9	100.0	100.0
	Nonfatal	Count	8		
		% within DOI	47.1	-	-
Total		Count	17	1	1

Tragically, in this study, it is determined that 12.7% of those who had occupational accidents did not use appropriate personal protective equipment (PPE) or did not use PPE at all. The noteworthy finding is that all victims using inappropriate PPE have died (Table 7). According to the last Bureau of Labor Statistics report on Personal Protective Equipment revealed that when a worker was injured, they were not using PPE in most cases [45]. Among the workers who sustained head injuries, 84% of them were not wearing hard hats, and 99% of workers who suffered facial injuries were not using face protection devices [45]. In United Kingdom, the data show that around 9,000 accidents related to PPE are reported to the health and safety executive every year. This data is similar to construction industry, which has the largest number of fatal accidents and one of the highest fatal injury rates and it proves how important it is to use correct PPE [46].

Table 7 - Relationship of PPE and degree of injury

			Personal Protective Equipment		
			Not available	**Not appropriate**	**Defective**
Degree of Injury (DOI)	Fatal	Count	7	6	3
		% within DOI	38.9	100.0	37.5
	Nonfatal	Count	11		5
		% within DOI	61.1	-	62.5
Total		Count	18	6	8

The results of the investigations show that workers who worked with inadequate protection measures had the most number of injuries. Moreover, it has been determined that violation of the rules, poor inspection and improper working methods lead to accidents. If safety and health training is provided, then it may act as a tool in reducing injury severity [47]. However,

it was found that training was inadequate in the accidents examined (Table 8). To prevent future accidents the following steps must be undertaken to reduce the accidents: the registration system should be installed, the maintenance should be done by the experts, the personnel and the protectors should be inspected effectively, and the advice of the machine builders should be paid attention. Furthermore, maintenance, repair, and control instructions should be prepared for each machine and facility and should be adhered strictly.

Table 8 - Relationship of Training, Supervision, Surveillance, and degree of injury.

			Training, supervision, surveillance				
			Inadequate protection measure	**Violate the rules**	**Poor inspection**	**Improper working method**	**Inadequate training**
Degree of Injury (DOI)	Fatal	Count	29	31	28	25	15
		% within DOI	65.9	73.8	68.3	6.5	75.0
	Nonfatal	Count	15	11	13	15	5
		% within DOI	34.1	26.2	31.7	37.5	25.0
Total		Count	44	42	41	40	20

5. CONCLUSIONS

In this study, the accidents occurred during the operation/maintenance activities of US dams between 1984-2018 were analyzed from the OSHA database and 88 cases were selected and classified.

This study investigated the risks that may arise in operation and maintenance works and the causes of accidents in dams, reservoirs and auxiliary facilities and further examined the precautions to be taken against these risks. Eighty-eight accidents were selected from the larger database of OSHA since they fulfilled the requirements to perform the statistical analyses.

The precautions to be taken to prevent future accidents according to the distribution of accident causes are summarized below.

- Operation and maintenance works should not be rushed and should be done in a planned manner.
- Permits should be obtained from the competent authorities, and the permitting authorities should make the necessary checks. A proper inspection and auto control mechanism should be established and maintained.
- Operation and maintenance should be done by experts or expert teams. Adequate training should be provided to the maintenance team on the principles of machine protection, electrical and mechanical safety, operating permits for maintenance work.

- Any machine part, function, or process that might cause injury must be safeguarded. If the operation of a machine or accidental contact with it could injure the operator or others in the vicinity, the hazards must be either controlled or eliminated.
- Various situations or malfunctions during normal operation at machine benches and facilities should be recorded, and these records should be used during major revision and maintenance works.

Limitations of this study include the occurrence on OSHA accident reports, unavailability of data before 1984, unfilled information categories especially in older accident reports, and inadequacy of employment data solely of dam companies.

Further research efforts could consider performing comparative studies between dam construction/maintenance work and other construction/maintenance sectors. The study presented here focused mostly on identifying risks and hazards that dam workers are exposed to on job sites. It was observed that accidents such as drowning, which are unlikely to happen on other construction sites, could be encountered more frequently on dam construction / maintenance activities. If there is adequate additional data, the findings of this study could be helpful in a future study that analyzes and discuss whether dam maintenance/construction is any different from other construction work.

Operation and maintenance workers also experience various risks that may cause occupational diseases such as noise (hearing loss), dust (respiratory system diseases), and ergonomics (musculoskeletal system disorders). However, note that our study does not cover occupational diseases. In future studies, the subject can also be investigated from this aspect.

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