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Influence of Operational Factors on Geothermal Rig Accident Types and Recommended Controls

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ABSTRACT

Geothermal drilling operations expose personnel involved to a variety of hazards that can lead to different types of accidents which include and are not limited to *struck* by/against, caught on/between, slip/trip/fall, sprains/strain, contact with hazardous chemicals and, cuts. These accidents are known to cause fatal accidents and disabling injuries that can limit productivity of drilling operations. There is need to identify control measures that effectively minimize risks of fatal and serious injury which seem to have stable rates in the drilling industry. Based on the fact that multiple factors contribute to an accident, this research set out to determine the influence of four geothermal rig operational factors on types of accident encountered, immediate causes of injury, root causes and effective corrective actions necessary to minimize occurrence and recurrence of common accidents. The operational factors considered were personnel function, assignment location, drilling operation and body part involved. All injury accidents encountered in Menengai Geothermal Project site from 2010 to end of 2017 were used to determine the relationship between each operational risk factor and different types of accidents using chi-squared statistical test for independence. It was determined that task assignment location and the body part mainly involved in executing an assignment are related to accident types while roles of deployed personnel and the operation at hand have no relationship with the same. Different locations on the rig site therefore require specific controls to address hazards associated with differently characterized rig equipment and procedural controls that prescribe safe positioning and task execution methods are necessary to minimize risks of injury. No association between operation at hand and personnel role indicates that all rig operations present equal chance of encountering different kinds of injury and precautions taken should equally address all foreseeable hazards that can be expected to occur in different interacting operations. Moreover, since all persons are at equal risk of encountering any type of accident there is need for consistent compliance to safety requirements by everyone on the rig site. Effective control measures to address root causes of injury center around ensuring that workers can foresee task related hazard and are provided with actionable instruments to take corrective action. Workplace tools and equipment should be of sound construction and safe work procedures to control hazardous forms of energy must be implemented. Moreover, task execution should be supervised to discourage unsafe behavior or deviation from stipulated practice. Appropriate personal protective equipment must be used in conjunction with engineering and administrative controls to reduce hazard exposure to acceptable levels.

1. Introduction

Executing geothermal drilling operations involves use of machinery, equipment and human effort that predispose involved personnel to risks of injury that can have a negative impact on group and individual productivity. Over the last three years, International Association of Drilling Contractors (IADC) indicated that incident statistics for the drilling industry have remained relatively steady at an average of 9 fatalities, 329 lost time injuries, 381 restricted work cases and 436 medical treatment injuries IADC (2018a). Given the aforementioned, it is evident that effectiveness of control measures taken to eliminate risks of injury or reduce them to acceptable levels especially with regard to fatal injury is not assured. There is need to identify the best controls and actions required to effectively implement them in order to address all risks related to causes of different types of accidents encountered in drilling rigs.

The United States Occupational Safety and Health Administration (OSHA) define hazards as a potential for harm associated with a condition or activity that if left uncontrolled can result in injury or illness OSHA (2011). Operational factors required to execute drilling tasks which include personnel, equipment, materials and work environment constitute a scheme for hazard identification that are useful in reducing risks of failing to identify and control hazards Leathley (2012). Exposure to hazards due to inadequacies in these factors in the form of unsafe acts and conditions can cause different types of accidents which can have varying levels of severity hence cost implications. United Kingdom safety regulator - Health and Safety Executive (HSE) indicate that being struck by objects and falling from height top the list in causing fatal accidents as show in figure 1.

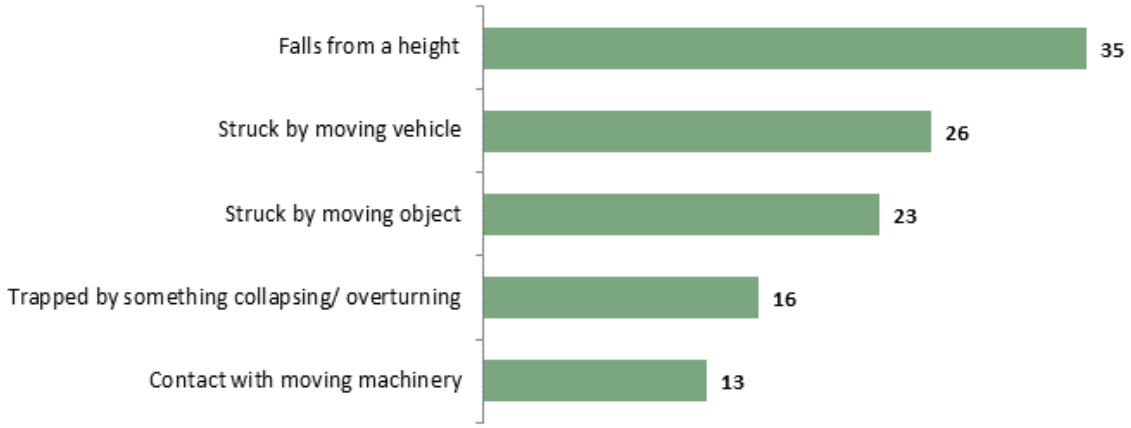

Figure 1: Main kinds of fatal workplace accidents – Source: HSE (2018)

Two most frequent causes of fatal accident indicated in figure 1 also top OSHA construction "fatal four" i.e. falls – 38.7%, struck by object – 9.4%, electrocution – 8.3% and caught-in/between – 7.3%. OSHA further note that eliminating the fatal four would save 631workers lives in America every year OSHA (2017). Falls and contact with objects also feature prominently in United States total injury fatalities published by the Bureau of Labor Statistics (BLS) as shown in Figure 2

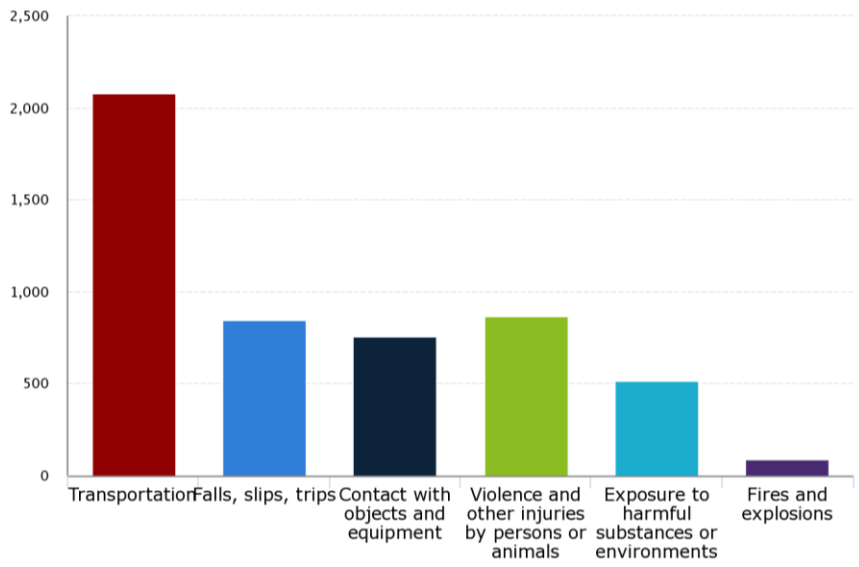

Figure 2: Fatal occupational injuries by event, 2016 – Source BLS (2017)

It is therefore necessary to identify and control risks which increase the probability of encountering common types of accidents known to have high risk of severe or fatal injury which can escalate operational costs and hamper seamless execution of drilling activities if left unchecked.

Based on total recordable accidents encountered in Menengai Geothermal Project Site, this study sets out to identify the main types of accidents that can occur in geothermal rig sites, the significance of operational factors on risks of encountering the different types of accidents and the most effective controls derived from root cause analysis.

The rationale of this study is to determine critical elements that must be considered by industry players tasked with tailoring their safety management system to effectively implement control measures required to address hazards associated with significant kinds of accidents in their individual context.

A total of one hundred and fifty seven recordable accidents considered in this study occurred at rig sites since commissioning of drilling activities in November 2010 to December 2017. Recordable accidents in this context implies that they are limited to those which resulted in physical injury to personnel and required first aid administration on site or medical treatment in hospital. All accidents which occurred outside rig sites and those which occurred within rigs that resulted in property damage without injury to personnel such as fires, vehicle accidents and near misses which can be affected by risk factors considered and require specific control measures to address them were not considered.

2. Literature Review

The International Labor Organization (ILO) define occupational accidents as occurrences arising out of, or in the course of, work which results in a fatal or non-fatal injury ILO (2015). A list of different types of accidents which have occurred in the geothermal project site being considered is outlined by OSHAcademy (2013) as follows:

- Struck-by – A person is forcefully struck by and object. The force of contact is provided by the object

- Stuck-against – A person forcefully strikes an object. The person provides the force or energy
- Contact-by – Contact by a substance or material that by its very nature, is harmful and causes injury
- Contact with – A person comes into contact with a harmful substance or material. The person initiates the contact.
- Caught-in – A person or part of him/her is trapped, or otherwise caught in an opening or enclosure
- Caught-between – A person is crushed, pinched or otherwise caught between a moving and a stationary object or between two moving objects
- Fall-to-surface – A person slips or trips and falls to the surface he/she is standing or walking on
- Fall to below - A person slips or trips and falls to a level below the one he/she was walking or standing on
- Over-exertion – A person over-extends or strains himself/herself while performing work
- Bodily reaction – Caused solely by stress imposed by free movement of the body or assumption of a strained or unnatural body position

Out of the aforementioned types of accidents, IADC (2018) annual reports for total recordable accidents indicated that at least 95.26% accidents were due to struck by/against caught between/on, slip and fall, sprains/strain, cuts and chemical contact as shown in Table 1 . It can therefore be expected that these types of accidents are most commonly encountered in geothermal drilling sites and measures taken to limit their occurrence will go a long way in significantly reducing overall incident rates.

No	Accident Type	% Frequency
1	Struck By/Against	30.59%
2	Caught On/ Between	34.66%
3	Slip/Trip/Fall	16.65%
4	Cut	4.26%
5	Contact With	1.65%
6	Sprain/Strain/Overexertion	7.45%
7	Other	4.47%
TOTAL		100.00%

Table 1: IADC 2017 Annual Report for Industry Totals – Total recordable incidents by incident type

Harvey (1984) notes that accident causation and prevention theories have evolved from simple single factor theories which identify one (or few) aspects of as cause and propose one (or few) remedies as the solution to complex multiple factor theories that formally acknowledge the possibility that many factors could potentially cause an accident to occur.

Giegle Safety Group (2013) note that as opposed to the Domino single factor theory proposed by Heinrich which poises that 88% of all accidents are caused by unsafe acts of people, 10% by unsafe actions and 2 % by acts of God, the system approach takes into account dynamics of systems that interact with overall safety programs and conclude that accidents are defects of the system contributed by behavioral and environmental factors.

Control measures required to reduce risks of encountering accidents to acceptable levels can be derived from immediate and root causes deduced from objective accident investigations that

look beyond blaming the person but instead identifying systems weaknesses that lead to occurrence and recurrence of immediate causes which depict themselves in the form of unsafe acts and conditions.

Based on Raouf (2011) structure of accidents in Figure 1 and the multiple cause theory that there are several factors which contribute to accidents, this paper seeks to determine the influence of operational factors which mainly characterize the work environment and assignment being executed on increasing risks of encountering specific types of accidents and relating the risks factors to control measures associated with immediate causes of injury and safety management system root causes by analyzing concerned variables of geothermal rig site accidents.

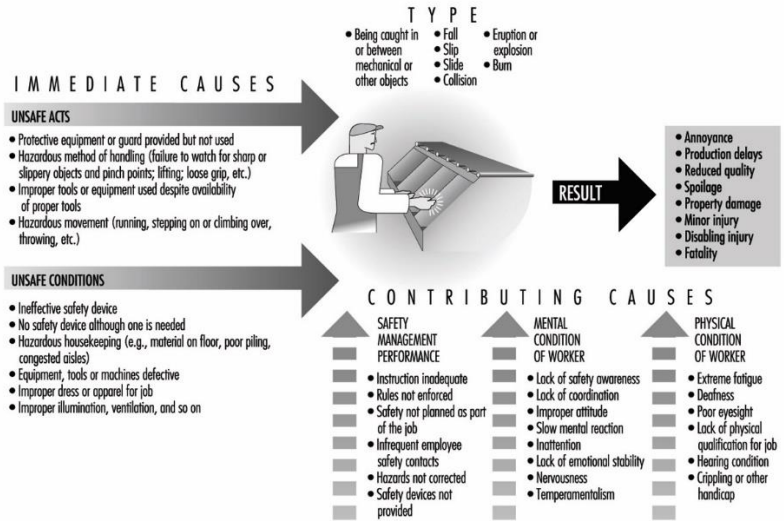

Figure 3: Structure of accidents – Source: Raouf (2011)

Immediate causes of injury for accidents considered in this research and Rooney and Heuvel (2014) root cause map were used to determine root causes and control measures for specific types of accidents. Types of accidents and contributing causes in Raouf (2011) structure of accidents were related.

3. Materials/Methodology

Information related to all injury rig site accidents in Menengai Geothermal Project were collected and five operational variables of interest were grouped as shown in Table 2 based on the recorded data

No	Variable	Categories			
1	Accident type	i. ii. iii.	Stuck By/against; Caught on/between, Falls,	iv. v. vi.	Cut, Contact with, Sprain/Strain
2	Assignment	i. ii. iii.	Floorman/Derrickman, Assistant, Contractor,	iv. v.	Technician, Supervisor
3	Area of Assignment	i. ii. iii.	Floor/Derrick; Pipe rack, Mud pump/Genset/tanks,	iv. v.	Cellar/Substructure, Quarters/Stores/Welding Shop, Compressor

4	Main Operation	i. ii.	Drilling Ahead, Rig Move/Rigging,	iii. iv.	Maintenance, Cementing
5	Body Part Involved	i. ii.	Upper Extremity, Lower Extremity,	iii. iv.	Head, Trunk
6	Equipment Used	i. ii. iii. iv. v.	Tongs, Tubulars, Engines/Pumps/Machinery, Material, Decks/Stairs/Guards/Beams	vi. vii. viii. ix. x.	Hand Tools, Elevators/TDS, Pressure hoses/lines, Lifting Equipment/accessories BOP Stack/ Wellhead

Table 2: Accident variables

In this research, different types of accidents types considered by IADC (2018) which have occurred in the project site being studied were categorized as shown in Table 3. Closely related types of accident were merged since identification of overall controls required to address root causes which is a key objective of this research address both specific and closely related types of accidents.

IADC		Research	
No	Accident Type	No	Accident Type
1	Caught On	1	Caught On/Between
2	Caught Between/In		
3	Struck By	2	Struck By/Against
4	Struck Against		
5	Slip Fall- Same Level	3	Slip/Trip/Fall
6	Slip Fall- Different Level		
7	Strain/Overexertion	4	Strain/Sprain
8	Sprain		
9	Chemicals/Fluid Contact	5	Contact With
10	Cut	6	Cut

Table 3: Accident categories

Microsoft excel ifs () function was used to filter out variables listed above from accident log sheet and determine their frequency. Chi-squared test for interdependence test below was then used to test the relationship between accident types and four operational variable of interest i.e. assignment, area of assignment, main operation, body part involved and equipment used.

Step 1: Based on observed frequencies – Table 4, a contingency table of expected frequencies - Table 5, which assumes no association between variables being tested for independence was computed for each observed frequency using Equation 1

$E_{i,j=\frac{o_{ri}}{n}\times o_{cj}}$ ------ Equation 1

Variable 1	Variable 2 (Accident Types)				
	1	2	……	c	Total
1	O_{11}	O_{12}	……	O_{1c}	Or_1
2	O_{21}	O_{22}	……	O_{2c}	Or_2
:	:				
r	O_{r1}	O_{r2}	……	O_{rc}	O_{rr}
Total	O_{C1}	O_{C2}		O_{CC}	n

Table 4: Observed frequency two way table

Variable 1	Variable 2 (Accident Types)				
	1	2	……	c	Total
1	E_{11}	E_{12}	……	E_{1c}	E_{r1}
2	E_{21}	E_{22}	……	E_{2c}	E_{r2}
:	:				
r	E_{r1}	E_{r2}	……	E_{rc}	E_{rr}
Total	E_{C1}	E_{C2}		E_{CC}	n

Table 5: Expected frequency two way table

Step 2: Degrees of freedom (df) was then computed from total row (r.) and columns (c.) using Equation 2

$df = (\mathrm{r}-1)(\mathrm{c}-1)$------ Equation 2

Step 3: Equation 3 below was then used to compute the Chi-squared statistics given degrees of freedom obtained in step 2 using observed and expected frequencies

$X_{df}^2 = \sum_{ij}^{rc}\left[\frac{(\mathrm{O_{ij}}-\mathrm{E_{ij}})^2}{\mathrm{E_{ij}}}\right]$ ------ Equation 3

Step 4: Probability (p-value) of obtaining the X_{df}^2 obtained from equation 3 or greater was determined from chi square table for determined degrees of freedom and compared to significance level of 0.05 i.e. A p-value of <0.05 indicates the probability of the expected values varying from the observed frequency by chance is less than 5 percent hence the null hypothesis which assumes no relation is nullified. Since the probability of the variables varying due to a

relationship is 95%. A p-value > 0.05 on the other hand validates the null hypotheses of no relationship between the variables of interest

Out of three statistical tests for correlation that would have been used to test the association of rig site accidents considered, the Chi-square test was chosen over Pearson and Spearman correlation since the variables are discrete and categorical. The former is suitable for continuous variables while the latter for ordinal variables University of Minnesota (2018).

4. Data Presentation, Analysis and Interpretation

This section presents the trends of accident types and their relationship with four operational risk factors i.e. operational function, task assignment location, drilling operation and body part involved

4.1 Accident types

Frequency of six types of accidents which were tested for association with four operational factors at the rig site were computed and tabulated in Table 6.

No	Accident Type	Frequency
1	Struck By/Against	47.13%
2	Caught On/ Between	26.75%
3	Slip/Trip/Fall	11.46%
4	Cut	7.64%
5	Contact With	3.18%
6	Sprain/Strain/Overexertion	3.82%
TOTAL		100.00%

Table 6: Accident type frequency percentages

Personnel being struck by moving objects or striking against objects account for almost half of the accidents encountered in a geothermal rig site. Getting caught on object or between two moving objects accounts for almost a third while slips trips and falls account for approximately 10% of accidents. Caught on/between accidents in Menengai Rig Sites are less than struck by/against accidents as opposed to IADC (2018b) trend in Table 1.

4.2 Operational Function

Personnel deployed to work at the rig site have different roles and responsibilities. It can therefore be expected that different functions which have distinct inputs to meet overall drilling operation targets could be exposed to operational hazards at varying risks levels to reduce or increase their risks of encountering different types of accidents. Chi-square test for independence was used to determine relationship between function and accident type two way table from which frequency percentages are shown in Table 7.

No	Function	Struck	Caught	Fall	Cut	Contact	Sprain	Total
1	Floorman	24.84%	15.29%	3.82%	3.18%	0.64%	3.18%	50.96%
2	Assistant	7.64%	5.10%	3.82%	2.55%	0.00%	0.00%	19.11%
3	Contractor	8.28%	3.18%	1.27%	0.64%	0.64%	0.00%	14.01%
4	Technician	3.82%	2.55%	1.91%	0.64%	1.91%	0.64%	11.46%
5	Supervisor	2.55%	0.64%	0.64%	0.64%	0.00%	0.00%	4.46%
	TOTAL	**47.13%**	**26.75%**	**11.46%**	**7.64%**	**3.18%**	**3.82%**	**100.00%**

Table 7: Operational function accident type percentages

Rig floormen and derrickmen encounter approximately half of total recorded injury accidents followed by assistants i.e. roustabouts, drivers and lifting equipment operators who account for approximately a fifth of the accidents. Contractors who represent temporary manpower engaged to support execution of work e.g. rig move operations account for approximately 15% accidents which is equivalent to the total contribution by maintenance technicians and supervisors. This trend decreases from floormen / derrickmen to assistants/contractor similar to that indicated by IADC (2016) and only vary with regard to technicians and supervisors where the former encounter more accidents that the latter in Menengai Project compared IADC (2016) industry representation where more accidents have been encountered by supervisors than technicians. This is most likely attributable to the different intensities of responsibilities which can be expected to vary by setting.

The calculated chi-square value of 24.89 with a p-value of 0.2053 greater than the significance level of 0.05 indicates no relationship between the operational function assigned to personnel deployed at the rig site and the risk of encountering different types of accidents. Any person deployed at the rig site can encounter any type of accident if required precautions are not considered. It should therefore be mandatory for all persons present at the rig site to comply with safety measures minimize accident risks. Management and supervisors should lead by example to encourage compliance.

4.3 Task Assignment Location

Different locations to which personnel are deployed in the rig site are set up differently and are designed to achieve different operational drilling objectives which include and are not limited to power generation, circulating drilling fluid, rotating and hoisting drill string. It can therefore be expected that different locations expose deployed personnel to different kinds of hazards that vary risks of encountering different types of accidents.

Actual task assignment location and accident type frequencies represented in the percentage Table 8 were used to determine the relationship between the variables using chi-squared test

No	Assignment Location	Struck	Caught	Fall	Cut	Contact	Sprain	Total
1	Floor/Derrick	24.84%	16.56%	3.18%	1.91%	0.00%	1.91%	48.41%
2	Pipe rack	7.64%	5.10%	3.82%	2.55%	0.64%	0.64%	20.38%
3	Mud pump/Generator	3.18%	1.91%	1.91%	3.18%	1.27%	1.27%	12.74%
4	Cellar/Substructure	8.92%	1.27%	1.27%	0.00%	0.64%	0.00%	12.10%
5	Quarters/Workshop	1.27%	1.27%	1.27%	0.00%	0.64%	0.00%	4.46%
6	Compressor	1.27%	0.64%	0.00%	0.00%	0.00%	0.00%	1.91%
	TOTAL	**47.13%**	**26.75%**	**11.46%**	**7.64%**	**3.18%**	**3.82%**	**100.00%**

Table 8: Accident location accident type frequencies

Approximately half of all injury incidents in rig sites occur at the rig floor where more intense and physically involving drilling operation activities such as making up/breaking out drill pipe connections occur. Accidents in the catwalk and pipe rack area account for a fifth of the accidents while the cellar/substructure and mud pump/generator which constitute the upper left quadrant of a rig location account for approximately a quarter of the accidents. The left wing of a rig location which consists of accommodation, stores and workshop encounters approximately five percent of accidents while a minimal number of accidents are encountered in the lower left quadrant of a rig location which constitute the air circulation system equipment.

The calculated chi-square value of 40.89 with a p-value of 0.0253 less than the significance level of 0.05 indicates association between the rig site task location and the probability of encountering specific types of accidents. This confirms the fact that stationary rig equipment which characterize different locations of a rig site present different kinds of hazards that increase the risks of encountering different types of accidents owing to the nature of equipment and activity executed in those locations. More or less of specific kinds of accidents can be expected to occur in different locations owing to different magnitudes of risks present. More struck by and caught on/between accidents are expected to occur at the rig floor than pipe rack, cellar and mud pump owing higher frequency of moving parts and equipment e.g. swinging tubular, moving tongs. Furthermore, there is a higher risk of getting cut or contacting materials and chemicals in the mud pump/generator area where the same are mostly handled than at the rig floor and derrick. Controls that adequately address hazards present in different locations are therefore necessary to minimize risks of encountering specific types of accidents mostly experienced in those locations.

4.4 Drilling Operation

Different drilling operations involve use of different techniques and operational procedures which can be expected to expose personnel to different hazards that present different risks of encountering different types of accidents. Rig operation and accident type frequencies used to test their relationship is represented in the percentage frequency Table 9.

No	Operation	Struck	Caught	Fall	Cut	Contact	Sprain	Total
1	Drilling Ahead	17.20%	15.92%	7.64%	3.18%	1.27%	2.55%	47.77%
2	Rig Move/Rigging	15.29%	4.46%	2.55%	1.91%	0.64%	0.64%	25.48%
3	Maintenance	10.83%	3.82%	1.27%	1.91%	0.64%	0.64%	19.11%
4	Cementing	3.82%	2.55%	0.00%	0.64%	0.64%	0.00%	7.64%
	TOTAL	**47.13%**	**26.75%**	**11.46%**	**7.64%**	**3.18%**	**3.82%**	**100.00%**

Table 9: Rig operation accident type frequencies

Drilling ahead, maintenance and cementing activities take 44%, 8% and 8% respectively of the total duration taken to complete drill a geothermal well in Menengai according to Okwiri (2015) time analysis. Drilling ahead which takes the most considerable duration accounts for approximately half of recorded injuries since personnel are exposed to occupational hazards for a longer period hence the higher chance of encountering accidents. More accidents encountered during maintenance activities compared to cementing operations which take approximately the same duration in the overall well drilling program implies that risks of injury presented by maintenance work are higher than those presented by cementing operations. Rig move which can be considered to take at most twice the duration taken by maintenance works

for the project site being examined account for a quarter of the injuries given the higher risk presented by dismantling, transfer and assembly of the rig structure.

The calculated chi-square value of 13.1267 with a p-value of 0.59 > the significance level of 0.05 indicates no association between the overall drilling operation at hand the type of accident encountered. This implies that all drilling operations executed in a geothermal rig present equal risks of encountering different kinds of accidents and safety measures adopted should be tailored to address related and unrelated hazards which could be associated with a single or multiple operations.

4.5 Body Part Involved

Different operations at the rig site involve manual handling and positioning that could put some parts of the body at higher risk of injury than others. It can therefore be expected that specific body parts could be at higher risk of encountering specific kinds of injury than others. Chi-square test was used to determine the relationship between accident type and injured person body part using actual data from which the following percentage frequencies in Table 10 were derived.

No	Body Part	Struck	Caught	Fall	Cut	Contact	Sprain	Total
1	Upper Extremity	21.66%	22.93%	3.82%	5.10%	0.64%	0.64%	54.78%
2	Lower Extremity	14.65%	3.18%	4.46%	2.55%	0.64%	1.91%	27.39%
3	Head	6.37%	0.00%	1.91%	0.00%	1.91%	0.00%	10.19%
4	Trunk	4.46%	0.64%	1.27%	0.00%	0.00%	1.27%	7.64%
TOTAL		**47.13%**	**26.75%**	**11.46%**	**7.64%**	**3.18%**	**3.82%**	**100.00%**

Table 10 : Body part injured accident type frequencies

It is notable that slightly over half of total injuries encountered in the rig site affect the upper extremities which consists of the upper arm, elbow, forearm, wrist and hand since most of rig operations involve use of the same to handle tools and equipment. Lower extremity composed of thigh, knee, shin, calf, ankle and foot are injured in slightly over a quarter of the injuries, while the head and trunk injuries account for approximately a fifth of the injuries.

The calculated chi-square value of 47.62967 with a p-value of 2.9944E-5 < the significance level of 0.05 indicates strong association between the body part injured and the type of accident encountered. There is a higher risk of swinging objects and those that are moving to cause struck by and caught between accidents in the arm radius. Furthermore cuts are mainly experienced in upper extremities involved in handling and lower extremities involves in movement. Control measures to address prevention of injuries to specific body parts should therefore emphasize safe work procedures which prescribe the most suitable working positioned and protective equipment required to safety complete tasks specific tasks at hand.

4.6 Control Measures

Based on all injury accidents that have occurred in the geothermal drilling project site under consideration, root causes were derived from immediate causes of injury using the Rooney and Heuvel (2014) model for which effective control measures for each type identified are outlined in Table 11. LTA- Less than Adequate; OTJ- On the Job

No	Accident Type	Immediate Cause of Injury	Root Causes	Recommended Controls
1	Struck By/Against	1.1 Improper handling and body position	1.1.1Training in proper manual handling techniques LTA 1.1.2 Equipment handling provisions LTA or unclear	1.1.1.2 Train workers on proper manual handling techniques and supervise compliance 1.1.2.1 Identify equipment with inadequate handling points, fabricate and install required additional handling points and color code to enhance visibility
		1.2 Moving hand tool, equipment, sling 1.3 Swinging object –load, equipment, tubular, platform 1.4 Knocking on stationary objects 1.5 Rotating part	1.2/3/4/5.1 Worker implemented task hazard identification and control procedures missing or LTA	1.2.x1 Develop OTJ hazard identification/risk assessment procedures, train workers on implementation and monitor compliance
		1.6. Dropped load, object, tubular, equipment,	1.6.1 Dropped Object Management System(DOMS) missing or LTA	1.6.1.1 Develop dropped object management procedures, train workers on effective implementation and monitor compliance
		1.7 Flying object- Pressure ejected ,broken hand tool	1.7.1 Procedures to control stored hazardous energy not available or inadequate	1.7.1.1. Develop/improve permit to work and hazardous energy control procedures e.g., LOTO, train workers on effective implementation and monitor compliance
		1.8 Backlashing pressure horse, sling	1.7.2/8.1 Implementation of equipment reliability program LTA	
		1.9 Congested workspace	1.9.1 Housekeeping LTA	1.9.1.1. Develop Proper housekeeping procedures based on 5S methodology, train workers on implementation and supervise compliance

No	Accident Type	Immediate Causes	Root Causes	Recommended Controls
2	Caught in/on/between	2.1 Twisting and turning lifting accessories – shackles, slings 2.2 Swinging elevators, doors 2.3 Swinging/dropping of detached part, equipment, pipes 2.4 Rolling and swinging tubular 2.5 Moving equipment, hand tools 2.6 Closing valves 2.7 Rotating part	2.1.1 Proper rigging and slinging procedures not available or LTA 2.2.2 No or LTA Training and certification on rigging and slinging 2.2.2. Equipment designed handling points LTA 2.2/3/4.1 OTJ hazard identification and control procedures missing or LTA 2.5.1 Equipment transfer, loading and unloading procedures missing of LTA 2.6/7.1 Procedures and equipment required to control release of hazardous energy missing or LTA 2.6/7.2 Procedures and equipment required to ensure clear communication missing or LTA	2.1.1.2 Develop rigging/slinging procedures, train workers and supervise implementation 2.2.2.1 Identify requirements for additional handling points required, fabricate and install clearly mark them, train workers on proper handling and monitor compliance 2.2/3/4.1 Develop/improve OTJ hazard identification and control procedures, train workers and supervise compliance 2.5.1.1.Develop loading procedures and work instructions, train workers on effective implementation and monitor compliance 2.6/7.1.1 Develop hazard control procedures/work instructions, train workers and supervise compliance 2.6/7/2.1 Determine and procure communication equipment required, train works on use, support with clear work instructions and supervise compliance
3	Slip/Trip/Fall	3.1 Slippery surface	3.1.1. Spill control procedure missing or LTA	3.1.1.1 Develop spill control procedures, train

		3.2 Tripping obstacle 3.3 Uncovered hole, pit 3.4 Loosing staircase step 3.5 Standing on narrow beam/rod 3.6 Dropped personnel cabin Working on sharply sloped surface 3.7 Improperly secured working surface	3.2.1 Housekeeping LTA 3.3/4/5/6.1 OTJ hazard identification and control procedures missing or LTA 3.7.1 Job completion checklist and site risk assessment LTA	workers and supervise compliance 3.2.1.1. Develop proper housekeeping procedures based on 5S methodology, train workers and monitor compliance 3.3/4/5/6.1.1 Develop OTJ hazard identification and control procedures, train workers and supervise compliance 3.7.1.1 Revise pre/post job inspection checklists to consider all foreseeable hazards, train workers on implementation and monitor compliance.

No	Accident Type	Immediate Causes	Root Causes	Recommended Controls
4.	Cut	4.1 Contact with sharp/abrasive edge – drum, equipment, tin, beams and slings 4.2 Inserting hand in very constricted equipment spaces	4.1.1 Procurement / fabrication of tools required to cut drums and tins LTA 4.1.2. Protective clothing /Equipment LTA 4.2.1 Equipment maintenance procedures not available 4.2.2 Training on equipment maintenance LTA	4.1.1.1 Avail tools required cut drums and containers and train staff on their use 4.1.2.1 Avail cut resistant hand gloves, train staff on their correct use and enforce compliance 4.2.1.1 Document safe equipment maintenance procedures, OTJ hazard identification, train staff on correct implementation and ensure compliance

5.	Contact with	5.1 High pressure release of fluid and chemicals 5.2 Mixing/ hopping chemicals 5.3Wire brush sprays 5.4 Drainage of trapped fluid	5.1.1 Procedures to control stored hazardous energy not available or inadequate 5.2/3/4.1 Worker implemented task hazard identification and control procedures missing or LTA 5.2/3/4.2 Protective clothing /Equipment LTA	5.1.1.1 Train workers on implementation of hazardous energy control procedures and supervise compliance 5.x.1.1 Train workers on task related hazard identification procedures, monitor and monitor compliance 5.x.2.1 Determine and avail most suitable and appropriate task specific protective clothing e.g. safety glasses and goggles, train workers on appropriate use, issue and supervise compliance
6	Sprain/Strain	6.1 Rapidly twisting body part 6.2 Overexerting pressure on body part 6.3 Body part pulled by moving equipment 6.4 Lifting loads heavier than personal lifting capacity	6.1/2/3/4.1 Worker implemented task hazard identification and control procedures missing or LTA 6.1/2/3/4.1 Worker training on manual handling and workplace ergonomics LTA 6.4.1 Requirements for additional lifting aids not determined or LTA	6.x.1.1 5.x.1.1 Train workers on task related hazard identification procedures, and workplace ergonomics monitor and monitor compliance 6.4.1.1 Identify, procure and train workers on proper use of lifting aids which could include and are not limited to chain blocks and trolleys. Maintain in proper working condition and monitor compliance

Table 11: Accident causes and control measures

Root cause analysis identifies that implementing worker driven OTJ hazard analysis and control mechanisms, training and supervision play a critical role in preventing all six types of accidents encountered. Different types of accidents are addressed by further mitigations as follows:

i. Struck-by and caught between accidents due to improper hand placement can be prevented by installing missing handling point and clearly marking them to constantly

remind workers on correct placement. Conspicuous color coding minimizes risks of pinched finger which can cause disabling amputations.

ii. Proper housekeeping removes unnecessary clutter which works towards providing free movement and working space. This reduces risks of personnel placing themselves in the line of fire where they predispose themselves to being struck by objects or getting caught between moving objects.

iii. Good housekeeping further eliminates risks of obstacles, slippery surfaces and unguarded walkways to prevent slip, trip and fall accidents.

iv. Use of suitable personal protective equipment (PPE) reduces risk of bodily injury due to cuts and contact with hazardous substances. PPE selected must be suitable to limit hazard to acceptable levels.

v. Provision and use of handling aids such as forklifts, trolleys and pulleys is necessary to minimize risks of sprains, strains and overexertion injuries due to lifting loads that exceed personnel lifting capacity. Availing and using tools designed for opening metallic containers eliminates use of homemade tools or misuse of tools minimize cut accidents.

vi. Implementation of Dropped Object Management System minimizes risks of struck by injuries due to dropped objects which include tools used by persons working at height or loose unsecured parts which might drop due to vibration, raising or lowering mast.

vii. Training and certifying designated riggers, signal men on proper lifting, rigging and load securing practice reduces risks of swinging and dropped loads that increase risks of encountering both struck by and caught between accidents. Lifting plans must be implemented for non-routine critical lifts

viii. Implementation of permit to work systems e.g. lock out tag out, confined space entry, hot works, critical lift, and working at height control unexpected release of hazardous energy that contribute to struck by and contact with accidents.

Safety efforts listed above entail implementation of engineering, administrative and personal protective equipment controls ranked in the National Institute for Occupational Safety and Health (NIOSH) hierarchy of hazard controls shown in Figure 4

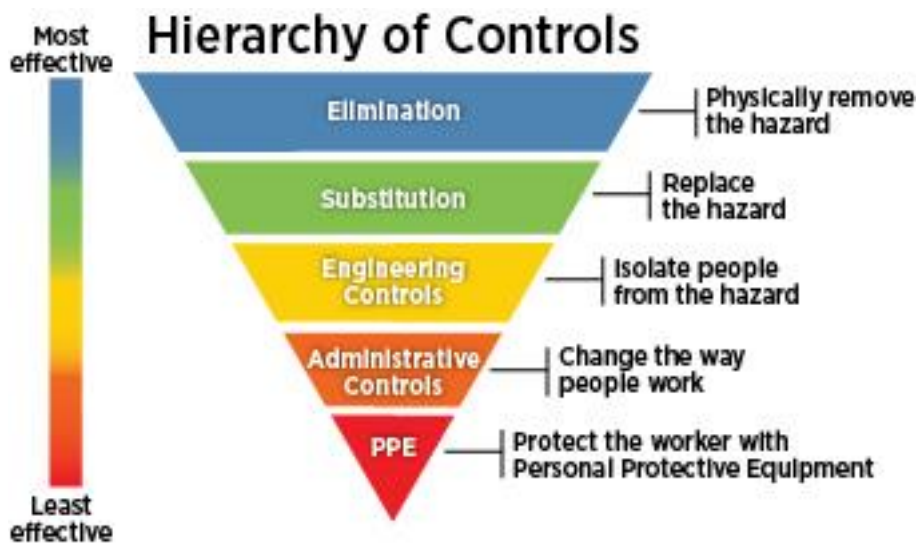

Figure 4: Hierarchy of Hazard Controls - Source: NIOSH (2018)

It is critical to note that engineering controls involve modification of equipment design to isolate personnel from hazards while administrative measures deal with worker competence, implementation safe work procedures together with supervision. Personal protective equipment on the other hand don't eliminate the hazard and must be used in conjunction with both engineering and administrative controls where the later fall short of reducing hazard exposure to acceptable levels.

5. Conclusion

Drilling operations in geothermal rigs present occupation hazards that can increase risk of injury if required controls are not implemented. Increased injury rates can be costly through reduced productivity and accident costs which include and are not limited to worker replacement, injury compensation, sick pay, and property damage. Six common types of accidents that were found to occur in a geothermal land rig include, struck by/against, caught on/between, slip/trip/fall, sprains/strain, contact with hazardous chemicals and cuts.

Based on the fact that multiple factors contribute to the occurrence of accidents, examination of the influence of operational risk factors in geothermal drilling rigs which include personnel function, assignment location, drilling operation and body part involved on the type of accident encountered determined that task assignment location and the body part mainly involved in executing an assignment are related to accident types while roles of deployed personnel and the operation at hand have no relationship with accident types. Different locations on the rig site therefore require specific controls to address hazards associated with differently characterized rig equipment and procedural controls that prescribe safe positioning and task execution methods are necessary to minimize risks of injury. No association between operation at hand and personnel role indicates that all rig operations present equal chance of encountering different kinds of injury and precautions taken should equally address all foreseeable hazards that can be expected to occur in different interacting operations. Moreover since all persons are at equal risk of encountering any type of accident there is need for compliance to safety requirement by everyone on the rig site.

Effective control measures to address root causes of injury center around ensuring that workers are aware of hazard and are in a position to take corrective action, workplace tools and equipment are of sound construction, safe work procedures to control hazardous forms of energy are implemented and work is supervised to minimize risk of unsafe behavior or deviation from stipulated procedures. Personal protective equipment must be used in conjunction with engineering and administrative controls to reduce hazard exposure to acceptable levels. It is hoped that highlighted aspects to consider when selecting control measures to prevent occurrence and recurrence of common types of accident which account for over 90% injuries in a typical rig will provide sound basis and direction for stakeholders tasked with enhancing safety in geothermal land rigs.

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