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# Understanding Occupational Accidents in Tunnelling Construction using a Natural Experiment



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# UNDERSTANDING OCCUPATIONAL ACCIDENTS IN TUNNELLING CONSTRUCTION USING A NATURAL EXPERIMENT


## Abstract

**Background:** Reducing occupational accidents is of utmost importance. This research investigated how individual and job-related risk factors affect occupational accidents in one of the largest tunnelling companies in Iran.

**Methods:** A descriptive cross-sectional natural experiment utilizing data from 760 employees who consented to participate in the study. 150 individuals had a history of occupational accidents and 610 individuals did not. Information about accidents was extracted from reports, medical records, and interviews.

**Results:** The main causes of accidents were unsafe acts performed by workers. 71% by unsafe acts **alone, and another 12% unsafe acts in unsafe conditions**. The odds ratio of occupational accidents was significantly higher in workers aged under 30 years ($p$ = 0.016), with a high school diploma or lower educational achievement ($p$ = 0.012), low job satisfaction ($p$ = 0.035), work experience less than 16 years ($p$ = 0.023), as well as lack of regular exercise ($p$ = 0.001). Within the final adjusted logistic model, low levels of education (OR= 5.81; 95% CI, 1.03-9.03) and younger age group (OR= 2.38 95% CI, 0.24 to 8.02) remained significant.

**Conclusion:** Use of young and inexperienced staff, low education, and lack of simple and understandable safety guidelines for workers in the tunnelling industry have led to unsafe acts that can increase the rate of occupational accidents. Changes in working conditions, and unstable job security also contribute to explaining the accident rates in this 12-month period. Managers should pay special attention to these individual-organizational factors to prevent accidents and promote safety.


**Keywords:** Construction Industry; Risk Management; Safety Behaviours; Safety Literacy; Young Workers

**Introduction**

The construction industry is an important employer in many parts of the world (1). It is also an industry in which occupational accidents remain a serious threat to workers (2) especially in developing countries (3). Occupational accidents in general are a serious occupational health threat (4). It is important to understand the determinants of these accidents towards providing evidence-based recommendations for safety promotion. The International Labour Organization has recently asserted that the global number of occupational accidents annually exceeds 350 million, and the number of job-related deaths equates to more than one thousand people every single day (3). Whilst occupational accidents are a global phenomenon, and investigations have shown that some occupational accidents are neither reported nor recorded (5), there is evidence that in Europe most of the occupational accidents have happened on construction projects (6). Findings also suggest a higher numbers of fatal accidents occur in the Middle East (7), and a regional examination of fatal occupational accidents in Northern Iran indicated 40% were aligned to construction projects (8).

The purpose of accident analysis is to gain accurate and objective information about the causes of accidents to prevent their reoccurrence (9). Individual factors (age, work experience, and occupational accident history), environmental factors and equipment (dangerous conditions and type of event), and project factors (type of project, type of activity, induction, management and health & safety training) are important variables affecting the occurrence of occupational accidents (5) including those taking place on construction projects (10,11). Among construction occupations, employees on tunnelling projects account for a group with the most frequent occupational accidents (12).

In recent years, there has been significant investment in building tunnels for roads, water transfer, sewage systems, and subway transportation in Iran. Alongside this investment has been intense competition among tunnelling companies for work contracts, and consequently the focus has become oriented to work effectiveness and efficiency. Estimating the economic costs of workplace accidents, however, is difficult. There are both direct and indirect costs for both organisation and employee, and these vary across type of industry, age and experience of worker, pay and compensation packages, and type of accident (13). Nevertheless, previous estimates of the cost of occupational accidents range from 2% to 14% of gross national income (14). Despite these costs, there is evidence that just 4% of employers believe that investment in safety management makes good business sense, in line with a recent comment that health and safety is generally viewed as a hassle (15). It remains, however, that managers who are concerned with economic costs, if not also corporate social responsibility, should recognise that reducing accidents and related costs is of utmost importance (13). For all these reasons, understanding the predictors of the high levels reportable accidents on tunnelling projects is important.

**Tackling occupational accidents through the use of health and safety management policies and legislation originally focused on removing working conditions deemed unsafe. While the rigor of legislation in construction industry differs according to nation, unsafe working conditions do not account for all causes of occupational accidents regardless of nation or sector. Human factors, and the concept of unsafe acts are also recognised as a major cause of occupational accidents (16–22). Unsafe acts include human error (16) which itself has a multitude of causes (17), and risk taking – whether through ignorance or recklessness (18). There are a variety of theories of the cause of construction site accidents, however these essentially draw upon these two concepts of unsafe conditions and unsafe acts (19). Abdelhamid and Everett (20) distinguish between worker and management behaviours, and suggest that accidents can result from management inaction, which, in practice is the root of unsafe working conditions, but also mitigates unsafe acts in unsafe conditions. Their Accident Root Cause Tracing Model indicates that**

**there can also be unavoidable accidents due to non-human related events. We interpret this to mean that there can be usually safe working conditions which are rendered unsafe in extreme conditions. Nevertheless, even in this model (20), it remains that an unavoidable accident is recognised as an initially unsafe working condition, that perhaps could have been foreseen. It has also been suggested that "unavoidable accidents have to be expected in the construction industry" (21 p.58). This begs the question of whether there are still reasons to the unexpected negative event that led to the accident that should be mitigated against. Whilst Heinrich's seminal investigation (22) suggested 2% of accidents were Acts of God, it remains unsupported. For completeness, Heinrich suggested that unsafe conditions were the cause of 10% of industrial accident, and unsafe acts accounted for the remaining 88%. Following Abdelhamid and Everett, however, we expected some of the unsafe acts on tunnelling projects to be result from a decision to proceed with work despite knowing that their working conditions were unsafe (20). Thus, it was of interest to consider such occupational accidents as unsafe acts-conditions. That is, occupational accidents in tunnelling could be caused by unsafe working conditions, unsafe acts, unsafe acts in unsafe working conditions, or unavoidable Acts of God.**

Hence, the aim of this study was to draw upon available recent data in the form of a natural experiment to determine how individual and job-related variables affected the incidence of occupational accidents in the previous 12 months in a large tunnelling company in Iran.

## Materials and Methods

*Design and participants*

A natural experiment cross-sectional study was conducted in three occupational groups employed at a large tunnelling company in Iran. The study design was a comparison of employees who had suffered at least one occupational injury, which had made them leave their work for at least one day, with workers of the same company without an occupational accident history in the previous 12 months. As is typical of heavy construction workforces, all the employees were men. Participants were workers from the company headquarters (management, the warehouse, and the central workshop), mechanized tunnel drilling projects (via Tunnel Boring Machine), and traditional drilling method projects (including Jumbo Drills Tunnelling Machine). They had all been actively involved in tunnelling projects for at least 12 months. All 1640 employees of the company were invited to participate; 760 individuals volunteered and gave informed consent to join the study. In the previous twelve months 150 participants had experienced an occupational accident and 610 participants had not. Accidents outside of this period, and accidents that did not take place at work were excluded from the comparison.

*Data collection and analysis*

A short self-declaration questionnaire was used to determine age group, work experience, education level, marital status, exercise habit, smoking habit, and job satisfaction. Anthropomorphic measurements (height and weight) were taken by a researcher using appropriate equipment to accurately calculate the Body Mass Index (BMI) of each participant. To prepare for understanding the odds of an accident according to predictor variables, and a subsequent regression analysis, data were dichotomised. The age of an employee was classified into two groups: under 30 and 30 years and older. **WHO criteria were used so that individuals with BMI 18.5–25 were classified as having a normal BMI, and those outside of this range an abnormal BMI (23).** To determine smoking habit a dichotomous (yes / no) question was asked "Do you smoke every day" (24). Exercise habit was classified (yes / no) according to a minimum habit of doing exercise which caused a light sweat for over 30 minutes, twice weekly, for over a year (25). Job satisfaction was measured by a single item which asked participants whether they were generally satisfied with their job (26) with a yes / no response format.

Accident data was collected from personnel files and medical reports archived in the Health, Safety, and Environment (HSE) unit of the company. Individual, organisational and environmental factors involved in each accident were extracted and recorded. Where there was missing information, this was obtained by conducting a short interview with the worker involved. Archived reports of accidents, and interviews with the managers of tunnelling projects, as well as the injured people were used to determine the cause of each accident. **A bottom-up approach was used to analyse the accident data. The data was classified by cross-referencing information to checklists and classification methods used in previous validated studies (27–29). The cause of each occupational accident was categorized into one of three into groups: unsafe acts, unsafe conditions, and unsafe acts-conditions. Examples of unsafe acts and unsafe conditions are shown in Table I below. Accidents were classified as unsafe acts-conditions when there was clear evidence that the unsafe act was a result of unsafe conditions in which the employee proceeded regardless.**

***Insert Table I here***

All analyses were performed using SPSS Version 24 (Chicago, IL, USA). The conventional level of significance was used ($p < .05$). Descriptive statistics were reported for all variables. Chi-square test ($\chi^2$) was used for estimating crude relations. An adjusted logistic regression analysis used to remove the effect of confounding variables.

## Results

The nature of injuries (n=150) caused by the tunnelling project accidents is shown in Fig. 1. The most frequent injuries in this population were fractures (27%).

*Insert Fig. 1 here*

**The vast majority of accidents occurred on the tunnelling projects. 71% of injuries were caused by unsafe acts, and another 12% cause by unsafe acts associated with unsafe conditions. About one in six accidents was caused by unsafe working conditions There were no unavoidable accidents. (See Table II).** Almost half of the occupational accidents occurred on Fridays (i.e. overtime), and Saturdays (the first day of the week in Iran, as a Muslim state) (See Table III).

*Insert Table II here*

*Insert Table III here*

Table IV reports the odds ratios of occurrence of occupational accidents. Odds of an accident were higher in those aged under 30 years, those without higher education, employees without job satisfaction, individuals with less than 16 years of work experience, as well as those workers who did not exercise regularly. No significant relationship was observed between other individual variables and history of occupational accidents.

*Insert Table IV here*

In order to eliminate the effect of confounders, a logistic regression was performed. Variables were entered into the model using a stepwise method (see Table V). Level of education and age group were significantly related to occurrence of occupational accidents after adjusting for confounders.

*Insert Table V here*

## Discussion

In this natural experiment in Iran, approximately one-fifth of this workforce had experienced a reportable occupational accident in the previous 12-month period. In the UK, the accident rate in the construction sector as whole was substantially lower in the same period, nevertheless even in the UK the economic cost of workplace injury in this sector was estimated to cost £524 million using the latest 2017/18 figures (2). This strongly suggests that management interventions to promote safety in the tunnelling industry in Iran, and elsewhere, to reduce tunnelling accidents and injuries would benefit both tunnelling companies and their employees. We found that almost three-quarters of the main causes of accidents on the tunnelling projects were associated with unsafe acts by workers. This was true for both traditional drilling projects and mechanized projects. Level of education and age provided an important insight into understanding the difference between those who had experienced an occupational accident, and those who had not.

Education attainment, a proxy measure for safety literacy and understanding of safety messages, emerged as the key factor for understanding the incidence of accidents among this group of workers engaged on tunnel drilling projects. Those with higher education had less accidents. This strongly suggests the involvement of inadequate knowledge of safety guidelines, in the lack of correct adherence to them, which in turn, could be related to inappropriate expectations of understanding the available guidance.

There is surprisingly little research on the role of literacy in safety critical jobs. **The question "Why did the worker fail to understand the unsafe condition?" is a question on the Accident Root Causes Tracing Model (20). Potential responses include insufficient knowledge, wrong assumptions, did not follow the correct procedures, did not know the correct procedures. However, this does not go further to consider why this might be.** Salah & Pendley (30) asserted that safety literacy is important for engineering students, and Bust *et al*. (31) provided an outline of the issue of communicating safety messages to migrant workers. In the UK, the Health & Safety Executive (32) argued that to "revitalize" health and safety messages in the construction industry, improvements to communications in workforces with low levels of literacy was a priority for reducing accident rates. That is, information is provided in compliance with the law, but in practice messages can be meaningless because of language and education level barriers. Visual images have been used as an intervention on construction sites however their efficacy has not been rigorously explored.

The relationship between low health literacy and poor health status has become clearer over the past 20 years (33) with simple, plain language for health information the recommended intervention to improve population health (34). Similarly, to minimize accidents on drilling projects – and we suggest, throughout the construction industry – it is essential that the safety guidelines that define and explain the complex machinery, devices and procedures are delivered in plain language. Information about health and safety hazards, whether spoken or written, should be at a low reading age, with supporting visual graphics as much as possible. Just as different newspapers write at different reading age levels according to their target audience, safety managers would do well to tailor their rules and guidance to the lowest level of education. This will maximise opportunities for all workers to assimilate the necessary information.

All workers have the right to know of any hazards present on a job they are doing. There is evidence that many of those operating as safety officers can misunderstand the behavioural requirements of safety critical construction work because of low literacy skills (35). This is a vital area for intervention given the frequent and extensive changes in working conditions on each different tunnelling project. In addition, there are many other hazardous occupational factors in tunnelling work. Low literacy levels constrain the ability of the construction industry to manage health & safety risks effectively (36). The results of our investigation strongly suggest that low safety literacy is related to unsafe acts which in turn, increases the rate of occupational accidents in tunnelling.

A review of the causes of occupational accidents at construction sites in Malaysia also low levels of education and training opportunities for workers (37). We therefore suggest that the implementation of short-term and practical training courses for workers would make a major contribution to accident prevention. Such courses can ensure all employees understand why safety and health considerations are important and why they must adhere to safety policy and procedures (38). It should be noted that mere provision of training classes by a HSE unit without highlighting the importance and the reasons for training can also have a negative impact on the effectiveness of the HSE programmes; they can be seen as a hassle (15).

In this study, workers on tunnelling projects who were under 30 years old reported significantly more occupational accidents. Our investigations showed that in this work, physically and mentally demanding and risky jobs were often left to younger people. Less work experience, insufficient training, inadequate skills in terms of facing various hazardous conditions of tunnel drilling projects and the risky behaviour of younger workers were key reasons for increased accidents among younger employees. On the other hand, lower age itself, is usually associated with lower work experience, which itself is related to occupational accidents (9). Nevertheless, the findings of the present study follow the findings of investigations of the effect of age and work experience on occupational accidents among workers in France (39) and Taiwan (40).

Although there have been reports that married workers experienced more occupational accidents than non-married employees (41), our findings were in line with the review of 6,722 occupational injuries in Iran that reported no significant relation between accidents and marital status (9).

There was a significant difference in job satisfaction between those workers who had suffered an occupational accident and those who had not. This can be understood when referring to evidence that job satisfaction affords more attention to safety, motivation, knowledge, and compliance (42). Similarly, there is evidence that job dissatisfaction can lead to inattention to the principles and objectives of their organization in health and safety issues, and thus prevention strategies may be ignored (43). Nevertheless, it may also be true that after an occupational accident, an employee becomes dissatisfied with their work, so the relevance of this outcome must be treated with caution. Generally, job dissatisfaction is the result of numerous factors in organizations; the concept needs to be studied more thoroughly as the evidence remains that employees with lower job satisfaction were more likely to have accidents (44,45).

**Finally, it is interesting to note that 83% of accidents in this natural case study were essentially a result of unsafe acts. This finding was similar to the 88% Heinrich reported in his seminal work (22). Whilst not completely dismissing the potential for unavoidable accidents – Henrich reported 2% – we did not see any in this 12-month reporting period. We do not support the assertion that occupational accidents are unavoidable in construction (21). There are usually issues to consider that can prevent similar occupational accidents occurring on future projects.**



*Limitations*

A limitation of this study was its cross-sectional design. The lifetime of tunnelling projects is limited, and the workers are frequently displaced, which makes it difficult to follow up on workers longitudinally. There remains a need to conduct a nationwide study of accidents in construction projects including tunnelling, damming, and road construction, where all factors associated with occupational accidents can be considered.

## Conclusion

In our study of occupational accidents in Iran's tunnelling industry one-fifth of the participants from one large organisation had experienced a reportable occupational accident in a twelve-month period. Our findings suggest the use of young workers with relatively little on-the-job experience, and those with low levels of education contribute to this high rate of occupational accidents. Therefore, tunnel drilling project managers need to pay special attention to these factors to promote employee safety. In particular, safety literacy is a challenge for those with lower educational achievement. We recommend a review of procedures involved in disseminating safety information is called for, to ensure the project-specific information is tailored to the literacy levels of the workers, alongside some form of assessment of understanding of the safety information provided as an induction process for all projects.

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**Conflict of Interest:** The authors declare that there is no conflict of interest regarding this research and publication.



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**Table I. Examples of unsafe acts and unsafe conditions**

| Unsafe acts | Unsafe conditions |
|---|---|
| Operating a machine at an incorrect speed | Inadequate, inefficient or absent guarding |
| Turning off safety devices | Missing equipment |
| Failure to use all available resources | Missing information |
| Using inadequate equipment / using equipment incorrectly | Inappropriate instructions |
| Not adopting appropriate position or posture | Defective hand tools, equipment, substances |
| Failure to communicate | Poor design / layout of site – workflow, overcrowding, congestion |
| Failure to adhere to brief | Insufficient staffing |
| Violation of training rules | Failure to provide sufficient time for job |
| Working on moving or dangerous equipment | Inadequate or inappropriate lighting (e.g. presence of glare) |
| Distracting, teasing, abusing, startling other workers | Inadequate ventilation |
| Not wearing PPE (e.g. grinding without wearing safety goggles) | Unsafe clothing, adequate PPE not provided |
| Working without authority (e.g. entering a confined space before it has been declared safe). | Unsafe processes: mechanical, chemical, electrical |
| Adjusting moving machinery (e.g. lubricating bearings or changing the drive belts while the machine is still running). | Substandard housekeeping. (Absence of waste bins, aisles, storage, signs & notices) |
| Chance taking (e.g. running in front of a forklift truck) | Excessive noise – cannot hear instructions |

**Table II. Frequency of occupational accidents in three occupational groups based on the cause of accidents (n = 150)**

| Activity group | N | Unsafe acts | Unsafe acts-conditions | Unsafe conditions |
|---|---|---|---|---|
| Headquarters | 10 | 5 (50%) | 3 (30%) | 2 (20%) |
| Mechanized drilling project | 70 | 56 (80%) | 3 (4.3%) | 11 (15.7%) |
| Traditional drilling project | 70 | 46 (65.7%) | 12 (17.2%) | 12 (17.1%) |
| Total | 150 | 107 (71.3%) | 18 (12%) | 25 (16.7%) |

**Table III. Daily frequency of occupational accidents (n = 150)**

| Weekdays | N (%) |
|---|---|
| Saturday | 39 (26%) |
| Sunday | 9 (6%) |
| Monday | 13 (9%) |
| Thursday | 11 (7%) |
| Wednesday | 18 (12%) |
| Tuesday | 25 (17%) |
| Friday | 35 (23%) |

**Table IV. The relationship of individual and job-related characteristics according to occupational accident status**

| Variable | | Occupational Accident (n = 150) | | No Accident (n = 610) | | Odds Ratio (CI 95%) |
|---|---|---|---|---|---|---|
| | | n | % | n | % | |
| Age group (years) | < 30 | 99 | 66.0 | 399 | 65.4 | 1.03 (0.89-1.17) |
| | 30 + | 51 | 34.0 | 211 | 34.6 | |
| BMI range | Abnormal | 59 | 39.3 | 262 | 43 | 0.86 (0.83-0.89) |
| | Normal (20-25) | 91 | 60.7 | 348 | 57 | |
| Education level | Under diploma | 115 | 76.7 | 350 | 57.4 | 2.44 (1.28-3.6) |
| | Higher education | 35 | 23.3 | 260 | 42.6 | |
| Marital status | Single | 98 | 65.3 | 90 | 14.8 | 10.89 (6.93-14.85) |
| | Married | 52 | 34.7 | 520 | 85.2 | |
| Job satisfaction | No | 93 | 62 | 235 | 38.5 | 2.6 (0.64-4.56) |
| | Yes | 57 | 38 | 375 | 61.5 | |
| Smoker | Yes | 65 | 43.3 | 310 | 50.8 | 0.74 (0.54-0.93) |
| | No | 85 | 56.7 | 300 | 49.2 | |
| Work experience (years) | ≤15 | 126 | 84 | 399 | 65.2 | 2.78 (1.08-4.48) |
| | >15 | 24 | 16 | 211 | 34.8 | |
| Exercise habit | No | 115 | 76.7 | 355 | 58.2 | 2.03 (0.45-3.61) |
| | Yes | 35 | 23.3 | 255 | 41.8 | |

**Table V. Logistic regression results of factors related to occupational accidents**

| Variable | B | SE | OR | CI 95% | | *p* |
|---|---|---|---|---|---|---|
| | | | | Lower | Upper | |
| Education level | 1.76 | 0.88 | 5.81 | 1.03 | 9.03 | 0.002 |
| Age group | 0.62 | 0.23 | 1.81 | 0.22 | 2.71 | 0.048 |
| Marital status | 0.03 | 0.15 | 0.26 | 0.01 | 0.53 | 0.814 |
| Job satisfaction | 0.05 | 0.17 | 0.36 | 0.09 | 0.99 | 0.782 |
| Smoker | 0.19 | 0.14 | 0.13 | 0.08 | 1.43 | 0.198 |
| Work experience | 0.39 | 0.43 | 0.74 | 0.12 | 1.84 | 0.359 |
| Exercise habit | 0.11 | 0.12 | 0.71 | 0.17 | 1.31 | 0.399 |

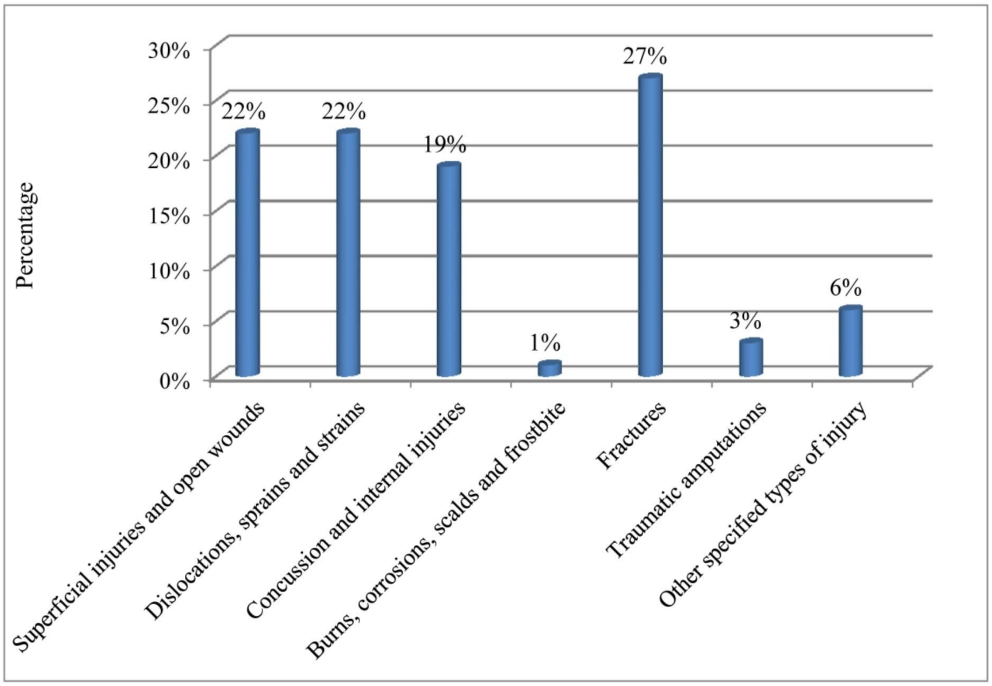


Figure 1. Consequences of occupational accidents based on the International Labour Organisation injury categories.

Fig. 1. Consequences of occupational accidents based on the International Labour Organisation injury categories.

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