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A Methodology for the Identification of Confined Spaces in Industry

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Abstract. Work in confined space is a high-risk activity posing a serious life-threatening hazard to workers who perform it. Accidents in confined spaces frequently lead to multiple fatalities. The cause of accidents and fatalities due to confined space work is related to the lack of awareness about the presence and the risks of such hazardous workplaces. This paper introduces a methodology for the identification of confined spaces in industry. The aim is to provide a useful tool for helping researchers and practitioners to recognize of confined spaces in industry. Four different characteristics of confinement are investigated: geometric features, access, internal configuration, and atmosphere and environment. The proposed methodology includes the definition of the Confined Space Risk Index (CSRI) for the analysis of the risk related to the investigated confined space. Finally, two case studies show the application of the proposed methodology to two suspected confined spaces in industry.

Keywords. Confined space; Confined space work; risk assessment; risk index.

1 Introduction

Confined space work is a high-risk activity, posing a serious dangerous hazard to the workers. Hazards in confined spaces are difficult to evaluate and manage, due to the complex characteristics of such particular work environments [1]. Both the features of the confined area and the characteristics of the performed task have direct impact on the overall risk level of a specific confined space activity. Despite international efforts in defining consistent procedures and recommendations for safe confined space work, past and recent statistics show that fatal incidents still occur [2].

The 29 CFR 1910.146 standard of the American OSHA is widely known as the Permit-Required Confined Spaces (PRCS) Standard for confined space work in general industry [3]. Such standard provides a general definition of “confined space”, together with requirements for practices and procedures to protect employees in gen-

eral industry from the hazards of entry into permit-required confined spaces. The PRCS defines “Confined space” as a space that is large enough and configured that an employee can enter and perform work, has limited openings of entry or exit and is not designed for continuous occupancy [4, 5]. Examples of confined spaces include silos, vessels, boilers, storage tanks, sewers and pipelines. Less common types of confined spaces are industry. Examples of such spaces are the interior areas of machines where operators access to perform maintenance tasks.

The PRCS Standard protects employees who enter confined spaces while engaged in general industry work. This standard has not been extended to cover employees entering confined spaces while engaged in specific industries, as construction work or confined space workers in agriculture because of unique characteristics of such worksites. Despite the numerous directions of the OSHA’s standards, employers in general industry have difficulty determining if spaces are permit-required confined spaces. Several accidents and injuries related to confined space work showed that workers access to confined areas without proper training and personal protective equipment, exposing themselves to high levels of hazards [11, 12]. The lack of situation awareness is an underlying cause of human errors, especially when workers access to areas not designed for continuous occupancy as confined spaces. Rescue attempts in confined spaces are also hazardous situations, since emergency response is a low-frequency, high-risk operation. Many would-be rescuers perish while trying to rescue a victim after a confined space accident. Would-be rescuers deaths include trained fire-fighters and competent personnel who had years of experience, despite the requirements for training, planning and expertise with confined space rescue procedures. Data and statistics reveal that the 60% of confined space fatalities in U.S. occur among would-be rescuers [13]. The chain of would-be rescuer deaths is an on-going phenomenon globally challenging. The Canadian Centre for Occupational Health and Safety and the European Agency for Safety and Health at Work (EU-OSHA) state the same 60-percent statistic [14]. These data reveal a hidden phenomenon, i.e. both employers and workers fail to identify confined space work hazards [2, 15].

This paper introduces the structure of a tool for the identification of confined spaces in industry. The aim was to realize an effective tool to prevent workers entry into high-risk confined spaces. The tool addresses workers during the complex identification of high-risk confined spaces. Finally, the tool supports the mandatory risk assessment for confined spaces computing the risk index for the analyzed confined space and task.

2 Identifying confined spaces: a challenging task

The U.S. OSHA outlines the confined space features to help employers and employees in recognizing such hazardous workplaces. The PRCS outlines the boundary line between non-permit and permit-required confined spaces, i.e. a permit-required confined space is distinguished by the hazards present and the ability of the employer to eliminate them [16]. Particularly, a permit-required confined space contains or has potential to contain a hazardous atmosphere, contains a material that could potentially

engulf a worker, has an internal configuration that could trap or asphyxiate a worker, or presents any other serious, recognized hazard. This definition has been repeated for years, mentioning the OSHA regulations and analyzing every detail. Design features of confined spaces increase risk to entrants. Such features include the physical configuration of entry and exit portals, structural weaknesses in walls and the absence of anchor points necessary for effecting emergency rescue [17, 18] .

The tool for the confined space identification includes a simplified application of the PRCS definition. The characteristics of the confined space are gathered in four different categories: geometric features; access; internal configuration; atmosphere and environment.

Limited dimensions characterize confined spaces. Following the definition of the OSHA's standard 29 CFR 1910.146, a confined space is large enough and so configured that an employee can bodily enter and perform assigned work. The concept of limitation of a dimension is referred to the dimension of the human body, fully equipped to face the worst possible scenario. The minimum working area of a worker may be computed as the circumference drawn by his arm. Given the length of the arm of the 99th percentile man as equal to 800 mm [19] and an increase due to the PPE (e.g., protective gloves) of 5 mm, the minimum working area of a worker is equal to a circumference with a ray of 805 mm. Consequently, the space can be defined as "geometrically confined" if the circumference with a diameter of 1,800 mm (ray 900 mm) and center at the intersection between the transverse plane and the longitudinal axis is not completely clear and free from obstructions. Aggravating conditions of the geometric features of a confined space include the presence of hollowed areas and extensions far from the entry.

The international standards on anthropometric measures provide further useful dimensions of the human body [20-23] . Such standards allow determining the dimensions of the human body ellipse, which are 600 mm for the major axis (shoulder breadth) and 450 mm for the minor axis (body width). Consequently, the access of a space is confined if the diameter or the shortest dimension of the entry is smaller than 600 mm. The presence of a singular vertical access or the lack of protection and signal are aggravating conditions of the confined access.

Internal configuration refers to the internal characteristics of the space. The necessary condition of the confined internal configuration is that the space is not designed for continuous occupancy. The presence of material that has the potential for engulfing the entrant or residuals from previous operations increase the exposure of the worker to the risks of confined space work, aggravating the conditions of the confined space.

Finally, a space is atmospherically confined if it contains or has potential to contain a hazardous atmosphere. Specifically, the absence of a natural or artificial efficient ventilation system that ensures proper ventilation in every accessible point is the necessary condition to define the confined atmosphere of the space. Aggravating conditions of the atmospherically confined space include the characteristics of the expected operations, (e.g., hot and cold works, stock of heavy and bulky materials, and tests), high concentrations of explosive and toxic substances, and the presence of noise.

Each confinement category identifies a dimension of the confined space. Specifically, a space can be limited in four different dimensions, i.e. geometric features, access, internal configuration, and atmosphere and environment. Based on the described confined space characteristics, the following Section 3 shows the algorithm for the identification of confined spaces.

3 Algorithm for the identification of a confined space

The aforementioned categories outline a structured representation of the characteristics of confined spaces. The presence of a confined space is confirmed when a necessary condition is verified. Therefore, the space can be confined in its geometric features, access, internal configuration, and atmosphere and environment. These categories define the structure of the algorithm for the identification of confined spaces in Figure 1. The algorithm in Figure 1 guides workers and practitioners through the process for the identification of confined spaces. Specifically, the answer “YES” to one of the four necessary conditions defines the presence of a confined space. The types of confinement refer to the specific categories for which the user answers “YES”. In case of affirmative answer, the procedure suggests the investigation of the aggravating conditions. Based on the algorithm in Figure 1, Figure 2 shows a checklist including both necessary and aggravating conditions, for each category. The checklist is part of the risk assessment required by the current law. Workers and practitioners complete the checklist prior to perform the operations in the suspected confined space. A tick is assigned to each condition concerning the situation in the suspected confined space. The ticks in the four questions A1, B1, C1 and D1 on necessary conditions define the presence of the confined space. As an example, a tick in questions A1, B1 and D1 define a space with limited geometric features, limited access and atmospherically confined. The aggravating conditions contribute to the quantification of the risk index for the suspected confined space. When a necessary condition is not identified, the user skips the aggravating conditions for the corresponding category and moves to the next (e.g., if A1 does not concern the suspected confined space, skip A2 and A3, and go to condition B1). The definition of the risk index and the parameters for its calculation are in the following Section 4.

4 Confined Space Risk Index (CSRI)

The answers to the questions of the checklist in Figure 3 contribute to the definition of the Confined Space Risk Index (CSRI). Specifically, a score of one is attributed to each answer with the tick. Questions without the tick have no score. The space is confined if at least one of the necessary conditions A1, B1, C1 or D1 is concerned. The aggravating conditions in each category contribute to increase the CSRI. The following Equation (1) defines the CSRI.

$$CSRI = A1 \cdot \left[1 + \left(\frac{\sum_{i=A2}^{A3} Ai}{2} \right) \right] + B1 \cdot \left[1 + \left(\frac{\sum_{i=B2}^{B4} Bi}{3} \right) \right] + C1 \cdot \left[1 + \left(\frac{\sum_{i=C2}^{C14} Ci}{13} \right) \right] + D1 \cdot \left[1 + \left(\frac{\sum_{i=D2}^{D12} Di}{11} \right) \right] \quad (1)$$

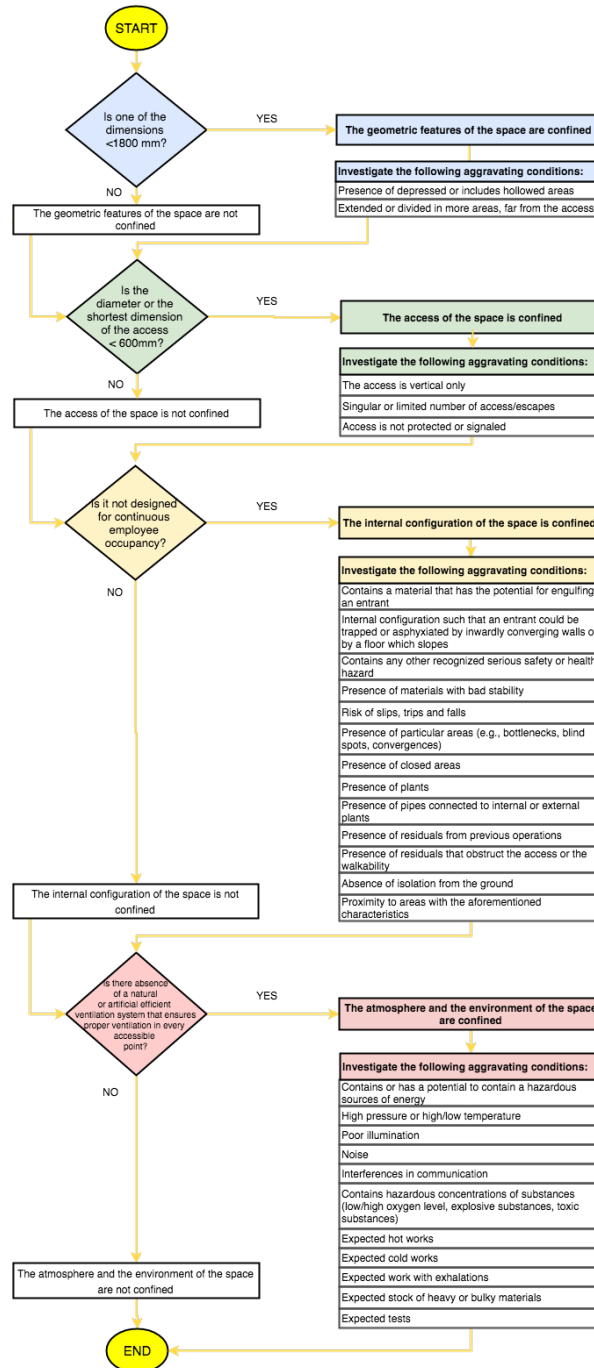


Fig. 1. Algorithm of the confined space identification tool

IDENTIFICATION OF A CONFINED SPACE		
Review each condition for the suspected confined space of interest, place a tick in the column on the right as appropriate.		
CATEGORY	CONDITION	CONCERN
GEOMETRIC FEATURES	A1. Geometrically limited if at least one of its dimensions <1800 mm	
	A2. Depressed or includes hollowed areas	
	A3. Extended or divided in more areas, far from the access	
ACCESS	B1. Diameter or the shortest dimension of the access < 600mm	
	B2. The access is vertical only	
	B3. Singular or limited number of access/escapes	
	B4. Access is not protected or signaled	
INTERNAL CONFIGURATION	C1. Not designed for continuous employee occupancy	
	C2. Contains a material that has the potential for engulfing an entrant	
	C3. Internal configuration such that an entrant could be trapped or asphyxiated by inwardly converging walls or by a floor which slopes	
	C4. Contains any other recognized serious safety or health hazard	
	C5. Presence of materials with bad stability	
	C6. Risk of slips, trips and falls	
	C7. Presence of particular areas (e.g., bottlenecks, blind spots, convergences)	
	C8. Presence of closed areas	
	C9. Presence of plants	
	C10. Presence of pipes connected to internal or external plants	
	C11. Presence of residuals from previous operations	
	C12. Presence of residuals that obstruct the access or the walkability	
	C13. Absence of isolation from the ground	
	C14. Proximity to areas with the aforementioned characteristics	
ATMOSPHERE AND ENVIRONMENT	D1. Absence of a natural or artificial efficient ventilation system that ensures proper ventilation in every accessible point	
	D2. Contains or has a potential to contain a hazardous sources of energy	
	D3. High pressure or high/low temperature	
	D4. Poor illumination	
	D5. Noise	
	D6. Interferences in communication	
	D7. Contains hazardous concentrations of substances (low/high oxygen level, explosive substances, toxic substances)	
	D8. Expected hot works	
	D9. Expected cold works	
	D10. Expected work with exhalations	
	D11. Expected stock of heavy or bulky materials	
	D12. Expected tests	

Fig. 2. Checklist for the identification of a confined space

Table 1. Ranges that define risk levels.

CSRI Value	Risk Level	Consequences
0	No risk	No confined space, no consequences
$1 \leq \text{CSRI} < 3$	Low risk	Acceptable: no significant consequences
$3 \leq \text{CSRI} < 5$	Medium risk	Improve structural risk factors or adopt risk control measures
$5 \leq \text{CSRI} \leq 8$	Significant risk	Redesign tasks and workplaces according to priorities. Avoid entry if possible.

CRSI is a number between 0 and 8. The value of the CRSI is 0 if no necessary condition for confinement concerns the space investigated. The maximum value for the CRSI is 8 and it represents a confined space where all the necessary and aggravating conditions are verified. The value of the resulting index is then compared with the ranges in Table 1, which defines the corresponding risk level. Working in confined space poses or is likely to pose a risk to the safety and health of workers. In case of low risk, risk control measures as engineering controls, administrative controls and PPE should be taken. When the risk is high, workers should not enter the confined space. Tasks should be redesigned to avoid man entry and including the adoption of non-man entry technologies for work in confined spaces [24]. A possible alternative is the redesign of the workplace to eliminate the necessary conditions concerning the identified confined space. The following Section 5 shows two practical applications of the checklist and the CSRI for two confined spaces in industry.

5 Quick applications of the checklist and CSRI calculation

5.1 Case study 1: Grain silo

The first case study concerns the application of the proposed checklist for the risk assessment of silos for grain storage in an Italian mill. Silos have a rectangular section of 15 x 21 m. The height is 40 m. The internal surfaces have no openings, except for two manholes, which are on the top and on the lower part of the silo. The dimensions of the top manhole are 500 x 600 mm, while the lower manhole is 500 x 500 mm. Workers occasionally enter the silos for maintenance operations (e.g., unclog materials on the walls and inspect the grain). Such activities do not require specific equipment. Workers usually enter the space from the top manhole, with a shovel and a flashlight. Following the checklist in Figure 2, the necessary conditions for confinement concerning the space are B1, C1 and D1. As a consequence, the investigated silo is a confined space as its entries, internal configuration and atmosphere are confined. Further conditions concerning the space are B3, B4, C2, C3, C5, C6, C7, C14, D4 and D11. Following Equation (1) for the calculation of the risk index, the resulting CSRI is equal to 4.3. A medium risk level concerns the investigated confined space (Table 1) and the risk factors should be improved to reduce the risk level.

5.2 Case study 2: Metal tank in filtration plants

The manufacturing process of swimming pool filters requires workers to enter a cylindrical tank to perform welding of the metal components of the tank (e.g. top, lateral metal sheet, bottom and other small components). The tank diameter is 3 m. During welding operations, a positioning device sustains the tank with the diameter perpendicular to the floor. The width of the internal space where worker welds components is about 1.3 m, while the height is 3 m (tank diameter).

The worker enters the tank through a manhole of DN 500. All the four necessary conditions of the checklist concern the space, i.e. the tank is a confined space. Further

aggravating conditions are B3, B4, C14, D2, D3, D4, D8 and D10. The resulting CSRI is 5.2, which involves significant risk for the investigated confined space. Workers should not enter the space and the redesign of the task is suggested. For example, an autonomous welding robot could enter the tank, while manual worker supervises the welding operations from the outside.

6 Conclusions

This paper has introduced a method to identify confined spaces in industry. The aim was to define an algorithm for the recognition of high risk confined spaces and prevent workers access. The analysis of fatalities due to confined space work showed that the lack of awareness about the presence and the risk of confined spaces is the main cause of accident. The proposed algorithm defines a structured framework for the recognition of workplace confinement characteristics in industry. Four categories of confinement have been defined to identify confined spaces: geometric features, access, internal configuration, and atmosphere and environment. A necessary condition and a set of aggravating conditions characterize each confinement category. The workplace concerning at least one of the proposed necessary conditions is a confined space. Based on the structure of the proposed algorithm, a checklist was developed to address workers and practitioners through the identification of confined spaces in industry. Finally, the Confined Space Risk Index (CSRI) analyses the risk of the confined space, defining the risk level. This study will be the basis for the development of an interactive tool for the identification of confined spaces in industry. The tool will have a user-friendly interface and it will be accessible online from personal computers and other electronic devices (e.g., smart phones and tablets). Lastly, the CSRI will be improved including accident frequencies and the related risk factors.

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