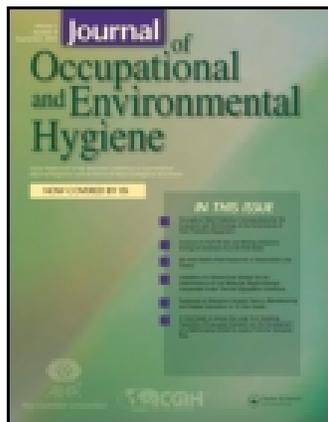


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Hazard Evaluation and Preventive Recommendations for an Unusual Confined Space Issue in an Opera Set Design

Anders Abelman^{a,b}, Steven E. Lacey^a, Andrey Gribovich^a, Colin Murphy^a & David Hinkamp^a

^a University of Illinois at Chicago, School of Public Health, Division of Environmental & Occupational Health Sciences, Chicago, Illinois

^b Now at ChemRisk, Inc., Chicago, Illinois

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Case Study

Hazard Evaluation and Preventive Recommendations for an Unusual Confined Space Issue in an Opera Set Design

INTRODUCTION

At the request of the Lyric Opera of Chicago, an occupational health hazard evaluation was conducted concerning a confined space issue within the set design of an operatic performance. Following one dance sequence and costume change, several dancers were to be placed inside flag-draped, military-grade human remains transfer cases (Figure 1) for 6 to 12 min, then exit the cases to begin the next dance sequence. Further, during one component, a performer was to dance on top of one of the cases with another performer inside of it.

After discussions with the operations manager and set design crew, two overarching concerns were identified as (1) the environmental conditions for the performer inside the casket and (2) the structural integrity of the transfer case under the load of the performer on top.

Environmental conditions of concern for the confined performer included breathing air quality and temperature inside the case; the ability to identify and respond to a possible medical emergency of the performer; as well as the risk of prompting a possible claustrophobic reaction in the performer.

Relevant Health and Safety Regulations

Confined Spaces

The U.S. Occupational Safety and Health Administration (OSHA) defines a confined space as one with limited or restricted means for entry or exit and that is not designed for continuous employee occupancy. In addition, a “permit-required” confined space has one or more of the following characteristics: potential to contain a hazardous atmosphere; potential of a material inside the space to engulf an entrant; tapered walls or sloping floors; or that contains another safety or health hazard (e.g., unguarded machinery).⁽¹⁾

Decreased Oxygen Environments

Ambient air contains approximately 21% oxygen (O₂) and 78% nitrogen, while the remaining fraction comprises trace gases, including carbon dioxide (CO₂).⁽²⁾ OSHA defines an oxygen-deficient atmosphere as an atmosphere with less than 19.5% oxygen; thus, any environment below that concentration is considered immediately dangerous to life and health (IDLH) and supplied-air respirators must be used.⁽³⁾ In addition, altering the concentration of other gases may also pose a health hazard. By breathing the air in a confined space an occupant will consume O₂ but also expire CO₂, thus decreasing the O₂ while increasing the CO₂ concentration. The OSHA IDLH for CO₂ is 40,000 ppm, or 4%.⁽⁴⁾ Above this level, signs of intoxication may occur. In this study, we had to ensure a supportive breathing atmosphere because even

Column Editor

James Couch

Reported by

Anders Abelmann*

Steven E. Lacey

Andrey Gribovich

Colin Murphy

David Hinkamp

University of Illinois at Chicago,
School of Public Health, Division of Environmental & Occupational Health Sciences, Chicago, Illinois

*Now at ChemRisk, Inc.,
Chicago, Illinois

Correspondence to: Steven E. Lacey, University of Illinois at Chicago, 2121 West Taylor Street (MC 922), Chicago, IL 60612; e-mail: slacey@uic.edu.



FIGURE 1. Human remains transfer case

minor changes to the composition of the breathing air may negatively impact the performers carrying out peak physical and mental activities.

METHODS

Breathing Air Quality

To evaluate the potential hazardous breathing air conditions with a performer occupying these cases, a simple mathematical model of oxygen consumption and carbon dioxide emission was used to anticipate atmospheric conditions.

In the model, ambient air concentrations of 21.0% O₂ and 0.04% CO₂ were assumed;⁽⁵⁾ heavy exertion was defined as a breathing rate of 20 breaths per minute and a breathing volume of 1 L per breath;⁽⁶⁾ expired air concentrations of O₂ and CO₂ were assumed to be 15.9% and 4.0%, respectively;^(7,8) and the mixing factor was estimated to be 1.25 within the transfer case. The maximum time inside the case was reported by the opera to be about 12 min. Equations 1 and 2 describe the concentration of O₂ and CO₂ over time, respectively.

$$C_{O_2,t} = \frac{C_{O_2,t-1} \times V_{total} - K_{uptake} \times V_B}{V_{total}} \quad (1)$$

$$C_{CO_2,t} = \frac{C_{CO_2,t-1} \times V_{total} + C_{CO_2,exhale} \times V_B}{V_{total}} \quad (2)$$

$$V_{total} = \frac{(V_{case} - V_{body})}{K_m}$$

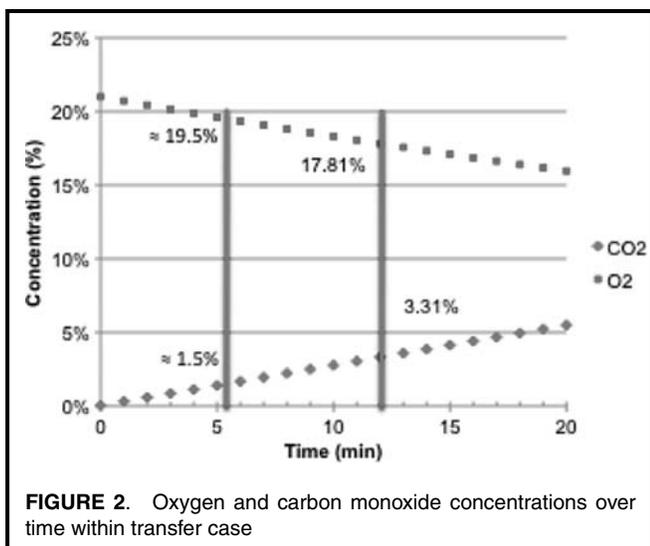
$$V_B = BV \times BR$$

where C_{x,t} = concentration of gas x at time t; V_{total} = total volume; K_{uptake} = oxygen uptake; V_B = volume of air exhaled/inhaled in 1 min; V_{case} = volume of transfer case; V_{body} = approximate volume of body in case (80 L); K_m = mixing factor; BV = breathing volume; BR = breathing rate.

This modeling exercise indicated that the as-manufactured case design may have impeded a performer's ability to achieve adequate respiratory support—the result of a slight decrease in oxygen concentration and an increased carbon dioxide concentration. In this simplified scenario, the OSHA IDLH oxygen level would be reached after about 3 min (Figure 2). Prior to the visit to the opera house, the set design crew had cut out small vents in the caskets' short side that were partly covered by a mesh material. There was concern that these openings were potentially insufficient in providing adequate air exchange, especially if the vents were to be covered by flags during the time they were occupied by the performers.

Structural Integrity of Case

The human remains transfer cases used in the production were made from aluminum 3003-H14, and measured 2.20 × 0.67 × 0.30 m. Modeling software (Pro Engineer 5.0; Parametric Technology Corporation, Needham, Mass.) was used to evaluate the performance of the case under the load of a performer, accounting for the cut-outs referenced above, as well as material fatigue from repeated performances. The modeled stress was applied at the center of the case top, as this is generally considered the weakest point of the case. Though the authors were told that performers might average



80 kg, a mass of 90 kg was used to integrate a safety factor to account for the dynamic load of a moving performer. The case material had a yield stress of 155 megapascals (MPa).

The results of the modeling indicated that for unaltered case conditions, the maximum stress experienced by the case material from the load would be approximately 125 MPa, with a maximum physical displacement of 2.4 cm. For the model accounting for recommended ventilation cut-outs, the maximum stress from the load was approximately 160 MPa, with a maximum physical displacement of 2.5 cm. Finally, for the model that included recommended ventilation cut-outs with a reinforced lid, the maximum stress seen by the case material was 60 MPa, with a displacement of 0.8 cm. Figure 3 shows an example output of the simulated load analysis. In summary, the cases in their original design would likely allow for a performer to act on top of it.

RECOMMENDATIONS

Based on the air quality and structural integrity modeling, the following recommendations were provided to the opera's technical director.

Ventilation of Space

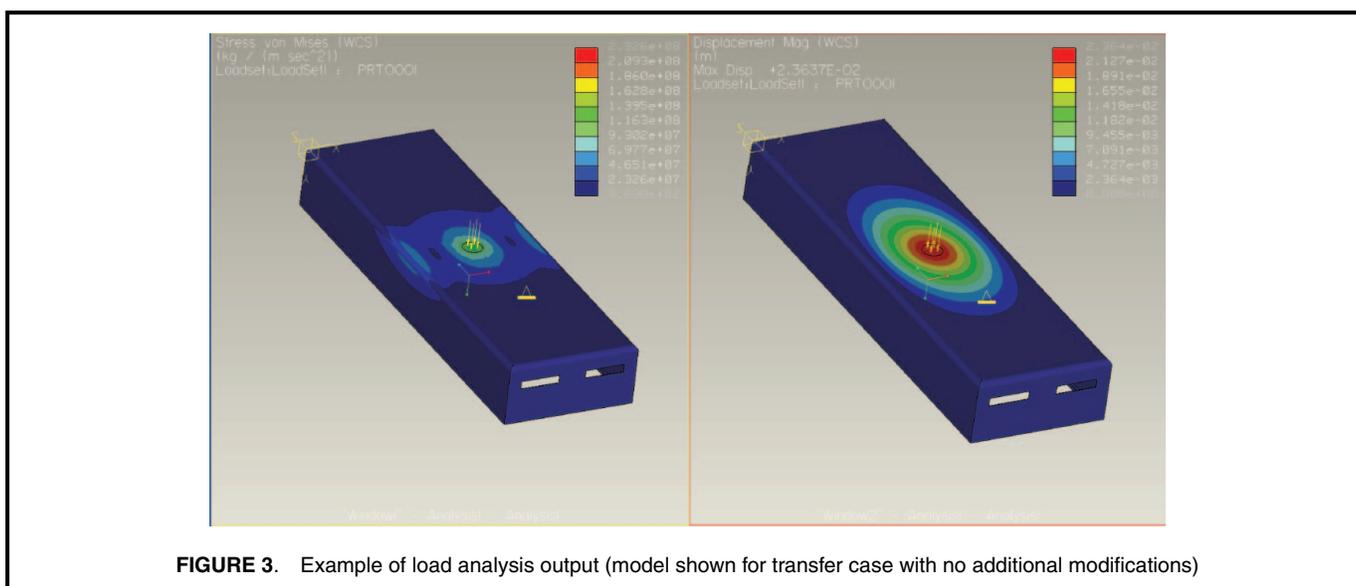
Additional vents were recommended, allowing for both air exchange and for viewing the performer while inside the case; the vents should not be covered by mesh or any other opaque material (such as a flag) that could inhibit air exchange or observation of performers. Installing these vents on only one side of the case (away from the audience) would provide sufficient ventilation and also reduce the temperature inside the case.

Three cutout vents measuring 30 × 20 cm were recommended, to be positioned such that each performer's face could be observed at all times. In addition, installation of fans was recommended to further facilitate air exchange, as well as aid in mixing and cooling.

Observation of Performers and Ensuring Egress

The modifications of the cases as described above would allow for line-of-sight observation of each performer's face and permit some light into the transfer case to reduce disorientation of the performer. In addition to providing ventilation, this would permit observation of the performer. In case of medical emergency, claustrophobia, or other concerns, the performer could alert the crew and enable prompt removal or other appropriate actions. This could also provide a sense of confidence for the performers, knowing that they were being observed and that they would receive help if needed.

It was further recommended that an off-stage employee be designated to observe each performer during their entire confinement period. A protocol for observing the performers



while inside the case was to be developed, including procedures for observation and signaling, establishing emergency procedures, and how to remove a performer from the case and stage.

Egress from Confined Space

Disabling all latches on all cases was recommended to eliminate the risk for trapping performers inside and to ensure rapid egress in case of an emergency.

Reinforcement of Case

Reinforcement of the lid did not appear necessary unless objects were placed on top of the case. The cases in their current design were likely to allow for a performer to dance on top without metal failure and collapse. For additional security against collapse of the top, additional reinforcement of the top was recommended.

Installing a 2.5 cm square aluminum beam (e.g., a single hollow 13 gauge aluminum 3003-H14) would strengthen the case to withstand repeated performer weight. It was the authors' understanding that the long dimension of the case would be hidden from the audience and could be modified without affecting the appearance.

IMPLEMENTATION OF RECOMMENDATIONS

On follow-up, the technical director reported that the cases were modified as per the ventilation, observation, and egress recommendations. Photos received, however, indicated that the final openings were smaller and spaced differently than recommended (Figure 4). Final placement of openings should still have allowed for adequate access to fresh air while continuing to provide line-of-sight contact with performers.

Fans were installed to facilitate air exchange, and all latches were permanently disabled. Finally, a stagehand was assigned to each case and was responsible for watching for signals or signs of distress while each performer was inside. Flags were draped over the front of the cases facing the audience but not over the backs where they could interfere with ventilation or observation.

The altered size and shape of the cutouts may have reduced the applicability of the structural integrity modeling. However, the reduced size of the ventilation cutouts likely reduced risk of material fatigue, which would have reduced the need for reinforcement. Information was not available regarding whether the case with the load bearing requirement had been reinforced.

Evaluation including monitoring of the atmosphere within the transfer case after ventilation modifications were made would have been ideal to ensure that the design was providing adequate air supply to the performers. Unfortunately, this was not feasible due to time constraints before the opening of the show.

CONCLUSIONS

The performing arts can involve a variety of safety and health concerns, and a specific performance may involve unique hazards. The authors hope that this case involving the potential health and safety issues of a confined space during performances results in a heightened awareness of potential hazards in other performance settings. Further, this case study demonstrates the benefit of an interdisciplinary occupational health and safety team of occupational hygiene, engineering, and medical expertise working with operations management and set construction to identify and remediate potential risks



FIGURE 4. Rear view of transfer case after implementation of modifications, cut-outs, and installation of fans

to performers, ensuring health protection without the loss of stage presentation.

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REFERENCES

1. "Occupational Safety and Health Standards, Personal Protective Equipment, Permit-Required Confined Spaces." *Code of Federal Regulations Title 29*, Part 1910.146. 2011.
2. "Pollutants in the Ambient Air." [Online] Available at <http://www.epa.gov/eogapti1/course422/ap2.html> (Accessed March 10, 2011).
3. "Occupational Safety and Health Standards, Personal Protective Equipment, Respiratory Protection." *Code of Federal Regulations Title 29*, Part 1910.134. 2011.
4. "Carbon Dioxide—IDLH Documentation." [Online] Available at <http://www.cdc.gov/niosh/idlh/124389.html> (Accessed March 10, 2011).
5. **Blasing, T., and S. Jon:** "Current Greenhouse Gas Concentrations." [Online] Available at http://cdiac.ornl.gov/pns/current_ghg.html (Accessed March 15, 2011).
6. **Aitken, R.J., A. Maynard, P. Baldwin, et al.:** Aerosol inhalability in low air movement environments. *J. Aerosol Sci.* 30(5):613–626 (1999).
7. **Eisenburger, P., G.C. Funk, G. Burda, et al.:** Gas concentrations in expired air during basic life support using different ratios of compression to ventilation. *Resuscitation* 73(1):115122 (2007).
8. **Hornuss, C., S. Praun, J. Villinger, et al.:** Real-time monitoring of propofol in expired air in humans undergoing total intravenous anesthesia. *Anesthesiology* 106(4):665 (2007).