Evaluation of Vibration Exposure for Interment Technicians

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Contents

The cover photo is a close-up image of sorbent tubes, which are used by the HHE Program to measure airborne exposures. This photo is an artistic representation that may not be related to this Health Hazard Evaluation.

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Highlights of this Evaluation

The Health Hazard Evaluation Program received a request from cemetery managers. They were concerned about injuries to employees who worked on the interment crew and operated a 10-ton power tip dumper ("dumper").

What We Did

- We visited the facility four times between September 2011 and March 2012.
- We measured the distance employees had to reach to operate controls within the dumper operator's workspace.
- We spoke with employees about their health and safety concerns.
- We measured whole body vibration exposure during operation of the dumper and backhoe.
- We compared exposure to whole body vibration during different driving speeds and loading conditions.

We evaluated vibration exposure to employees when operating the dumper and backhoe. Driving the dumper at higher speeds was associated with the highest exposure to vibration. We recommend restricting driving speed, increasing task rotation, and improving roadway and soil shed maintenance to reduce employees' vibration exposures.

What We Found

- Many operators' feet did not touch the foot controls when their back was against the backrest.
- Operating the dumper caused higher whole body vibration than operating the backhoe.
- Higher driving speed on the dumper produced higher whole body vibration.
- Driving speed appeared to be more important to vibration exposure than whether or not the dumper was loaded.

What the Employer Can Do

- Restrict driving speed of the dumper and backhoe. This could be achieved by either a governor device or establishing a policy and training employees.
- Rotate employees between the dumper and backhoe more often than every week.
- Improve and maintain roadways, especially sections of roadways that are used most often.
- Grade the soil shed area and the access roadways leading to the soil shed more often.

What Employees Can Do

- Drive the dumper and backhoe more slowly.
- Take the shortest route possible to the soil shed.
- Learn how to adjust the equipment, especially the seat.
- Report health concerns, injuries, and unsafe working conditions to your supervisor.

Abbreviations

HHE	Health hazard evaluation
hrs	Hours
HSE	Health and Safety Executive
ISO	International Organization for Standardization
min	Minutes
mph	Miles per hour
m/s/s	Meters per second per second
NAICS	North American Industry Classification System
NIOSH	National Institute for Occupational Safety and Health
RMS	Root mean square

Introduction

The Health Hazard Evaluation Program (HHE) received a request from cemetery managers to evaluate potential ergonomic issues and injuries of employees working in the interment crew. The cemetery sat on 133 acres of land and contained more than 44 miles of roadways. The interment crew hauled soil and gravel and excavated, graveled, filled, and tamped gravesites. Additional jobs included moving headstones and markers as well as assisting with groundskeeping. The National Institute for Occupational Safety and Health (NIOSH) team was asked to evaluate the 10-ton power tip dumper ("dumper") operator's workspace after it had been modified to incorporate an air ride seat. The air ride seat was added after an employee sustained a back injury on the equipment. An air ride seat is desirable with equipment that causes whole body vibration. However, the addition of the air ride suspension system caused a substantial increase in the height of the seat pan from the floor; the new seat was approximately 8 inches higher than the original. Shorter operators were unable to reach the foot controls and taller operators had to laterally flex their neck to keep from hitting their head on the roof. An HHE request was submitted for assistance with these new concerns. We sent an interim letter in September 2012 that contained preliminary vibration results and recommendations.

Methods

Operator Workspace Layout and Anthropometrics

On September 6, 2011, we observed interment operations including hauling soil and gravel and excavating, graveling, filling, and tamping the gravesites. We also measured distances between vehicle components (seat, operating pedals, and steering wheel) with the seat in the lowest and most forward adjustment position (Figure 1). We used a standard tape measure, a string and line level, and a carpenter's protractor. We created a computer-aided drawing of the workspace and anthropometrically-scaled manikins in Jack®, a human modeling software program (Siemens PLM Software, Plano, Texas). Anthropometrics refers to the measurement of human body size. The models examined the reach distances to the pedals for operators of the selected heights with their back on the backrest. The seat, Wise Seats model WM1825, was modeled from a drawing (with seat dimensions) from the product brochure and user manual distributed by the manufacturer (Wise, Memphis, Tennessee). The model has limitations because it does not account for the compression of the seat cushion material or displacement in the air suspension system under the weight of an operator. It also does not account for the compression of fleshy soft tissue (e.g., buttocks) of the human. Male manikins of 95th percentile, 50th percentile, and 5th

Figure 1. Operator's workspace of the 10-ton power tip dumper.

percentile height were used to provide a range of the working population. These are the body heights of males taller than 95% of the population, the average of the population, and shorter than 95% of the population.

Employee Interviews

On October 7, 2011, we interviewed employees about their health and safety concerns and their recommendations for modifying the equipment or work practices.

Exposure to Whole Body Vibration in the Dumper and Backhoe

We evaluated whole body vibration exposure to the interment crew during the operation of the dumper and backhoe on November 23, 2011. We instructed the employees to drive at their normal speed. The machines were driven at approximately the same speed, one following the other from location to location. We selected conditions believed to create the highest vibration levels and, therefore, the more hazardous conditions during the operation of these machines. The soil shed area was of interest because it was accessed via unpaved roads, and operators drove over this section of road for every interment service. The particular events of interest were:

- Entry to soil shed area – Travel on the primitive unpaved access road to the soil shed area. The dumper was loaded with excavated soil during this recording.
- Exit from soil shed area – Travel on the primitive unpaved access road to exit the soil shed area. The dumper was unloaded during this recording.
- Paved roads – Travel on paved sections of roadway through the cemetery. We sampled the roads that the employees drove that particular day and they did not reflect particular road roughness conditions.

We measured motions that create vibration between the seat and the operator for both the dumper and backhoe during regularly scheduled interment operations. We measured these motions with a sensor that detects motion (acceleration) in three directions (axes) (NexGen Ergonomics, Pointe Claire, Quebec) embedded in a rubber seat pad oriented as specified by International Organization for Standardization (ISO) 2631-1 [ISO 1997]. ISO 2631-1 is an accepted standard for measuring, analyzing, and reporting results for whole body vibration of a seated operator in a vehicle cab. The sampling rate was 1,000 Hertz (1,000 samples per second). The positive z-axis was vertical upward perpendicular to the seating surface, and the positive x-axis projected anteriorly (forward) from the operator. The system was equipped with a data logger that we mounted to the side of the operator's seat using a padded pouch and tie wraps. We taped the cables from the accelerometer to the underside and back of the seat so the measurement device was not intrusive to the operator. We used a continuous measurement approach in which the data logger was manually started, and measurements were uninterrupted. A handheld stopwatch was synchronized with the start of the data logger so that specific events could be identified in the data. We manually noted the stopwatch times at which various events of interest occurred. This allowed us to identify segments of data that corresponded to the events of interest.

Effect of Dumper Driving Speed and Loading on Vibration Exposure

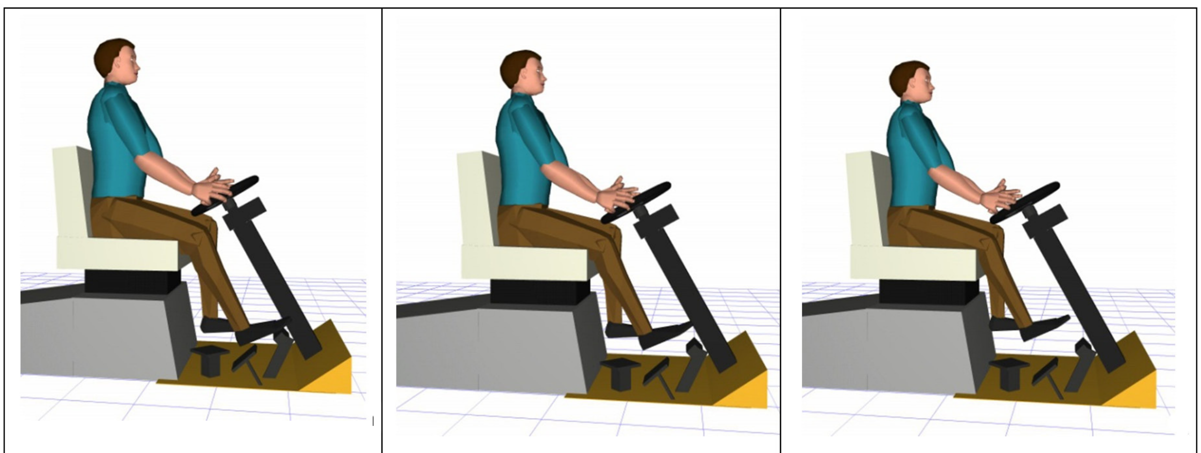
We measured vibration exposure in March 2012 on a single dumper operator driving on a frequently travelled section of paved cemetery roads. The dumper operator made trips along a common route between the barn and the soil shed. Landmarks that were 1 mile apart were used as references for timing these trips. Two driving speeds were evaluated by having the dumper operator follow a vehicle driven by the cemetery safety director. The faster speed was 10–15 miles per hour (mph) and the slower was 5–10 mph. The cemetery had a posted speed limit of 20 mph. Because of the need to obey stop signs, yield intersections, and deal with cemetery visitors, the test could not involve a constant driving speed over the route. The speed of the loaded dumper was limited when it went up a steeper section of road. Average speeds over the 1 mile route were within target ranges of 10–15 mph and 5–10 mph. These average speeds were calculated by dividing the 1 mile route distance by the travel time between the landmarks (converted from seconds to hours).

Vibration exposure was summarized over the same section of road for four experimental conditions – two loading conditions at two average speed conditions. The "unloaded" condition was with the dumper empty, while the "loaded" condition was with the dumper loaded with soil from a single gravesite.

Results and Discussion

Operator Workspace Layout and Anthropometrics

Anthropometrically scaled manikins of 95th percentile, 50th percentile, and 5th percentile males are shown in Figure 2. The computer modeling confirmed that the distances to reach the operating pedals appear to be excessive even for the tallest operator.



95th Percentile male (*taller* than 95% of population)	50th Percentile male (average of population)	5th Percentile male (*shorter* than 95% of population)

Figure 2. Computer aided rendering of tall, average height, and short male operators seated in the dumper with back against seat backrest.

With the operator's back against the seat backrest, the feet of many operators would not touch the pedals. This would force the operator to shift forward in the seat to reach the pedals. The modification to extend the pedal stem was helpful, but was not enough. When the soles of the feet cannot make contact with a solid surface, jarring and jolting forces cannot be absorbed through the lower body and are transmitted directly to the pelvis. If the operator were to have a foot rest for the left foot that was reachable, the left leg could absorb some of the jolting forces. One operator reported that he had learned where the rough sections of road were and would prepare for these sections of rough road by sitting forward on the seat to absorb the jolting forces with his legs. This is a clear indicator that the workspace design does not allow the legs to absorb these forces.

Shifting forward off the backrest to reach the pedals means the operator loses the benefits of the seat backrest. Not having the back on the seat backrest increases use of the back muscles and eventually causes fatigue. It is beneficial to have contact with the backrest in addition to contact of both feet on operating pedals or foot rests. This foot contact allows the operator to absorb some of the jarring/jolting forces through the legs. If the feet are hanging from the seat, a larger portion of the forces from vehicle vibration must be absorbed directly through the seat into the buttocks, pelvis, and torso.

Employee Interviews

We spoke with eight interment technicians about possible workplace exposures and their medical history. Most of the employees had no current body aches or pains and no health problems they believed were related to their job. Employees were concerned about rotation patterns, driving speed, wheel type and pressure, problems getting into and out of equipment, road condition, and carrying and using the tamper. After the interviews, we measured the bottom step height of the dumper (25 inches) and found entering and exiting the workspace difficult. We also observed use of the tamper and removal of headstones and footstones. Back injury risk may be increased when periods of whole body vibration are mixed with activities that burden the spine through twisting, bending, and lifting [HSE 2005].

Exposure to Whole Body Vibration in the Dumper and Backhoe

We summarized vibration data for periods of time corresponding to events of interest. Some of the measurement intervals were less than 108 seconds, which is specified in ISO 2631-1 as the minimum measurement duration. As a result these values should be interpreted cautiously. Results are reported for the dominant axis of acceleration, which in this case was the z-axis (vertical acceleration), in Table 1. The ISO exposure caution zone is the amount of time that can be spent at the particular acceleration without causing health effects.

Table 1. Weighted RMS acceleration (z-axis) for tested driving conditions with dumper and backhoe

Condition	Machine	Recording time (seconds)	Weighted RMS* acceleration (m/s/s)	ISO exposure caution zone
Entry to soil shed loaded	Dumper	45†	3.30	9–22 min
Exit from soil shed unloaded	Dumper	220	3.11	10–25 min
Paved road loaded	Dumper	225	2.27	18–47 min
Paved road unloaded	Dumper	150	1.71	33–82 min
Stationary while filled	Dumper	106	0.204	> 8 hrs
Entry to soil shed area	Backhoe	45†	1.12	1.25–3 hrs
Exit from soil shed area	Backhoe	100	1.32	1–2.5 hrs
Paved road	Backhoe	375	1.37	51 min–2 hrs
Stationary while filling dumper	Backhoe	106	0.283	> 8 hrs

*RMS acceleration is the root mean squared (a measure of time average) intensity of the vibration in the up/down direction (vertical z-axis).

†These task durations were considerably less than 108 seconds, the minimum sampling duration recommended in ISO 2631-1.

On the basis of ISO 2631-1 guidelines and our measurements under the current condition of each machine, driving the dumper was associated with higher exposure to whole body vibration than driving the backhoe. The analysis suggested that the soil shed area was associated with higher vibration levels than the paved roads (Figure 3). This finding was expected as the soil shed area consisted of an unpaved access area that was not well graded.

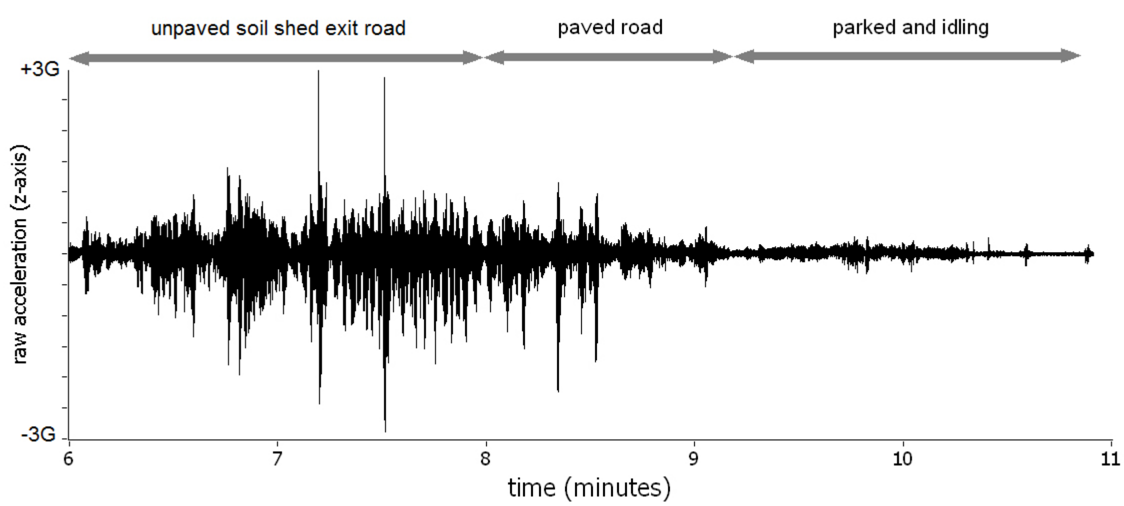


Figure 3. Dumper driver vibration levels from the soil shed road, paved road, and parked but idling.

However, the interment technician only drove the dumper in the soil shed area a few times per day and the length of the unpaved road was short. The exposure to the soil shed road was predictable because the portion of unpaved road was constant and the number of services in a given day would affect the travel time on this road. The duration of exposure to paved road driving through the cemetery was more variable, because this depended on the number of services held in a given day and the location of the gravesites.

Effect of Dumper Driving Speed and Loading on Vibration Exposure

The results in Table 2 suggested that higher driving speed was associated with greater vibration transmitted to the operator. Statistical testing of this result was not possible because of the small number of measurements; however, the data set was consistent with expectation. The effect of driving speed on vibration exposure also appeared to be more important than whether or not the dumper was loaded.

Table 2. Weighted RMS acceleration levels as a function of test condition (driving speed and loading)

Target driving speed	Loading	Calculated average driving speed (mph)	Weighted RMS z-axis (m/s/s)	Weighted RMS sum (m/s/s)
slow	unloaded	7.9	0.91	1.36
slow	loaded	8.2	0.97	1.59
fast	unloaded	13.1	1.61	2.36
fast	loaded	11.6	1.48	2.13

Figure 4 illustrates the relationship between driving speed and the vibration level (weighted RMS, z-axis) transmitted to the operator. The linear relationship must be interpreted cautiously with only four measurements. However, this relationship was also consistent with expectation and based upon our measurements suggested that a 42% reduction in RMS vertical acceleration might be achieved by reducing average driving speed of the dumper from 13 to 8 mph.

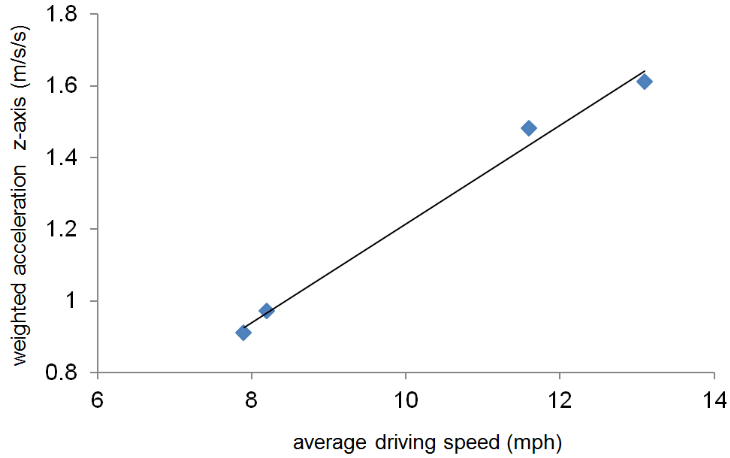


Figure 4. Relationship between average driving speed and vertical acceleration level (weighted RMS, z-axis). This relationship appears linear, but this must be interpreted cautiously because of the small number of measurements.

Conclusions

Interment employees were exposed to whole body vibration due to the configuration of the dumper and the condition of the roadways and soil shed area. The results of this evaluation suggest that reducing driving speed of the dumper during these activities would reduce whole body vibration to the operator. The risk of injury could be reduced by engineering (e.g., redesigning the cab configuration) and administrative controls (e.g., restricting driving speed).

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage the cemetery to use a labor-management health and safety committee or working group to discuss our recommendations and develop an action plan. Those involved in the work can best set priorities and assess the feasibility of our recommendations for the specific situation at the cemetery.

Our recommendations are based on an approach known as the hierarchy of controls. This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and personal protective equipment may be needed.

Engineering Controls

Engineering controls reduce employees' exposures by removing the hazard from the process or by placing a barrier between the hazard and the employee. Engineering controls protect employees effectively without placing primary responsibility of implementation on the employee.

1. Install a governor device on the equipment to mechanically restrict driving speed.
2. Install an intermediate step on the dumper that can fold down when needed and fold up when the dumper is moving.
3. Reduce the distance of the seat pan to the floor and foot operating controls on the dumper. All operators should have their feet on the operating controls and rigid foot rest surfaces while their back is in contact with the seat backrest.

Administrative Controls

The term administrative controls refers to employer-dictated work practices and policies to reduce or prevent hazardous exposures. Their effectiveness depends on employer commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that policies and procedures are followed consistently.

1. Implement tools, equipment, and work practices to minimize stresses on the spine during tasks such as using the tamper.
2. Rotate employees between equipment more often than once a week. Consider ISO 2631-1 limits for whole body vibration exposure duration in the administrative practice of task rotation.
3. If installing a governor device for controlling driving speed is not feasible, develop and enforce a policy to limit speed. Ensure that employees are trained on the policy.
4. Maintain roadways, particularly sections of the roadways that are used most often, by filling potholes and keeping the surface flat and smooth.
5. Provide more frequent grading of the soil shed access roadways and the soil shed area. The highest vibration levels were observed in the soil shed area.
6. Minimize the distance traveled in trips to the soil shed.
7. Train employees on the use of the seat adjustment. Some employees indicated that they had not been trained on the adjustability features.

References

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