ABSTRACT

Whole-body vibration (WBV) is a health hazard faced by heavy earth moving machine (HEMM) operators in mining as well as in the industries like agriculture, forestry and manufacturing. In surface coal mines, the dumper, drill, and shovel operators are the worst sufferers from WBV syndrome. WBV is perceived when a human is supported by a surface that is shaking and the vibration affects the body parts away from the point of contact. In many work environments, people are primarily exposed to vibration while working in sitting posture. They are exposed to a wide range of vibration magnitudes, waveforms, and durations, which may be continuous or transient. Depending on the magnitude and duration of exposure, WBV causes impacts on the health and safety of human being and specifically, it is reflected on the musculoskeletal system leading to musculoskeletal disorders (MSDs) for prolonged exposure.

High prevalence of MSDs, mainly in upper limbs and lower back, is found among off-road vehicle operators in mining, agriculture and construction industries. Epidemiological studies on WBV demonstrate increased risk of lower back pain, sciatic pain, and degenerative changes in the spinal system, including lumbar intervertebral disc disorders. In addition, motion sickness, headache, impotence, chest and abdominal pain, increased heart rate, high blood pressure, blurred vision, and kidney disorders are reported as WBV syndromes in the past studies.

Research work indicated that impacts of WBV depend on multiple confounding factors, including the demography and anthropometry of the operator, duration of exposure, ergonomics of the seat design and the work environmental factors. Although many factors have been discussed in the literature, the cause of WBV and its health effects are still not explored fully. Therefore, there is a need to investigate the effect of WBV on heavy earth moving machinery (HEMMs) operators in mines and to understand the correlations that exist among the various confounding factors of WBV.

While operating the HEMM, vibration is transmitted through the machine seat and footrest, which are the surfaces that support the operator. The vibration is then transmitted through the operator–seat interface, and can lead to musculoskeletal

disorders. Investigation of WBV is truly multidisciplinary in nature and the role of contributing factors are still not fully explored to bring in the clarity in the causation of the injuries related to vibration; though a deeper understanding of the factors has been discussed in many researches. Therefore, the scope of the present research work is limited to the measurement of vibration following the guidelines of ISO 2631-1:1997 (Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration), supplemented by a questionnaire survey of a group of HEMM operators in coal mines. In order to understand the role of the contributing factors on causation of MSDs, a group of workers who are not exposed to machine vibrations are also considered in the questionnaire survey. The questionnaire incorporates the survey of personal information of the workers and also the discomfort/pain that the operators/workers are facing since last six months.

Though there has been considerable amount of research works on WBV exposure, there is a lack of systematic investigation of confounding factors on WBV and its related MSDs. Discomfort analysis of HEMM operators exposed to vibration, proposed in this thesis, is not found in the literature.

This research has been taken upto quantify whole-body vibration (WBV) of the operators of HEMM in four opencast mines. WBV exposure values have been compared with the ISO 2631-1:1997 guidelines. Discomfort survey is done to identify the physical problems of the operators. Case–control study is undertaken to compare the relative risk of the groups of subjects.

WBV in mines is investigated, giving focus to dumper, drill and shovel operators. Effect of WBV on human health is categorized. The guideline of the research, ISO 2631-1:1997 is stated with their history of development. The Bruel & Kjaer 'Human Vibration Analyzer type 4447' is used for the measurement of WBV.

Measurements were carried out at the operator–seat interface with a tri-axial seat pad accelerometer in combination with a control panel which records the vibrational

exposure in the form of signals through the vibration analyzer type 4447. The accelerometer mounted on the seat where the operators used to sit while operating the machine. Temporary adhesive tape was used to keep the seat pad accelerometer fixed onto the operator's seat during the measurements. The accelerometer records the vibration in three translational axes with reference to the human basi-centric axes, namely, fore-and-aft (x-axis), lateral (y-axis), and vertical (z-axis) axes. Positioning of the vibration seat pad accelerometer has been depicted.

Nordic and Stuart-Buttle standardized questionnaires guided for the development of questionnaire. Different contributing parameters that affect whole-body vibration considered in this study are personal, health-related as well as machine related factors. The WBV measurement was carried out for 150 HEMM [110 dumper, 20 shovel & 20 drill] operators.

The periods of data collection was between May 2017 to October 2018. Result of WBV measurement is compared for dumper, drill and shovel operators using box-plot. Comparing A(8) values for the three category of vehicle operators through box plotting, it is observed that maximum median A(8) value (0.85) is for dumper operators and minimum value (0.34) is for drill operators. Comparing of VDV(8) values for the HEMM operators is presented through box plotting it is found that maximum median VDV(8) value (23.70) is for dumper operators and minimum (10.99) is for shovel operators. Comparing the crest factor for HEMM operators, it is found that maximum median CF value is for shovel operators and minimum for dumper operators. Based on ISO2631-1:1997 criteria, health risk of the operators is evaluated. 94% dumper operators, 20% drill operators and 15% shovel operators are subjected to likely health risk. The vibration magnitude is maximum in z-axis for the HEMM operators.

In the discomfort survey, 11 body points were considered which were divided into five body regions. Calculation for the whole-body discomfort index (WBDI), body region discomfort index (BRDI) and mean maximum intensity (MMI) are explained through the mathematical expressions. The percentage of dumper operators who had discomfort in their body regions, neck, hand, upper back, lower back and leg were 28, 20, 38, 64

and 50 % respectively. The percentage of drill operators who had discomfort in their body regions, neck, hand, upper back, lower back and leg were 40, 10, 30, 60 and 60 % respectively. The percentage of shovel operators who had discomfort in their body regions, neck, hand, upper back, lower back and leg were 25, 10, 30, 50 and 30 % respectively. Discomfort of HEMM operators in neck, hand, upper back, lower back and leg region are 30.0, 15.6, 34.4, 60.0 and 47.8 respectively. Body region discomfort index of HEMM operators in neck, hand, upper back, lower back and leg region are 0.31, 0.24, 0.39, 0.55 and 0.33 respectively. Discomfort survey also revealed that dumper operators were highly exposed to WBV compared to shovel and drill operators

Correlation matrix for dumper, drill and shovel operators is indicated that A(8) value of dumper, drill and shovel operators is directly correlated (0.81–0.97) to VDV(8) value. Body DI of only dumper and shovel operators is directly correlated (0.83–0.87) to hand DI.

The case–control study is carried out between dumper operators (n=110) as case group and control group (n=110) who were not exposed to vibration. A workers' response device (WRD) questionnaire is used to collect the data through the questionnaire. In case–control study, out of 11 variables, only two variables (Lower back and Mine-2) are found statistically significant in the logistic regression model. Examining the odds ratios of the case group showed that the risk of lower back pain is 2.52 times (95% CI [1.19, 5.31]) more as compared to control group. Case group of Mine-2 is 2.0 times (95% CI [0.98, 4.08]) more prone to vibration hazards as compared to Mine-3 (the reference mine). The case–control study concludes that the vulnerability to vibration hazards is higher in case group than the control group.

The novelty of the present research work is the combination of WBV measurement and discomfort survey in Indian mines. The present study is expected to guide the mine management to take appropriate steps in their planning against the WBV impacts. It would provide useful data-base for assessing the appropriateness of ISO 2631-1:1997 under Indian mining condition, and thereby, formulating pertinent occupational health policies to protect the millions of Indian mine workers especially the dumper operators, who are exposed to high level workplace WBV.