



WORKERS' COMPENSATION BOARD OF BC

ENGINEERING SECTION REPORT

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ARCS Reference No: 0135-20

Bus Drivers & Human Vibration

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Project Number: 7.24-03257

Date: September, 2003

Introduction

The WCB Engineering Section was invited to participate in an Ergonomic study of bus drivers. The objectives were to measure and evaluate steering wheel hand arm vibration (HAV) and seat whole-body vibration (WBV) for sample buses drawn from the bus fleet while they were operated under typical driving conditions.

Equipment Used

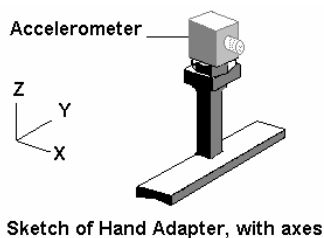
Human Vibration Meter: Larson-Davis Model HVM100, S/N0217,
HAV Accelerometer: Triaxial PCB SEN021, S/N P13333
WBV Triaxial Seat Pad Accelerometer: Larsen Davis
Accelerometer Calibrator: Bruel & Kjaer Accelerometer Calibrator Type 4291

The equipment meets the requirements of ISO Standard 8041, *Human Response to vibration – Measuring instrumentation*.

Procedure

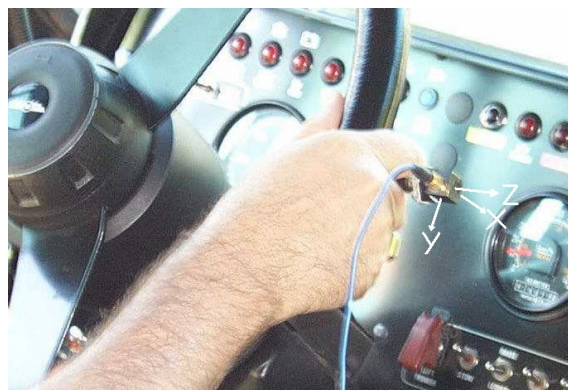
Hand-arm Vibration, HAV

A triaxial accelerometer (mass = 10.6 gm) was mounted on a small hand-adapter (see sketch). In use, the adapter's base was held by the driver against the driving wheel, while being gripped between two digits of the hand being tested. In this way, vibration of the handle was sampled along the three mutually orthogonal basicentric axes of the hand, the x-, y- and z-axes (see photograph). The accelerometer, was calibrated by the accelerometer calibrator and agreed to within 3% of the manufacturer's accelerometer sensitivity calibration.



The Vibration Meter was set up to select the hand-arm frequency weighting, W_h , as defined in ISO 8041 and in ISO 5349-2 (2001) (see References).

The driver was requested to prevent the wheel from sliding through his hands while steering; he was requested to maintain a firm grip throughout the measurement sample. This measure was to prevent extraneous vibration which may have been generated in the sliding action of the hand over the finger grips moulded in the steering wheel when turning corners.

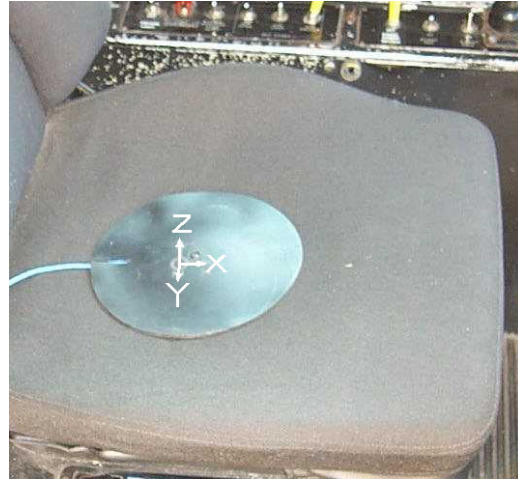


Whole-body Vibration, WBV

ISO 2631-1 requires measurement of frequency-weighted acceleration at the point of entry into the body. Acceleration measurements must be performed along three mutually perpendicular directions in space (see sketch). The sensitivity of the body to vibration at different frequencies is accounted for by frequency weightings inserted into the measurement chain. Frequency weighting, W_d , is identical for the x- and y-directions; the frequency weighting, W_k , for the z-direction differs.

A triaxial accelerometer, embedded in a nitrile rubber seat pad, was placed in the centre of the driver's seat with axes aligned as in the diagram (see photograph) and the driver was requested to sit on the cushion.

For HAV and WBV measurements the meter was monitored continuously. When sampling, the reading settled down to a value which changed little with time within a few minutes, indicating a representative sample had been acquired under prevailing conditions. Each vibration measurement was averaged over about 4 minutes, during which time the bus was driven by a bus driving instructor.



Test Bus Routes

The same routes were covered each time, i.e.

Routes for Vancouver-based buses:

From the Depot across Oak St. west to Crown St. along W. 41st Ave.

The route was broken into two parts to determine the effect of pavement which was newer between Western Boulevard and Oak St., older pavement remained between Western Boulevard and Crown St.

Routes for Richmond-based buses:

From the Depot N. on #5 Rd., west on Williams St., south on #3 Rd., and west on Steveston Hwy.

Highway 99 (travelling north and south) between Steveston and Westminster Highways so that effects of higher speed on vibration could be investigated.

Vibration Exposure Thresholds etc.

HAV: ACGIH's *Threshold Limit Values and Biological Exposure Indices* includes a table of recommended daily limits of exposure (TLVs®) to acceleration. For daily exposures of 4 to 8 hours, the TLV of the dominant, frequency-weighted (rms) component acceleration, a_h , shall not exceed 4 ms^{-2} .

WBV: ISO 2631-1 (1997) identifies a "health guidance caution zone." For an 8 hour daily exposure, numerical values defining the zone are:

- **below the zone**, where a_k and a_d are less than 0.5 ms^{-2} : "health effects have not been clearly documented and/or objectively observed";
- **in the zone**, where a_k and a_d are between 0.5 ms^{-2} and 0.8 ms^{-2} : "caution with respect to potential health is indicated" and
- **above the zone**, where a_k and a_d are greater than 0.8 ms^{-2} : "health risks are likely".

The Workers Compensation Board of British Columbia incorporated ACGIH's TLV for HAV and the WBV "boundaries" of ISO 2631 (1986) into its occupational health and safety regulation as guideline values. The WCB is currently proposing adoption of the ACGIH TLV for HAV and the values defining the WBV values of ISO 2631-1 (1997) "health guidance caution zone as regulatory limits.

HAV Results

The hand arm vibration data acquired on the bus steering wheels are summarized in Table 1.

Bus Type and number	Seat	Test Route	Frequency-weighted Acceleration, a_h , ms^{-2}			
			x-axis	y-axis	z-axis	Sum
Trolley #2863	Recaro	Crown - W. Blvd.	1.27	0.98	0.60	1.7
		W. Blvd. – Oak	1.06	0.75	0.42	1.4
High Floor #V3115	Recaro	Oak - W. Blvd.	0.83	0.48	0.49	1.1
		W. Blvd. - Crown	0.80	0.50	0.55	1.1
Low Floor #7195	USSC	Crown - W. Blvd	1.47	0.66	0.94	1.9
		W. Blvd. – Oak	1.19	0.49	0.64	1.4
Highway Coach #R9272	USSC	W. on Williams	0.82	0.44	0.22	0.95
		E. on Steveston	0.74	0.46	0.32	0.93
		N on Freeway	0.67	0.49	0.30	0.88
		S. on Freeway	0.82	0.49	0.32	1.00
Articulated #8065	USSC	N on Freeway	0.62	0.44	0.25	0.80
		S. on Freeway	0.76	0.56	0.35	1.00
		W. on Williams	0.76	0.54	0.27	0.96
		E. on Steveston	0.76	0.54	0.30	0.97
ACGIH recommended 4-8 h daily limits for acceleration, a_h			4.0	4.0	4.0	na

Table 1. Steering Wheel HAV Frequency-weighted Acceleration (rms)

WBV Results

The whole-body vibration data acquired on the bus driver's seat are summarized in Table 2.

Bus Type and number	Seat	Test Route	Frequency-weighted Acceleration, $a_{d&k}$, ms^{-2}			
			x-axis	y-axis	z-axis	Sum
Trolley #2863	Recaro	Oak - W. Blvd.	-	-	-	-
		W. Blvd. - Crown	0.14	0.14	0.23	0.36
High Floor #V3115	Recaro	Crown - W. Blvd	0.13	0.15	0.32	0.43
		W. Blvd. - Oak	0.14	0.14	0.30	0.41
Low Floor #7195	USSC	Oak - W. Blvd.	0.10	0.13	0.24	0.34
		W. Blvd. - Crown	0.12	0.14	0.27	0.36
Highway Coach #R9272	USSC	W. on Steveston	0.14	0.15	0.27	0.39
		W. on Steveston	0.14	0.12	0.37	0.45
		Williams - Steveston	0.13	0.12	0.25	0.35
Articulated #8065	USSC	N. on Freeway	0.12	0.11	0.39	0.45
		S. on Freeway	0.14	0.11	0.45	0.51
		W. on Williams	0.13	0.095	0.36	0.42
		E. on Steveston	0.090	0.096	0.27	0.33
ISO 2631-1 (1997) daily 8 h "health guidance caution" zone acceleration limits, a_d and a_k			0.5-0.8	0.5-0.8	0.5-0.8	na

Table 2. Seat WBV Frequency-weighted Acceleration (rms)

Conclusions

Hand-arm and whole-body vibration results are well below the recommended guideline values for HAV and WBV exposure currently referenced by the WCB of BC in Sections 7.26, 7.27 and 7.28 of the Occupational Health & Safety Regulation, 1998. Thus, the vibration experienced by drivers is not deemed to present a health risk to drivers of buses in this survey.

The dominant HAV vibration component is along the x-axis (parallel to the steering column). The steering wheel rim may be vibrating in an “umbrella” style mode. When the vibration was compared for all buses driven on city streets (where bus speed is comparable), the x-axis steering wheel HAV, $a_{h,x}$, is lowest for the articulated bus and highway coach (0.77 ms^{-2}) and higher for the high floor bus (0.82 ms^{-2}), trolley bus (1.16 ms^{-2}) and highest for the low floor bus (1.33 ms^{-2}).

Steering wheel HAV increased with road surface roughness. The trend was seen with Oakridge-based buses (the pavement on 41st Ave. was rougher on the Crown St. side of Western Boulevard). For example, averaging the vibration of all three buses operating on 41st Ave.: $a_{h,x} = 1.18 \text{ ms}^{-2}$ on the Crown St. side and $a_{h,x} = 1.03 \text{ ms}^{-2}$ for the Oak St. side of Western Boulevard.

Steering wheel HAV increased with speed along the highway; this can be seen from the mean values of $a_{h,x}$ for the Coach and Articulated buses. When driving north (average speed $\approx 80 \text{ kph}$) $a_{h,x} = 0.64 \text{ ms}^{-2}$; when heading south (average speed $\approx 90 \text{ kph}$) $a_{h,x} = 0.79 \text{ ms}^{-2}$.

The dominant driver seat WBV component is along the z-axis i.e. the vertical direction. All seats exhibited low lateral vibration (x- and y-axes), suggesting they have not developed looseness and are in good condition.

The mean z-axis seat WBV, $a_{k,z}$, of the Vancouver-based buses ($a_{k,z} = 0.27 \text{ ms}^{-2}$) is lower than for the coach (0.30 ms^{-2}) and articulated buses (0.32 ms^{-2}) even when all are driving city streets (at the same speed). This is interesting as road surfaces in Vancouver were noticeably rougher than in Richmond streets. One difference is in the driver seats where, in Vancouver-based buses, the Recaro is prevalent over the USSC seats installed in Richmond-based buses. To compare the transmissibility of the seats, accelerometers could be fixed to driver's seat and to the bus floor under the seat and simultaneous vibration measurements obtained. Also, drivers could be surveyed to see if they prefer one seat over another.

As with HAV, seat WBV increases with speed as seen on the highway runs where $a_{k,z} = 0.39 \text{ ms}^{-2}$ (north bound at $\approx 80 \text{ kph}$) and $a_{k,z} = 0.45 \text{ ms}^{-2}$ (south bound at $\approx 90 \text{ kph}$).

References

ISO 8041-1990, *Human response to vibration - Measuring instrumentation*. International Standard Organisation.

ISO 5349-1 (2001), *Mechanical vibration - Measurement and evaluation of human exposure to hand transmitted vibration - Part 1: General requirements*. International Standard Organisation.

ISO 5349-2 (2001), *Mechanical vibration - Measurement and evaluation of human exposure to hand transmitted vibration - Part 2: Practical guidance for measurement at the workplace*. International Standard Organisation.

ISO 2631-1 (1997), *Guide for the evaluation of human exposure to whole-body vibration*. "Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements". International Standard Organisation.

ACGIH (2003), *Threshold Limit Values and Biological Exposure Indices*. American Conference of Government Hygienists

Occupational Health & Safety Regulation, 1998. Workers' Compensation Board of British Columbia, 1998

APPENDIX. Sample HAV Histories

