INTERACTION OF WHEELCHAIRS AND SEGMENTAL PAVEMENT SURFACES

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ABSTRACT

This study evaluated vibration exposure of occupants in an electric powered and a manually propelled wheelchair over sidewalk pavement surfaces. In addition to vibration measurements, mechanical energy requirements for manual wheelchair propulsion were also examined. Ten unimpaired individuals traversed the following surfaces: cast-in-place concrete with a broom finish to represent the pavement norm; three interlocking concrete pavements installed in a 90° herringbone pattern; and two clay paver surfaces placed in a 45° herringbone pattern. The three interlocking concrete pavement surfaces consisted of units with no chamfer (Surface 2), a 2 mm wide chamfer (Surface 3), and an 8 mm wide chamfer (Surface 4). The two clay paver surfaces had 4 mm (Surface 5) wide chamfers and no chamfer (Surface 6).

Dynamic effects were measured from the instrumented wheelchairs included power of acceleration per octave, mechanical work required to propel over surfaces, peak acceleration, and the frequency at which peak acceleration occurs.

At 1 m/second, significant differences were found in peak accelerations between the seat and footrest ($p<0.0001$) and between the surfaces ($p=0.004$) for the manual and powered wheelchairs. The peak accelerations at the seat for surfaces 2, 5 and 6 were lower than the poured concrete surface using a manual wheelchair. Similar results in the peak accelerations were found with the electric powered wheelchair at 2 m/second. Results indicated that the poured concrete generated significantly higher ($p<0.0001$) vibration for most of the octaves examined.

The surfaces generated higher or no difference in power per octave throughout most of natural frequency range of seated humans. There were no statistically significant differences in the work required to traverse the surfaces in a manual wheelchair. This is probably because the surfaces all had similar grade and no cross-slope. When comparing the vibration data to ISO 2631, *Evaluation of Human Exposure to Whole-body Vibration*, at 1 m/s all surfaces except 4 and 5 exceed the exposure limit specified in this standard after greater than eight hours of wheelchair driving. It is unlikely that wheelchair users will traverse any of these pavements more than eight hours at a given time.

Proceedings of the 7th International Conference on Concrete Block Paving (PAVE AFRICA 2003) 12th – 15th October 2003
ISBN Number: 0-958-46091-4 Sun City, South Africa
Proceedings produced by: Document Transformation Technologies Conference Organised by: Conference Planners

Treating the poured concrete as the norm, surfaces 2, 3, 5 and 6 compared most favorably with the cast-in-place concrete surface in terms of shock and vibration exposure, and surface 4 produced mixed results. Surfaces 2, 3, 5 and 6 yielded results that were similar to the poured concrete, and these should be considered acceptable surfaces for pedestrian access routes for wheelchair users.

1. LEGISLATIVE CONTEXT

On January 10, 2001, the Public Rights-of-Way Access Advisory Committee (PROWAAC) released a report entitled, *Building a True Community* (PROWAAC, 2001). The Committee was commissioned by the United States Architectural and Transportation Barriers Compliance Board, a federal government agency (also known as the Access Board) responsible for issuing accessibility design guidelines for disabled persons. The PROWAAC report proposed a 1.5 m wide pedestrian access route having within it a 1.2 m wide "reduced vibration zone" for new and rehabilitated sidewalks in the public right-of-way. The intent of this zone was to eliminate irregular surface features under users of wheeled mobility devices, and under wheelchairs in particular. The PROWAAC report identified surfaces consisting of "individual paving units, bricks or other textured materials" as examples of undesirable surfaces in the pedestrian access route because of the vibration they cause and pain to some users of wheeled mobility aids.

The PROWAAC report identified a need for research on the measurement of the rolling vibration of pedestrian surfaces. A need was expressed for investigations into surface roughness, surface wavelength (vibration), and wheelchair features. In light of the need for research, the Interlocking Concrete Pavement Institute, Brick Industry of America, and the National Concrete Masonry Association jointly funded research with the University of Pittsburgh and the United States Veterans Health Administration (VHA) on smoothness of segmental pavements. The results are intended to assist the Access Board in developing guidelines for smoothness.

2. RESEARCH AND EXPERIMENTAL DESIGN

In March 2002, six test pavements were built outdoors adjacent to the Human Engineering Research Laboratory at the U.S. V.H.A. Hospital in Pittsburgh, Pennsylvania. Each test pavement was 1.2 m wide by 7.6 m in length. They included a poured concrete sidewalk having a broom finish with tooled joints every 1.2 m. Three adjacent test pavements were surfaced with 100 mm wide by 200 mm long rectangular concrete pavers placed in a 90° herringbone pattern. The units in each of these three areas differed only in chamfer sizes specifically consisting of 8 mm wide, 2 mm wide, and no chamfers. Two additional test pavements consisted of 100 mm by 200 mm clay pavers set in a 45° herringbone pattern. One of these areas had units with a 4 mm chamfer and the other with no chamfers. With the exception of the concrete paver with an 8 mm chamfer, these concrete and clay pavers were selected because they represent paving units typical to sidewalks. Table 1 lists the characteristics of the segmental paving units. Figure 1 delineates the chamfer dimensions.

Table 1. Characteristics of segmental paving units for test surfaces.

Surface				Dimensions, mm		
Number	**Paver Name**	**Chamfer Width**	**Material**	**Length**	**Width**	**Height**
2	Holland Paver	0 mm	Concrete	198	98	60
3	Holland Paver	2 mm	Concrete	198	98	80
4	Holland Paver	8 mm	Concrete	198	98	60
5	Whitacre-Greer	4 mm	Clay	204	102	57
6	Pathway Paver	0 mm	Clay	204	102	57

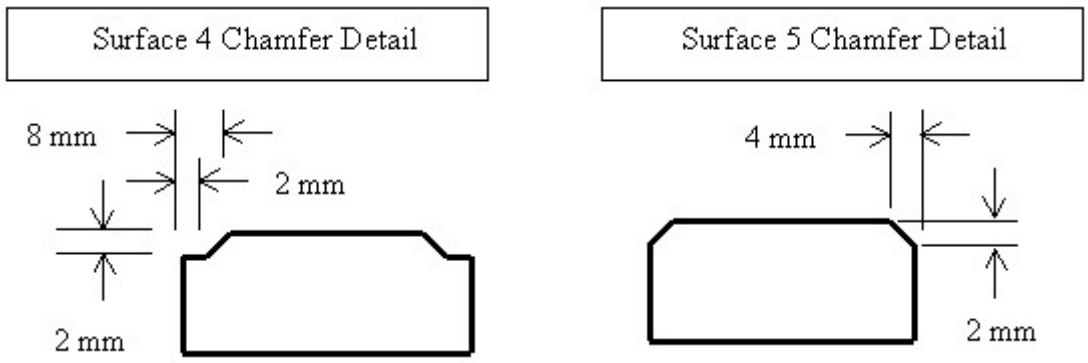

Figure 1. Chamfer details for Surfaces 4 and 5.

The design of the experiment included an instrumented manual wheelchair traveling at 1 m/s (typical walking/push speed) and an instrumented electric powered wheelchair traveling at 1 m/sec and 2 m/s (cruise speed). Instrumentation consisted of accelerometers at the footrest and on the seat of each wheelchair.

There are many wheelchairs on the market and those selected for use in this research were considered typical to those in service. Ten unimpaired persons 23 to 55 in age, volunteered as test subjects. Five men and five women were included in the study sample. The mean ± Standard Deviation (SD) age of the subjects was 32.5 ± 10.0 years, and the range was 23 to 55 years. The mean ± SD mass of the subjects was 71.1 ± 18.9 kg, and the range was 47 to 104 kg. The mean ± SD height of the subjects was 170 ± 11.2 cm, and the range was 157 to 187 cm. Subjects self-reported to be free from any shoulder pain that would prevent them from propelling a manual wheelchair, and had no reported history of cardiopulmonary disease. Each surface was traversed three times while taking measurements, making a total of 540 runs across the pavements.



Figure 2. The six test surfaces with cast in place concrete on the far left, three test areas of concrete pavers and two consisting of clay pavers.

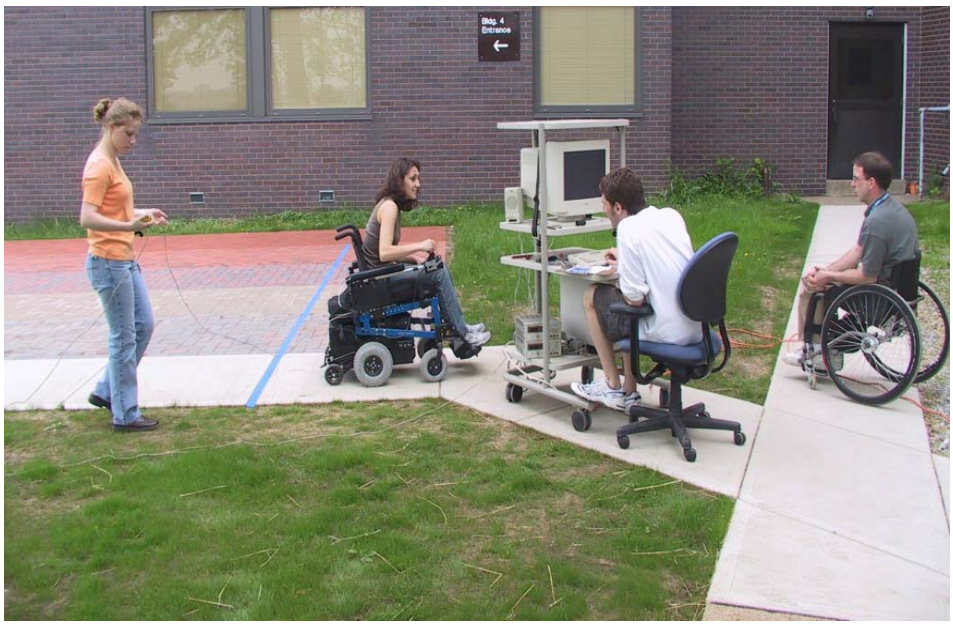

Figure 3. Powered wheel chair with accelerometers at the footrest and seat, and data collection apparatus.

The research objectives were (1) Measure the tri-axial accelerations (vibration) at the footrest and seat, including peak accelerations; (2) Through extrapolation of the data, compare the accelerations to the vibration exposure limits found in ISO 2631, *Evaluation of Human Exposure to Whole-Body Vibration* (ISO 1985). This standard sets limits to the number or minutes and frequencies of vibration (hertz) to which the human body can be exposed. (3) Test for any significant difference in the work required to traverse each surface with a manual wheelchair. This was done with the same device, called a SMART^{Wheel}, (Asato, 1993) specified in ASTM F 1951, *Standard Specification for Determination of Accessibility of Surface Systems Under and Around Playground Equipment* (ASTM, 1999). The tests were done during the spring of 2002.



Figure 4. Manual wheelchair with accelerometers at the footrest and seat, and the SMART^{wheel}

3. RESULTS

3.1 Peak Accelerations

A full description of the statistical analysis and modeling is given in Cooper, 2002. The results presented here summarize the findings. Table 2 summarizes the peak acceleration data. For the electric powered wheelchair moving at 1 m/s, the poured concrete surface generated higher peak accelerations compared to the concrete and clay pavers with no chamfer and the clay paver with a 4 mm chamfer. Again, with the exception of the pavers having 8 mm wide chamfers, all other segmental pavements produced lower vibrations than the poured concrete surface. The poured surface and the concrete pavers with an 8 mm chamfer generated similar vibrations.

For the powered wheelchair at 2 m/s (cruise speed), the results were similar to moving at 1 m/s. The poured concrete surface generated higher peak accelerations compared to the concrete and clay pavers with no chamfers, and the clay paver with a 4 mm chamfer. Similar to the 1 m/s velocity, at 2 m/s, all pavers except those with 8 mm wide chamfers produced lower vibrations than the poured concrete surface. The poured surface and the concrete pavers with an 8 mm chamfer generated similar vibrations.

Table 2. Peak accelerations in m/s^2, and the frequencies in Hz, at which they occur of foot and seat for manual and power wheelchairs over the test surfaces.

Surface	Wheelchair	Seat	Frequency	Foot	Frequency
1 cast-in-place conc.	Manual	13.41±3.13	2.51±1.25	35.36±7.34	2.21±0.68
	Power WC, 1 m/s	2.34±0.43	7.55±11.16	4.36±2.13	4.54±6.03
	Power WC, 2 m/s	5.16±0.91	6.13±7.06	8.82±3.80	10.47±12.56
2 0 mm chamfer concrete	Manual	5.30±2.16	3.70±1.3	13.98±4.67	5.46±6.82
	Power WC, 1 m/s	2.01±0.48	8.6±9.99	3.17±0.81	5.31±5.54
	Power WC, 2 m/s	4.04±1.02	8.18±9.81	6.67±2.00	11.76±11.89
3 2 mm chamfer concrete	Manual	8.35±4.15	4.11±4.87	19.47±7.20	8.13±8.83
	Power WC, 1 m/s	2.41±0.61	5.03±9.84	3.44±0.94	7.86±8.58
	Power WC, 2 m/s	4.64±0.83	6.2±6.55	7.71±1.94	11.98±12.17
4 8 mm chamfer concrete	Manual	18.22±2.10	10.14±9.79	40.98±3.94	12.29±9.78
	Power WC, 1 m/s	2.77±0.65	10.54±14.73	4.98±2.30	11.27±9.01
	Power WC, 2 m/s	5.34±1.33	7.28±9.37	10.15±4.75	23.52±17.32
5 4 mm chamfer clay	Manual	9.56±3.75	6.04±5.79	24.43±5.39	10.3±6.21
	Power WC, 1 m/s	2.19±0.61	4.38±5.34	3.86±1.20	7.9±6.78
	Power WC, 2 m/s	4.94±1.38	11.1±20.51	8.34±3.31	10.66±13.84
6 4 mm chamfer clay	Manual	8.00±2.40	2.72±1.73	23.78±6.29	4.29±4.25
	Power WC, 1 m/s	1.99±0.32	6.18±8.86	3.33±0.95	6.43±7.56
	Power WC, 2 m/s	4.72±0.93	5.75±6.68	7.75±2.43	7.89±8.28

3.2 Power per Octave

Table 3 shows the mean values for the seat and footrest vibrations. At 1 m/s, the majority of mean values for the sidewalk were higher than the mean values for other surfaces for all octaves for both seat and footrest vibrations. Results from the model indicated that the sidewalk resulted in significantly higher ($p<0.0001$) vibration for most of the octaves examined (1.6-2 Hz, 2-2.5 Hz, 2.5-3.15 Hz, 3.15-4 Hz, 6.3-8 Hz). For octaves 5-6.3 Hz and 8-10 Hz, the sidewalk and Surface 4 were similar in vibration, with the other surfaces having significantly lower vibration. At 2 m/s, no differences in the vibration were recorded for octaves 1.6-2 Hz, 2-2.5 Hz, 2.5-3.15 Hz. Mean values for both seat and footrest were highest for the cast-in-place concrete sidewalk and at several octaves lowest for Surface 4 at 2 m/s, with other surfaces being very similar in vibration.

Results from the model indicate that the standard concrete sidewalk recorded significantly ($p<0.001$) higher vibration values per octave than other surfaces for the octaves examined. Interestingly, for several of the octaves, Surface 4 recorded the lowest vibration at 2 m/s, although the differences were not statistically significant.

Table 3. Power per octave over the surfaces measured at the wheelchair footrest.

Surface	Wheelchair	2.5-3.15 Hz	4-5 Hz	6.3-8 Hz	10-12.5 Hz	16-20 Hz	25-31.5 Hz	40-50 Hz	63-80 Hz	100-125 Hz
1 – cast-in-place concrete	Manual Power, 1 m/s Power, 2 m/s	186.4±124.2 3.1±4.6 0.0±0.0	460.3±147.8 4.8±7.6 0.0±0.0	235.2±128.5 1.8±2.2 0.0±0.0	402.8±259.3 4.2±5.8 12.9±19.4	338.2±241.8 3.8±4.2 12.7±20.2	504.7±255.1 9.6±9.8 3.6±3.8	407.7±153.9 5.7±7.5 23.1±29.6	254.3±117.3 3.6±2.4 11.4±12.5	211.1±130.1 4.1±1.3 26.3±22.8
2 – conc. 0 mm chamfer	Manual Power, 1 m/s Power, 2 m/s	9.9±10.7 0.4±0.3 0.0±0.0	40.9±47.7 1.0±1.1 0.0±0.0	30.7±32.2 0.4±0.3 0.0±0.0	45.2±71.4 1.5±0.7 3.4±6.0	43.0±54.9 1.1±0.7 3.4±5.6	45.0±65.7 2.1±0.7 1.8±1.4	48.5±53.4 2.1±1.2 6.8±5.7	48.3±49.3 2.2±1.6 5.9±6.3	57.1±44.8 1.3±0.4 18.3±21.5
3 – conc. 2 mm chamfer	Manual Power, 1 m/s Power, 2 m/s	17.1±20.2 0.8±0.8 0.0±0.0	67.7±67.0 1.0±0.9 0.0±0.0	84.0±95.3 0.9±0.8 0.0±0.0	76.9±94.4 1.4±0.9 3.6±3.0	44.0±55.5 1.4±0.9 4.0±3.7	186.4±232.9 5.8±6.0 5.6±1.9	99.2±111.0 2.4±1.7 8.4±6.5	88.3±120.2 1.8±0.9 9.9±7.2	114.7±77.7 3.1±1.5 37.2±50.7
4 – conc. 8 mm chamfer	Manual Power, 1 m/s Power, 2 m/s	192.5±173.4 1.1±1.2 0.0±0.0	464.7±337.3 1.8±1.5 0.0±0.0	459.4±310.6 0.9±0.5 0.0±0.0	316.4±308.4 2.7±1.8 2.8±3.1	167.9±160.0 2.8±1.6 2.7±2.5	1388.3±697.8 13.7±4.3 2.8±1.7	475.1±293.6 3.2±2.1 5.9±3.5	319.0±182.7 3.8±2.6 7.0±6.5	723.0±451.0 6.0±4.1 60.7±78.2
5 – clay 0 mm chamfer	Manual Power, 1 m/s Power, 2 m/s	55.2±38.1 0.4±0.3 0.0±0.0	124.0±70.4 0.5±0.3 0.0±0.0	102.6±76.6 0.6±0.5 0.0±0.0	75.7±79.6 1.3±1.0 5.3±5.6	44.2±31.6 0.9±0.4 4.3±5.7	56.2±72.9 7.9±2.5 2.7±2.0	58.1±54.7 2.0±0.9 7.6±4.3	72.4±57.6 1.3±0.4 7.2±4.8	107.7±57.3 3.2±3.7 26.8±42.7
6 – clay 4 mm chamfer	Manual Power, 1 m/s Power, 2 m/s	60.7±46.8 1.0±1.0 0.0±0.0	118.0±75.0 1.0±1.1 0.0±0.0	102.8±74.3 0.5±0.3 0.0±0.0	103.3±88.1 1.4±1.4 8.0±7.8	101.6±70.7 1.5±1.1 7.8±7.6	106.5±70.9 3.9±1.2 2.4±1.5	162.9±110.8 3.1±2.4 11.1±8.1	161.8±92.4 2.2+1.1 8.7±5.9	142.5±70.4 3.2±2.3 14.1±14.0

Table 4. Power per octave over the surfaces measured at the wheelchair seat.

Surface	Wheelchair	2.5-3.15 Hz	4-5 Hz	6.3-8 Hz	10-12.5 Hz	16-20 Hz	25-31.5 Hz	40-50 Hz	63-80 Hz	100-125 Hz
1 – cast-in-place concrete	Manual Power, 1 m/s Power, 2 m/s	17.1±16.9 0.6±0.3 0.0±0.0	40.4±16.5 0.8±0.7 0.0±0.0	24.6±16.7 0.4±0.3 0.0±0.0	35.8±25.2 1.1±0.6 7.8±8.7	30.9±17.5 0.8±0.4 7.6±8.4	50.0±31.2 2.5±2.3 3.2±2.1	38.6±14.9 1.6±1.1 10.7±9.5	27.5±7.9 1.0±0.4 4.9±4.2	23.8±10.0 2.1±1.3 9.6±7.5
2 – conc. 0 mm chamfer	Manual Power, 1 m/s Power, 2 m/s	2.7±4.2 0.1±0.1 0.0±0.0	7.3±6.0 0.3±0.3 0.0±0.0	6.4±5.7 0.3±0.2 0.0±0.0	8.9±7.4 0.6±0.5 3.0±5.6	8.0±5.4 0.4±0.2 2.5±4.3	9.0±7.9 1.4±1.2 1.5±1.2	6.7±3.1 0.6±0.4 3.5±2.9	7.1±4.4 0.9±0.4 2.1±2.7	7.8±7.7 1.0±0.5 5.1±3.0
3 – conc. 2 mm chamfer	Manual Power, 1 m/s Power, 2 m/s	4.1±6.2 0.3±0.2 0.0±0.0	11.2±10.4 0.3±0.2 0.0±0.0	10.6±10.2 0.3±0.2 0.0±0.0	13.5±14.8 0.6±0.3 3.2±3.3	9.6±10.6 0.6±0.3 3.5±3.8	23.6±31.1 2.9±2.9 2.1±1.2	14.9±18.9 1.0±0.8 4.6±3.1	18.1±32.4 0.9±0.4 3.0±2.9	16.0±15.1 1.1±0.7 5.7±5.3
4 – conc. 8 mm chamfer	Manual Power, 1 m/s Power, 2 m/s	33.3±31.6 0.4±0.3 0.0±0.0	78.4±60.4 0.6±0.4 0.0±0.0	72.1±63.3 0.4±0.3 0.0±0.0	44.4±51.0 1.1±0.9 1.3±1.2	16.7±10.5 0.9±0.5 1.3±1.24	147.0±66.3 5.2±4.6 1.7±1.4	60.8±37.8 1.2±0.5 2.5±1.6	40.5±24.4 1.0±0.3 2.6±2.0	75.0±47.6 1.6±0.7 9.5±7.6
5 – clay 0 mm chamfer	Manual Power, 1 m/s Power, 2 m/s	7.6±4.9 0.2±0.2 0.0±0.0	19.1±13.3 0.2±0.1 0.0±0.0	18.0±20.8 0.3±0.2 0.0±0.0	13.5±24.1 0.4±0.2 2.8±3.6	6.1±3.2 0.4±0.3 2.9±3.4	10.8±14.1 2.7±4.1 2.2±1.0	9.4±7.8 0.8±0.4 4.0±2.1	9.9±9.8 0.7±0.2 2.3±2.0	12.7±9.5 1.1±0.3 6.0±4.3
6 – clay 4 mm chamfer	Manual Power, 1 m/s Power, 2 m/s	7.0±8.4 0.3±0.3 0.0±0.0	14.5±11.8 0.4±0.3 0.0±0.0	12.9±9.6 0.3±0.2 0.0±0.0	12.6±14.8 0.6±0.3 5.4±5.8	9.2±3.7 0.4±0.2 5.4±5.8	9.9±6.2 1.3±1.4 2.9±1.3	10.9±5.0 0.8±0.4 4.7±4.7	11.9±5.4 0.8±0.3 3.7±2.0	12.9±8.6 1.3±0.7 5.7±5.1

3.3 Average Work Required to Traverse Surfaces

The results in Table 5 showed no difference in the amount of work required traversing any of the surfaces. For the manual wheelchair moving at 1m/sec, peak accelerations were found to be lower than those from the poured concrete surface, except for the concrete pavers with 8 mm wide chamfers.

A similar pattern emerged in that overall vibration was lower among the paver surfaces than the poured concrete surface, except the paver with 8 mm chamfers that had mixed results.

Table 5. Average work in Nm for propulsion over surfaces at 1 m/s for manual wheelchair.

Surface	Mean ±Std dev.
1	3.33 ±0.80
2	3.28 ±0.83
3	3.25 ±0.67
4	3.29 ±0.73
5	3.23 ±0.73
6	3.30 ±0.78

3.4 Comparison to ISO 2631

ISO 2631 specifies vibration exposure limits to human body for 8 hours and it does not account for recovery periods, i.e., it assumes continuous exposure for 8 hours. In contrast, studies (Arva, 2001) show that users of electric powered wheelchairs move in them a total of about 3 hours a day. Those that use manual powered wheelchairs generally are moving between 2 and 3 hours per day. Table 6 demonstrates that the surfaces tested fit within these time frames for normal daily use of manual and powered wheelchairs. All surfaces meet the typical daily exposures with the exception of the pavers with 8 mm wide chamfers.

Table 6. Comparison to ISO 2631 exposure limits.

	Manual Wheelchair	**Electric Powered Wheelchair**	
Surface	**Exposure Limit (hours) at 1 m/s**	**Exposure Limit (hours) at 1 m/s**	**Exposure Limit (hours) at 2 m/s**
1 Poured concrete	2.8	8.7	2.4
2 Concrete paver 0 mm chamfer	3.6	9.7	2.8
3 Concrete paver 2 mm chamfer	3.0	8.0	2.6
4 Concrete Paver 8 mm chamfer	1.6	5.0	2.2
5 Clay paver 4 mm chamfer	2.7	7.7	2.5
6 Clay paver 0 mm chamfer	2.7	9.0	2.3

Figures 5, 6, and 7 show ensemble average curves of the seat accelerations for while driving the electric powered wheelchair over the six sidewalk superimposed over the curves for exposure limits defined in ISO 2631.

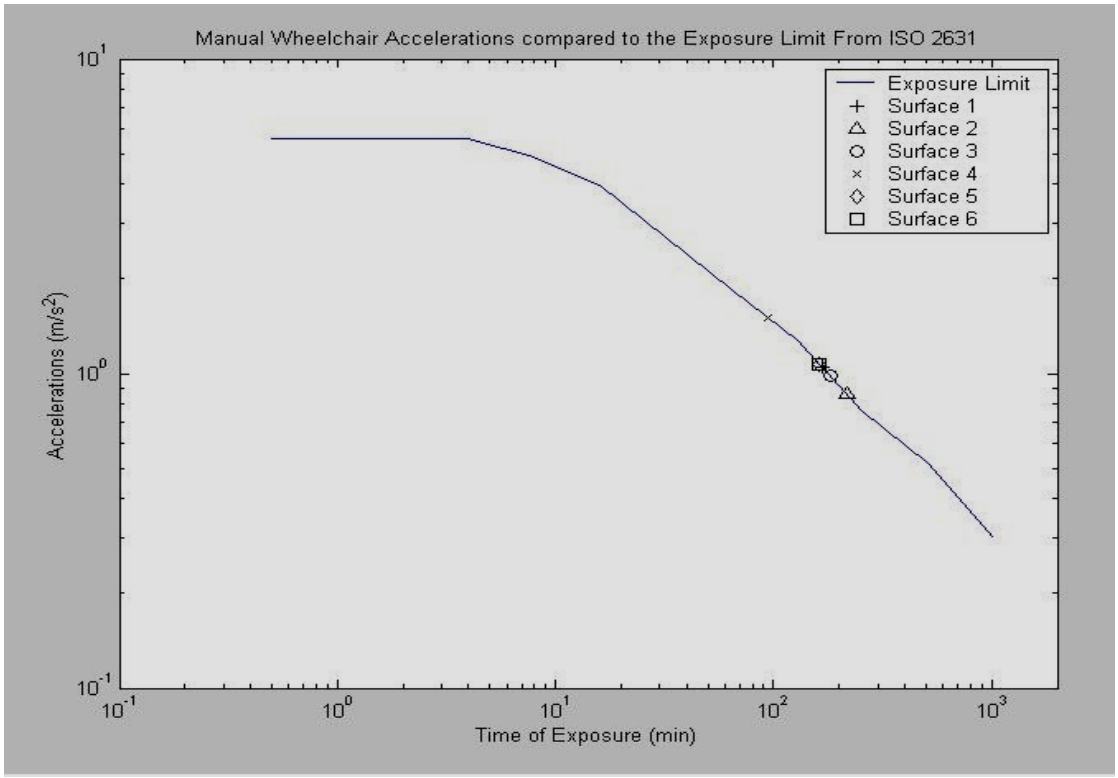

Figure 5. Manual wheelchair accelerations compared to the ISO 2631 exposure limits.

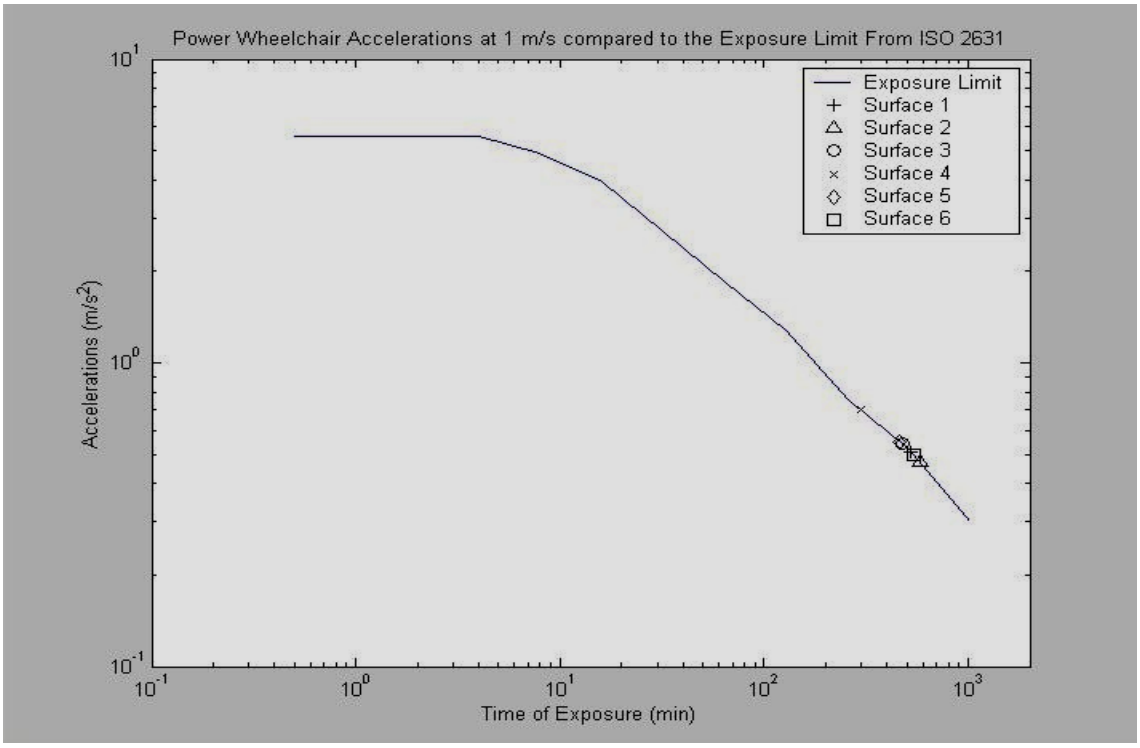

Figure 6. Electric wheelchair accelerations at 1 m/s compared to the ISO 2631 exposure limits

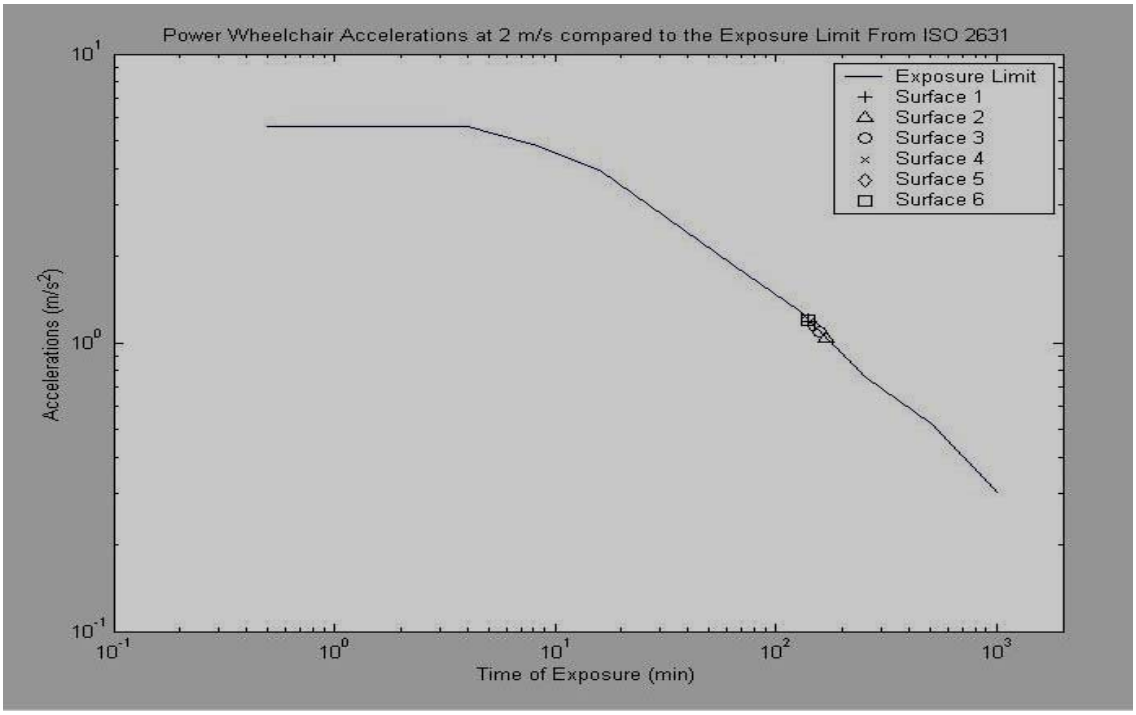

Figure 7. Electric wheelchair accelerations at 2 m/s compared to the ISO 2631 exposure limits.

4. CONCLUSIONS

The research showed that all pavers except that with an 8 mm chamfer are acceptable for use in the pedestrian access route with respect to the amount of work, peak accelerations, and exposure to vibration. Pavers with an 8 mm chamfer gave mixed results and may need further study. Concrete pavers with 8 mm wide chamfers are larger than most chamfered pavers and they were used for the purpose of providing an extreme gap between pavers. The typical chamfer dimension ranges between 4 and 6 mm. Therefore, most chamfered pavers in use would generate lower vibrations than evidenced in the report, and a higher capacity for exposure time when evaluated according to ISO 2361.

The chamfer widths that forms the total joint width, is a key factor in keeping vibrations near or below that of typical jointed, poured concrete sidewalk surfaces. The results indicate that the number of joints in a sidewalk have little impact on smoothness and vibration. Rather, joint widths greater than 13 mm appear to have a substantial influence on vibration in wheelchairs. Clearly, differences in vertical surface of pavers (lippage) impact peak vibrations can cause pain in some wheelchair users. Other factors affect smoothness such as the quality of the construction materials and procedures, as well as maintenance and repair of the surface during its use.

In 2002, the U.S. Access Board did not advance the PROWAAC's recommendation for a reduced vibration zone for wheelchairs in sidewalks in a draft accessibility design guidelines for the public right-of-way. The draft guidelines (Access Board, 2002) identified the need for further research on the relationship between surface roughness and wheeled mobility aids, including possible measurement protocols for the pedestrian access route. Therefore, a requirement for surface smoothness was not included. However, current design guidelines require that the pedestrian access route surfaces be firm, stable, and slip resistant. The guidelines also prohibit openings that are more than 13 mm in one dimension. The draft design guidelines commentary did not rule out the use of segmental pavement installed in a manner that provides a relatively flush surface and that is properly maintained.

5. REFERENCES

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INTERACTION OF WHEELCHAIRS AND SEGMENTAL PAVEMENT SURFACES

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Biography

David R. Smith
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With an architecture, engineering, and environmental planning background, David R. Smith has been involved with segmental concrete pavement since 1977. He has been working in the industry and for institutionalization of segmental concrete paving in North America since 1987. With many companies, he launched the Interlocking Concrete Pavement Institute (ICPI) in 1993. He has authored scores of magazine articles, brochures, and technical bulletins, technical papers, and promotional brochures for the ICPI.

His work includes co-authorship of ICPI technical manuals, *Port and Industrial Pavement Design with Concrete Pavements* and *Airfield Pavement Design with Concrete Pavers*. He has authored the *ICPI Concrete Paver Installation Contractor Certification Course* and *Permeable Interlocking Concrete Pavements*. David R. Smith is editor of *the Interlocking Concrete Pavement Magazine*, a quarterly publication featuring unique projects that circulates to thousands of designers and contractors. He also authored the design idea book, *Patio, Driveway and Plazas—The Pattern Language of Concrete Pavers*.

As a leading authority in North America on concrete segmental paving, Mr. Smith regularly speaks at national and international conferences. He is secretary-treasurer of the Small Element Paving Technologists. He is an active member of ASTM Committee C 27.20 on Architectural Precast Products, having written and revised product several standards on segmental concrete paving products for that organization. He is participates as a member in the American Society of Civil Engineers, American Public Works Association, Construction Specifications Institute, and the American Society of Landscape Architects. Mr. Smith has contributed continuing education programs to the American Society of Landscape Architects and to the American Institute of Architects.

His education includes a bachelor of Architecture and a masters of Urban and Regional Planning (environmental concentration) from Virginia Tech in Blacksburg, Virginia. As ICPI's Technical Director, he works daily with design professionals, contractors, and homeowners on the design, specification, construction, and maintenance of segmental concrete pavements.