THE CONTACT TIME AND THE CONTACT PRESSURE AS THE PARAMETERS OF THE SLIP RESISTANCE

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While there are many international and local standards to assess the slip risk for the floor and the footwear, they indicate different value in the same slippery condition. So, there has been some controversy concerning the reliability of the test methods. The aim of this study is to find the effect of contact time and contact pressure as the parameters of the slip resistance by experimental verification based on the biomechanical conditions of human gait. A slip resistance tester (SRT) designed for this study. The SRT control the biomechanical parameters of human slipping such as contact time, contact pressure, slip velocity and acceleration. The reliability of the SRT was verified by comparing with the utilized coefficient of friction measured by experiment of human slipping. As a result of this study, the contact time and contact pressure were dominant parameters of slip resistance and should be less than 0.09 sec and more than 400 kPa, respectively.

Introduction

There are various international and local standards to assess the slip risk of the floor and the footwear. But the devices to measure the slip resistance according to the standards have different control parameters and test methods as well as ratings. Therefore, the experts to assess the slip risk are confused. Furthermore, it is difficult to certify the reliability and the rationality of the apparatus because they indicate different value on the same slippery condition and have low correlation with each other (Ricotti *et al*., 2009, Grönqvist *et al*., 2000). To reduce the controversy, the researchers have agreed with the need of a device and test method that represents the human slip during locomotion biomechanically to measure accurate slip resistance quantitatively (Courtney *et al*., 2009).

The aim of this study is to evaluate the effect of biomechanical parameters such as contact time and contact pressure for the slip resistance to improve the accuracy and the reliability. In terms of that the required coefficient of friction (RCOF) is based on the utilized coefficient of friction (UCOF) which should be measured in condition of no-slip and that the slip resistance should be measured based on the static coefficient of friction (SCOF) to evaluate the condition of slip initiation, the variation of slip resistance is analyzed and biomechanical parameters are evaluated based on the SCOF.

Methods

This study consisted of three parts. Firstly, the contact time and contact pressure, which were concerned as main contribution factors to the slip resistance in this study, were analyzed. Secondly, we developed the slip resistance tester (SRT) which could control each parameter and studied the variation of slip resistance in accordance with each parameter. Finally, in order to verify the reliability of the SRT, the device was tested under wetted floor using distilled water and detergent solution and compared with the results of human subject under the same wetted conditions.

To analyze the contact time between the heel contact on the floor and the slip initiation and the contact pressure at the condition of the slip initiation, a participant was instructed to walk at from 84 steps to 132 steps per minute (every 12 steps is increased) across the 8 m long and 1.5 m wide walkway. And then the variations of the UCOF and foot pressure were measured with a force plate and pressure sensors (see Figure 1.). In order to ensure the same walking pattern during the whole experimental process including data acquisition, finding quantitative criteria of slip hazard, and walking trial, one participant is just recruited (gender : male, age : 40, height : 169cm, weight : 73kg).

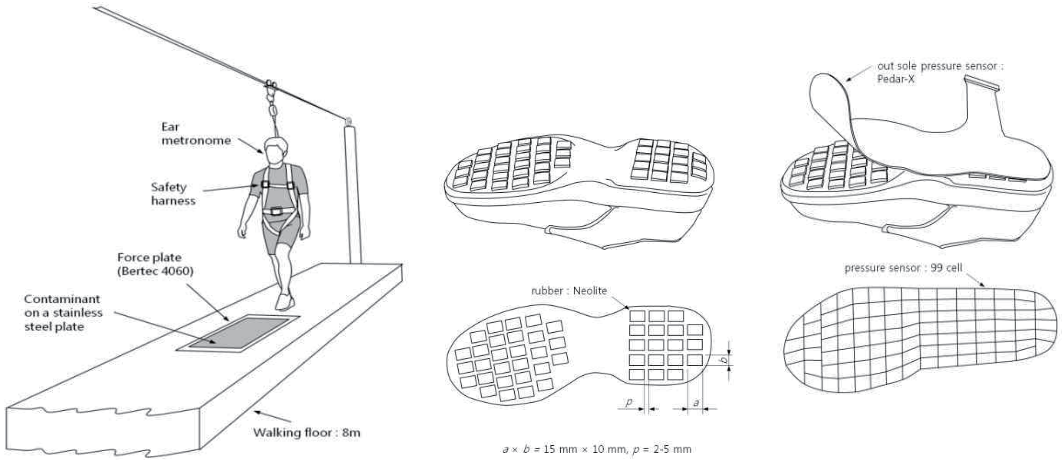


Figure 1. Walking floor with fall arresting harness, shoes for this study and pressure sensor attached under the outsole of the shoes

The walking speeds were controlled with metronome which was earphone type. The subject was asked to look horizontally forward and walk. Figure 1. shows the test shoes which was used during the all test procedure. The 46 pieces of Neolite rubber block (10mm×15mm×4mm) were attached onto outsole of test shoes using adhesive. The 28 pieces were attached at forepart of outsole and the 18 pieces were attached at heel area.

Figure 2. shows the schematic diagram of the SRT developed for this study. The apparatus allowed friction testing across a range of the contact times that are similar to those experienced during slipping. The weight was putted down to the floor before the weight was horizontally pulled with servo motor. The residence times between when the normal force is reached at 10N and when the horizontal force is reached at 10N are defined as contact time in this study

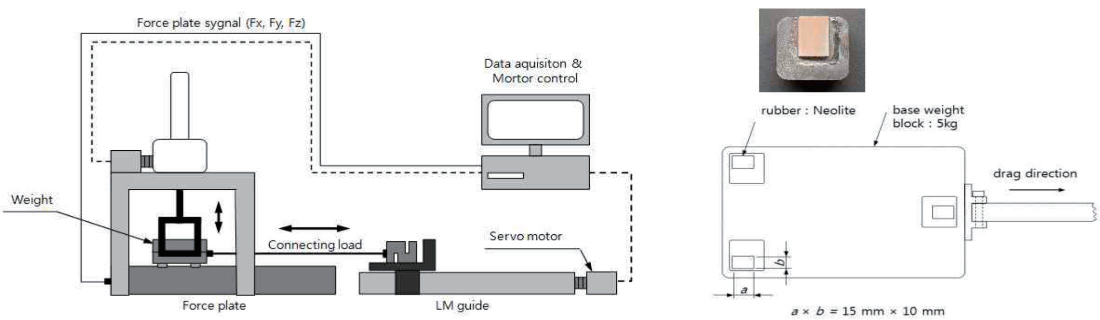


Figure 2. Schematic diagram of the slip resistance tester and control

The shoe sample, which was attached at bottom of weight block, was same material as was used at test shoe, i.e., Neolite rubber. This shoe sample was 1.5 cm × 1 cm and attached at three points under the weight as shown in Fig. 4-2. The test environments constantly were maintained through all trials. : The temperature were 20～22℃, the relative humidity were 30～40%.

In order to form slippery floor condition, the smooth stainless steel floor, which had a R_z roughness of 0.1 ㎛ and thickness of 1 mm, was selected and attached onto force plate. The distilled water and water with non ionic surfactant (Triton-X, 0.04%) were used as the contaminants which were poured on the selected floor. The subject walked under the same condition at which RCOF was measured. The reaction force and coefficient of friction were acquired during slipping.

The test conditions were as follows: the test pressure was 109, 218, 327, 436 kPa. The contact time, which was based on existing slipmeter and data from walking trials, was logarithmically increased from 1msec to 5000msec. The velocities and accelerations, which were based on previous study in our laboratory, were constantly set 1m/sec, 10 m/sec^2 respectively.

Results and discussion

Contact time

Figure 3 shows the average profiles of the UCOF depend on the walking speed from 84 step/min to 132 step/min. The UCOF are acquired from the ratio of vertical force and horizontal force when the subject walking 7 times on the walking floor installed the force plate.

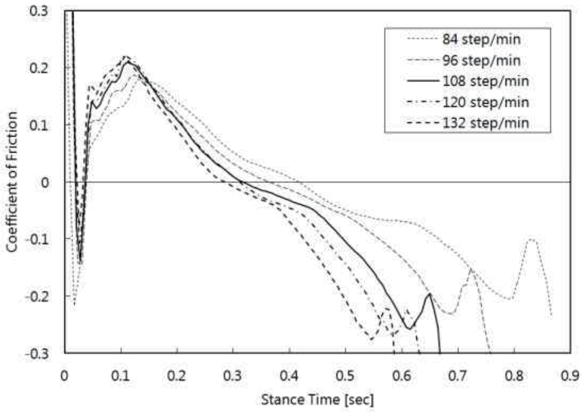


Figure 3. Utilized coefficient of friction for walking speed

The RCOF is the peak point value between 0.1s and 0.2s. If the physical slip resistance of contact surface between the shoe and the floor is higher than RCOF, the slip will not occur and human can walk normally. In other words, when a slip occurs, the maximum elapsed time of no-slip contact must be less than the time of RCOF occurs. In terms of the contact time as a parameter when measure a SCOF, the contact time before to drag the weight should not exceed the time of occurring RCOF.

The time of occurring RCOF is 0.15s at the walking speed 84 step/min, 0.1s at 132 step/min and decreases with increasing walking speed.(see Table 1.) Therefore, the SRT should control the contact time less than 0.1s.

Table 1. Variation of elapsed time when required coefficient of friction occurred according to increase walking speed

Walking speed [step/min]	84	96	108	120	132
Time [sec]	0.15	0.12	0.11	0.11	0.1

Contact pressure

The contact pressure when slip initiate is a value of increasing area of the contact pressure profile in the beginning of stance phase. Figure 4. shows the average value of contact pressure of at each walking speed. The contact pressure increases with increasing walking speed and is distributed between 350 kPa and 500 kPa. The mean value is 412.8 kPa and S.D is 56.5 kPa. Therefore, The SRT should control the contact pressure around 400 kPa.

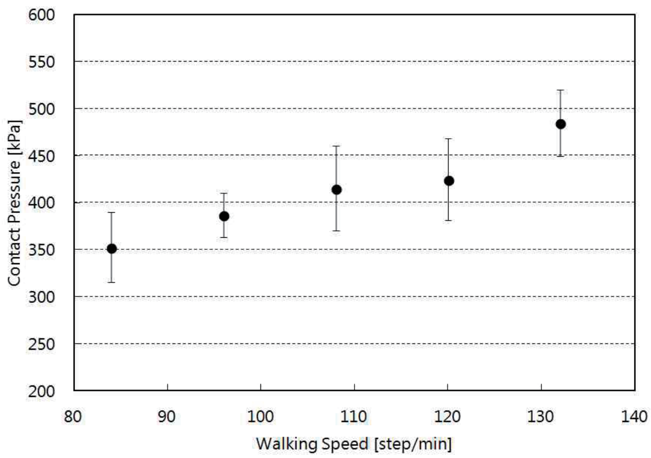


Figure 4. Average Contact pressure for the 5% previous range from the point of required coefficient of friction according to walking speed

Human slip

To verify the reliability of the SRT, the validation criteria are acquired by human slip experiment. Figure 5. shows the profile of Normal force and the UCOF. The solid line is a result of normal walking on the clean and dry stainless steel plate and the dashed line is a result when slip was occurred on the contaminated stainless steel plate with detergent(Triton-X 0.04%).

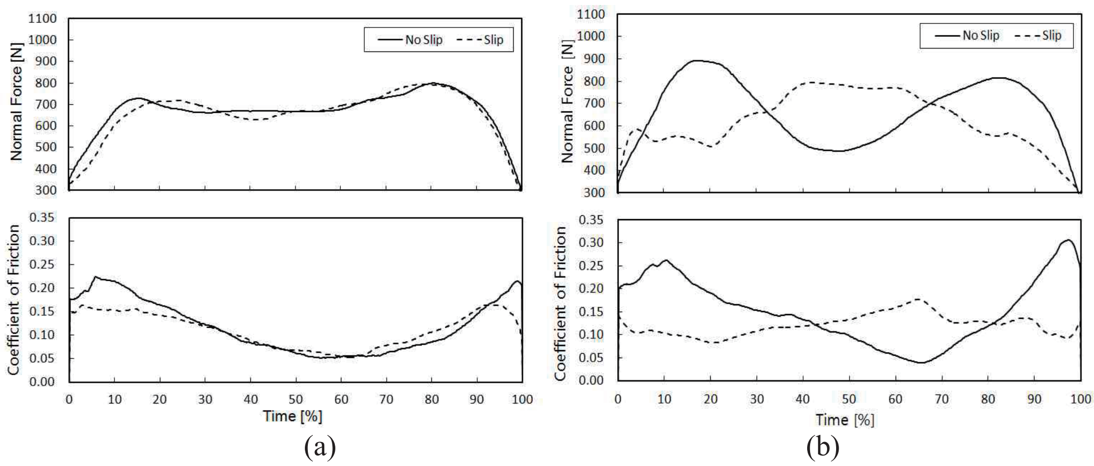


Figure 5. Normal force and utilized coefficient of friction during normal walking and slip

In the case of walking speed of 84 step/min(see Figure 5. (a)), the RCOF is 0.23(first peak point of solid line) and the maximum UCOF on the contaminated plate is about 0.15(dashed line). The value of the maximum UCOF is a physical COF between shoe sole and contaminated stainless steel plate. Therefore, theoretically the subject must be slipped. But the subject did not feel the slippery and did not slip and fall.

Figure 5. (b) shows the profile at walking speed 108 step/min. In this case, the subject lost the body balance and heel slip was occurred. The normal force profile when slip occurred did not trace the profile of normal walking at walking speed of 108 step/min. While the RCOF is approximately 0.25, the coefficient of friction between shoe and floor is under 0.15 as at the walking speed of 84 step/min.

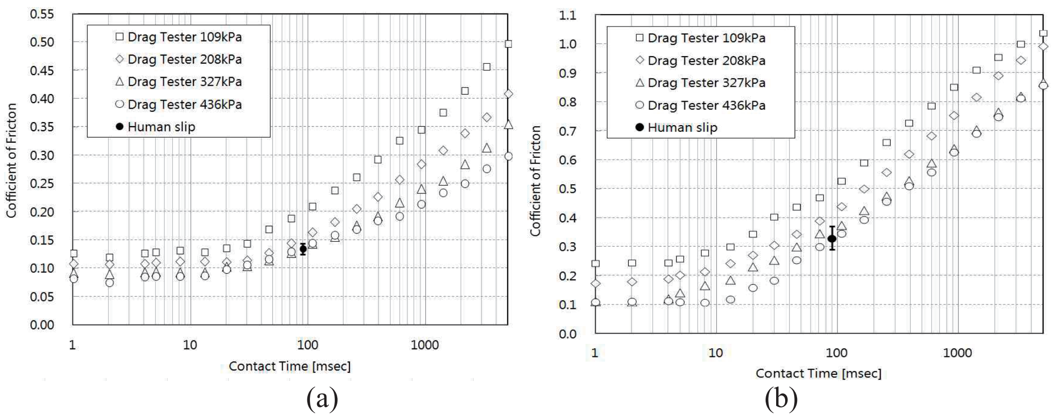
Regardless of walking speed, the slip resistance at slip initiation is 0.134 on the Triton-X 0.0.4%, 0.330 on distilled water, respectively(see Table 2.). Therefore, the measurement result of the slip resistance tester on the same condition of contaminated floor can be verified biomechanically by comparing with the results of the SRT.

Table 2. Slip resistance between stainless steel plate and Neolite rubber contaminated by Triton-x detergent and water

	Contaminant	
	Triton-x 0.04%	Water
Mean	0.134	0.330
S.D	0.010	0.040

Reliability of slip resistance tester

The measurement results of the device are compared with the slip resistance when heel slip occur. The coefficient of friction (COF) decreases and the variation of the COF increases with shortening the contact time and increases with increasing contact pressure (see Figure 6.). Figure 6. (a) shows the case which the floor was contaminated by Triton-x 0.04% and Figure 6. (b) shows the case which the floor was contaminated by water. In these figures, black points mark the average and the S.D of slip resistance when human slip occur on the same condition consisted for measuring COF by the SRT. In both cases, the slip resistances are on the regression line of the result of the device at the contact time of under 0.1s and contact pressure of between 327 kPa and 436kPa.



(a) (b)

Figure 6. Variation of slip resistance for contact time and pressure

Table 3. Slip resistance measured by the SRT and the human slip : mean (S.D)

Contaminant	Human slip	SRT	p-value
Triton-x 0.04%	0.134 (0.010)	0.138 (0.012)	0.560
Water	0.330 (0.040)	0.328 (0.012)	0.888

Therefore, the contact time and the contact pressure, as the parameters should be controlled, are dominant parameters for measuring the slip resistance quantitatively. The device can simulate the human slip when the contact time is under 0.1s and the contact pressure is about 400 kPa. The range of the parameters, as a result of previous study, are estimated too wide to assess the slip risk. So the reliability of the devices could not be insured.

Conclusion

The contact time and the contact pressure are dominant biomechanical parameters when measure the slip resistance based on the SCOF. Devices to measure the slip resistance should control the parameters as same as the condition of the human locomotion.

Reference

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