EVALUATION METHOD OF SLIPPERINESS BASED ON HUMAN PERCEPTION

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SUMMARY

Generally, the coefficient of friction is used to estimate whether a finished material surface is slippery or not. Although the coefficient of friction can be measured using several different types of testing equipment, it is difficult to apply these results directly to estimate the human perception of slipperiness.

The O -Y • PSM method [1][2][3][4][5] was developed by Prof. Dr. H.Ono(Tokyo Inst. of Tech.) in order to estimate slipperiness. This equipment is arranged to detect the human perception of slipperiness by a specially designed mechanism and testing method. It can estimate how a person feels the slipperiness, by a measured value(CSR). The details of development and future possibilities for O - Y • PSM are discussed in this paper.

1. INTRODUCTION

It is dangerous if one trips or slips and falls while walking. In order to avoid such danger, paving and flooring material should have non-slip finish. For the same reason, tiles should also have non-slip characteristics when they are used in public footpaths and floors.

The non-slip property is usually evaluated by measuring the coefficient of friction, for which many types of tester are available. The drag type tester from England(tortusa), the drag type tester from America and the testing method(DIN) from Germany which measures the largest inclination at which a person does not slip, are well known methods of measuring the non-slip property. Although these methods measure slip resistance , it remains uncertain whether the values measured by these method can be correlated to the actual perception of slipperiness felt by a human being. Although the DIN method uses a human, the results are dependent on human judgment and are therefore likely to certain errors of human judgement.

O-Y • PSM (Ono-Yoshioka Pull Slip Meter[1)2)3)4)5)]) is a testing machine developed by Professor Ono of the Tokyo Institute of Technology for measuring the human perception of slipperiness. The mechanism and specifications of the testing machine were developed so that the human perception of slipperiness could be detected. By measuring the CSR value(coefficient of slip resistance) using this testing machine, it is possible to rank how a person feels slipperiness.

This report describes the development of O-Y • PSM and explains how this method of measurement differs from other conventional methods of measuring slipperiness.

2. DEVELOPMENT OF O-Y • PSM

2.1. Establisment of the human perception on a slipperiness

The most important aspect of the testing machine is that there should be a strong correlation between the value measured by the machine and the rank of slipperiness perceived by a human. In other words, the machine should be able to reproduce the human perception of slipperiness. It is therefore necessary to establish an order of ranking to show what type of surface causes a human to feel that it is slippery and what type causes a human to feel that it is not slippery. This ranking was determined using the sensory evaluation method described below.

Several types of specimens of different materials and surface roughness were prepared, ranking from extremely slippery specimens to absolutely non-slippery ones. Subjects wearing shoes were asked to walk, dash and stop on these specimens and to indicate how they perceived slipperiness during each of these actions according to the ranks 1 to 7 shown in Table 1.(1)(rating scale method). Variance analysis of the results were carried out to confirm that there was consensus among the subjects (i.e. that the differences between the judgement of individual subjects was small). Then, using the psychological scaling theory, the sensory evaluation results were scaled according to each of the actions. This scale is hereafter referred to as the scale of slipperiness perception.

As shown in Fig.1, there is good correlation between the scales of slipperiness perception for each action. Therefore, the relative judgement of the level of slipperiness is not influenced by the type of action, showing that each action can be evaluated by a single measured value.

Table 1 Categories of judgement and questions

Category No.	(1) Perception	(2) Safety
① (-3)	Very Slippery	Very Dangerous
② (-2)	Slippery	Dangerous
③ (-1)	Slightly Slippery	Slightly Dangerous
④ (0)	Neutral	Neutral
⑤ (+1)	Slightly Non-slippery	Slightly Safe
⑥ (+2)	Non-slippery	Safe
⑦ (+3)	Very Non-slippery	Very Safe

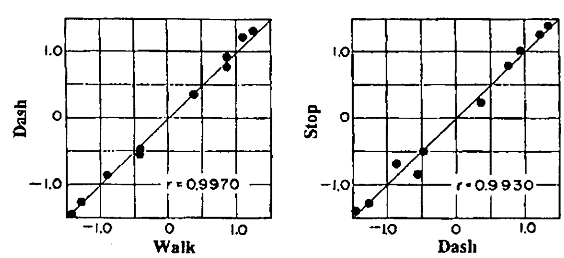

Fig.1 Relation of the scales of human sense on slipperiness in different actions

2.2. Design and trial manufacture of testing machine

Before proceeding to build a testing machine based on the theory explained in Section 2.1, it is necessary to analyze briefly the action of walking.

Fig.2 illustrates the load exerted on the floor when a person walks, dashes or stops. Although a large impact load is exerted when stopping, the load during other actions is, in general, nearly the same, and it is worth noting that when a person weighing 60Kg walks, the maximum vertical load is 80Kg.

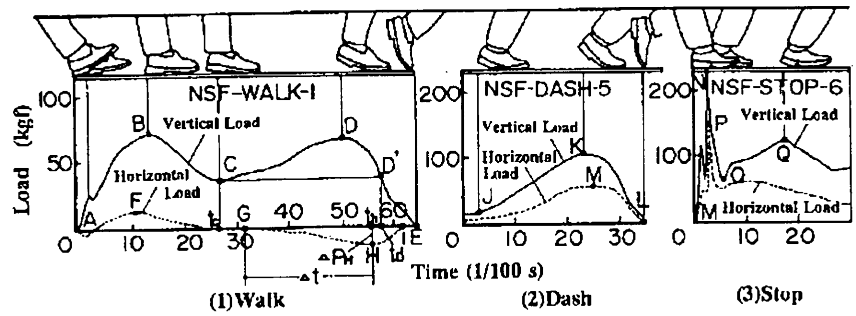

Fig.2 Relation between load and time in case that a person weighting 60kg walks

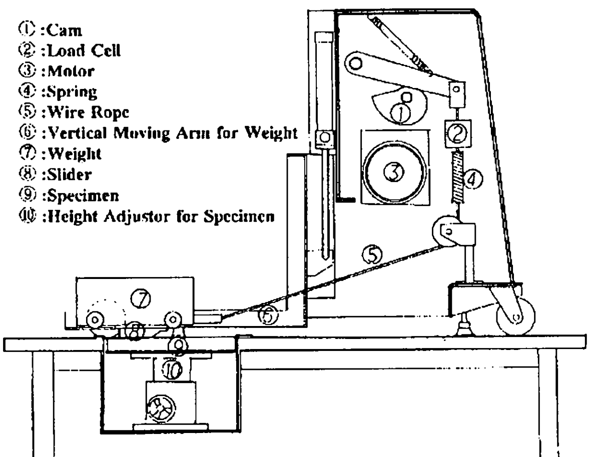

Fig.3 Outline of O-Y•PSM

Table 2 The rough specifications of the testing machine

Factor	Level
Vertical Load (W)	20, 40, 80 (kg)
Verocity of Tensil Load (V_{FT})	30, 80, 120 (kgf/s)
Area of Slide (A)	30, 45, 60 (cm^2)
Time Lag of Loading* (Ts)	0, 3, 6 (s)
Initial Tsnsil Load	3 (kgf)

* : Time lag from touch of slider on floor to exerting tensil load on slider.

When one considers the area of contact between the sole of the shoe and the floor, the part that slips may be either the heel or the front part of the shoe sole. A preliminary investigation showed that a majority of the people feel that it is the front part of the shoe that tends to slip more. In addition, it is estimated that the ranking of slipperiness was the same for heel and for the front part of the sole and that the movement of the front part was more stable than that of the heel. For these reasons, the front part of the sole was selected as the contact area. The contact area is therefore between 40 to 60 cm^2.

The testing machine could either be drag type, articulated strut type or pendulum type. Considering that the contact area for the slipping experiments is large (40 to 60cm^2) and that measurements should be possible on specimens even when subject to rain, we chose the horizontal drag type mechanism. (See Fig.3)

Based on the above conditions and on other conditions required for smooth operation, the rough specifications of the testing machine were drawn up as in Table 2.

2.3. Decision on the final specifications of the testing machine

The specimens used for sensory evaluation in Section 2.1 were measured under each of the conditions shown in Table 2. For each condition, the coefficient of slip resistance (CSR) was calculated by dividing the maximum drag load(P_{max}) by the vertical load(W) (See Fig.4). CSR is a coefficient that is similar to the coefficient of static friction. The sole of the shoe used for sensory evaluation was used as the skid in these measurements.

Examination of the relationship between the CSR values obtained under each condition and the scale of slipperiness perception obtained in Section 2.1 showed that the best correspondence is obtained under the following conditions : Ts = 0 s, V_{FT} = 80 kgf/s, W = 80 kg, A = 60 cm^2.

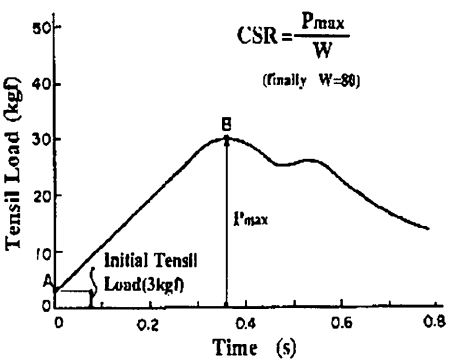

Fig.4 Relation between tensil load and time using slider for shoe

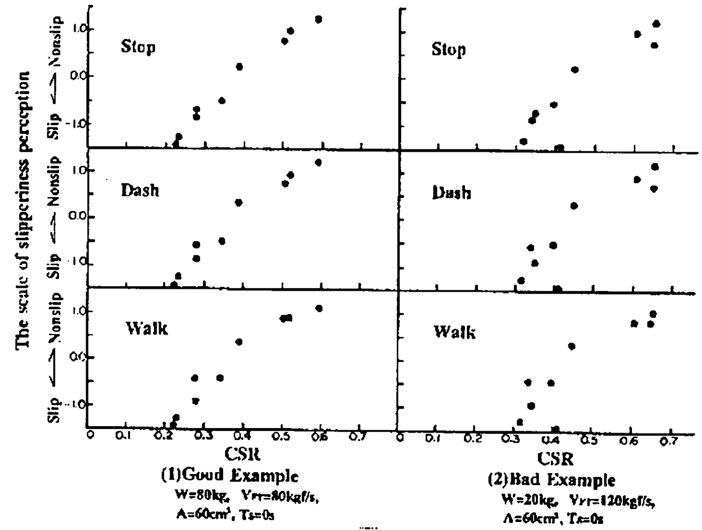

Fig.5 Relation between the scale of slipperiness perception and CSR of good condition and bad one

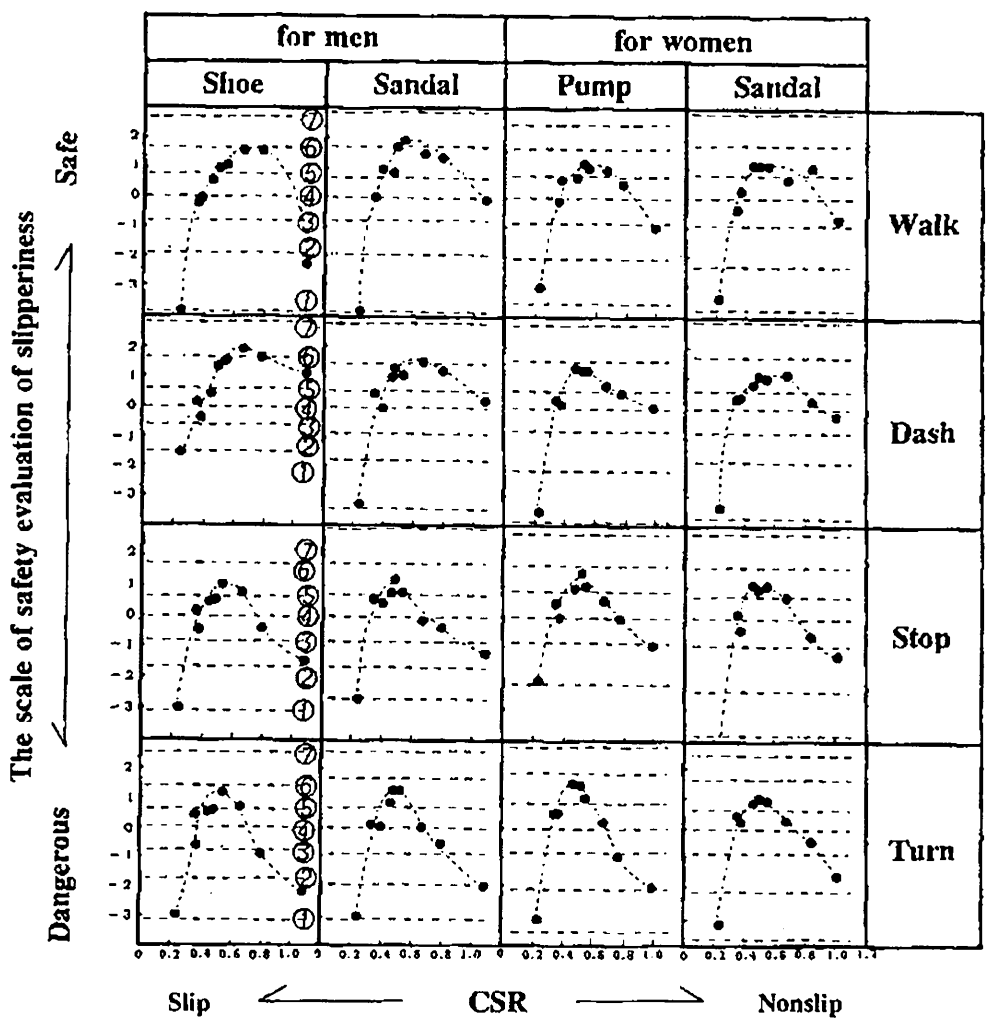

Fig.6 Relation between the scale of safety evaluation of slipperiness and CSR

The testing machine used under these conditions (finally, we changed area of slider from 60cm^2 to 56cm^2 (=7 X 8) is hereafter referred to as O-Y • PSM (Ono-Yoshioka Pull Slip Meter). Fig. 5 shows a good example ① (under the above mentioned conditions) and a bad example ②. It is evident from Fig. 5 that in order to simulate the human perception of slipperiness, the testing machine should be able to reproduce the walking action of a human to a certain extent.

2-4 Establisment of the scale of safety eveluation of slipperines

Sensory evaluation of slipping and not slipping was performed in Section 2.1. In general, it is believed that a slippery floor is dangerous and becomes safer as they become less slippery. However, we confirmed this assumption. A second sensory evaluation was carried out regarding safety and danger of floors. The same method as that described in Section 2.1 was used, but the evaluation was done according to the 7 levels listed in Table 1.(2).

Results of variance analysis showed that there was consensus among subjects and that dangerous and safe specimens could be clearly distinguished, allowing scaling according to each of the actions(walk, dash, stop). The scale obtained is hereafter referred to as the scale of safety evaluation of slipperiness.

Fig. 6 shows the relation between the scale of safety evaluation of slipperiness and the CSR values of the different specimens obtained in Section 2.3. For all types of shoes and actions, there is a peak at CSR = 0.5. Considering the result from Section 2.3 indicating that slipping is less likely to occur as CSR increases, it could be inferred from Fig. 6 that up to CSR = 0.5, less slipperiness means more safety. However, if the slipperiness decreases beyond this point, it becomes more dangerous. This is because tripping, stumbling , etc. may occur if the CSR is higher than necessary.

3. SETTING OF TESTING CONDITIONS TO SIMULATE RAIN OR OTHER ACTUAL CONDITION

The above is a description of the new testing and evaluation method that corresponds to the human perception of slipperiness. In actual use, however, the floors are not always in a clean and dry condition. Accidents are more likely to happen when the surface is wetted by rain or by water carried in by umbrella holders, or when oil is spattered on a kitchen floor etc.

It is necessary to standardize such conditions of testing here as an example, the setting of the standard condition for a rain-wetted surface is described. Using the O-Y • PSM, a search was made for a substance that would give the same CSR as that of rain water. It is observed that a mixture of water and dust in a 4:1

ratio yielded a CSR value closest to that in the case of rain water. This mixture was therefore used as the substitute for rain water.

4. REGARDING THE SKID USED FOR TESTING

When a manufacturer of tiles or other paving materials uses the above method for evaluating slipperiness, it is important to select a suitable skid. In order to examine this point, the difference in CSR was measured using a number of different shoes representative of those being sold in Japan, along with a number of different types of rubber used for the soles of the shoes. In the case of all soles, the CSR was not so small as long as the shoe sole's pattern remained intact. However, when the pattern of the shoe sole becomes wasted, it was found that the CSR values were different depending on the type of the sole. We chose the shoe sole(EVA, Shore Hardness 50, Thickness=Approx.1cm), which was more slippery without a sole pattern, as the standard skid. Since there may be some person who will continue to wear their shoes even after the sole is wasted, we used the standard skid in a state where the sole pattern has wasted away.

5. EVALUATION OF SLIPPERINESS OF BARE FEET

Up to Section 4, the evaluation of slipping when a person is wearing shoes was described. Professor Ono has also investigated the evaluation of slipping when the feet are bare. The method of evaluation is the same as the described in Section 2, but it is necessary to find a suitable skid as a substitute for bare feet. After a number of trials, we selected the substitute shown in Fig.7 and calculated the value CSR B shown in Fig.8.

The results were found to be in good correspondence to the scale of slipperiness(scale indicating whether safe or dangerous) of bare feet (see Fig.9). However, although the skid was found to give good correspondence to the human perception of slipperiness in the presence of water or soap water between feet and floor, the correspondence was poor under dry conditions. Thus, O-Y • OSM can be used to evaluate the slipping of bare feet under wet conditions such as in bathroom floors or pool sides.

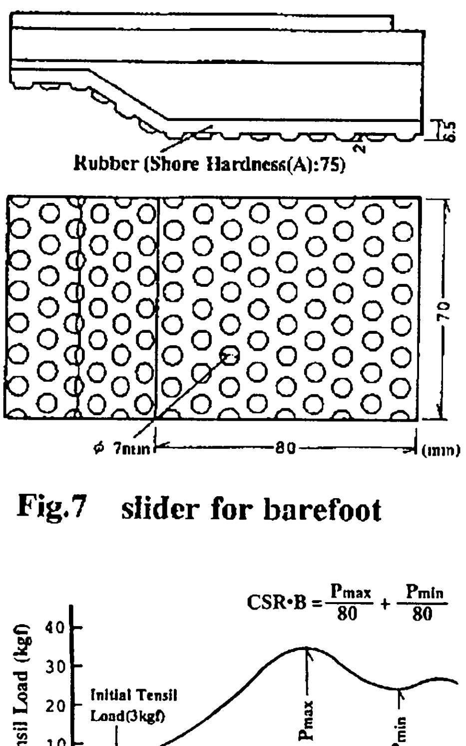

Fig.7 slider for barefoot

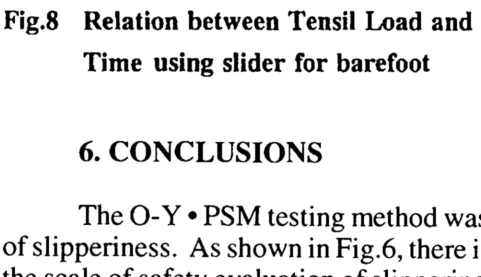

Fig.8 Relation between Tensil Load and Time using slider for barefoot

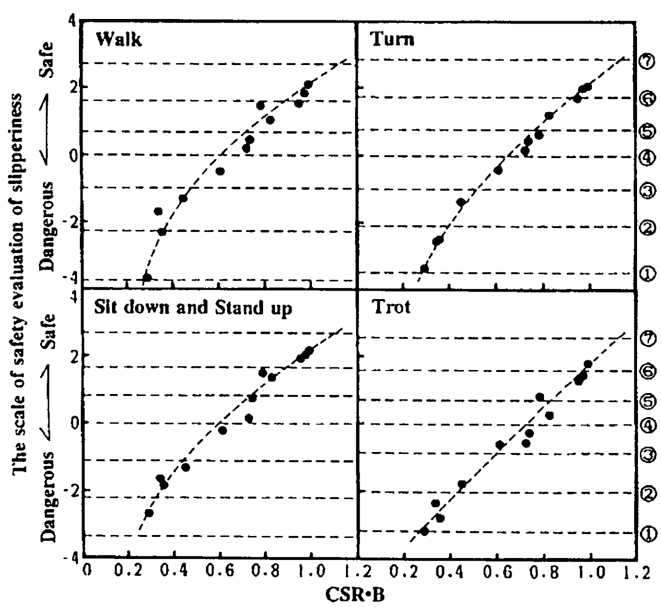

Fig.9 Relation between the scale of safety evaluation of slipperiness and CSR•B

6. CONCLUSIONS

The O-Y • PSM testing method was developed by Professor Ono to evaluate the human perception of slipperiness. As shown in Fig.6, there is smooth correspondence between the measured value CSR and the scale of safety evaluation of slipperiness. By measuring CSR of an unknown specimen and using this value in Fig.6, it is possible to evaluate the safety of slipperiness. It is also possible to evaluate the safety of slipperiness under rain-wet condition by coating the specimen surface with a mixture of water and dust in the ratio 4:1 and then measuring the CSR.

In addition, by using the skid shown in Fig.7 as the substitute for bare human feet, and measuring CSR • B of an unknown specimen, it is possible to evaluate through Fig.9 the safety of slipperiness in the case of bathroom floors and pool sides.

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