Recommendation for
Evaluation Index on Safety and Comfort Performance
of Daily Use Floors

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Subcommittee for Floor Performance Evaluation

Recommendation for Evaluation Index on Safety and Comfort Performance of Daily Use Floors

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Recommendation for Evaluation Index on Safety and Comfort Performance of Daily Use Floors

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*: These sections are available only in Japanese; English translations are not provided.

Chapter 1: General Remarks

Section 1: Purpose and Significance

> This recommendation outlines evaluation methods and suggested values for various performance criteria essential to ensuring the safety and comfort of building users on a daily basis.

Considering the recent diversification and complexity in building demands, coupled with the development and widespread adoption of new materials and construction methods, there has been a transition from traditional specification-based frameworks to performance-based approaches. Performance-based frameworks offer the advantage of meeting diverse building requirements efficiently through the flexible selection and combination of materials and construction techniques, moving beyond rigid specifications. Therefore, at the core of this framework are performance indicators that reflect the quality and appropriateness of a building for its users, focusing on the quantitative representation of material and construction quality from the users' perspective rather than solely on physical properties.

The overall performance of a building is considerably dependent on the performance of its individual components, among which the floor is a critical component. As the primary interface between the building's users, equipment, and various loads, the floor significantly influences daily safety and comfort. Table 1.1.1 details the general performance requirements for floors. Depending on the specific purpose and use of a space, additional performance criteria not listed in the table may be necessary. Floors must address a broad range of performance needs, particularly in terms of user safety and comfort. However, achieving a balance among these diverse performance requirements can be challenging with current technologies. Therefore, it is necessary to define the required performance levels for each criterion and select flooring that meets these standards through performance evaluation methods capable of quantitatively assessing each floor's performance. This document specifies the methods for evaluating performance and the recommended values for key performance items, focusing on those essential for the daily safety and comfort of building users.

The performance evaluation methods outlined in this recommendation include both measurement techniques for performance values, which reflect the quality as perceived by building users, and evaluation indices for comparing and assessing these values. These indices quantitatively represent the relationship between the performance values and the evaluations of daily safety and comfort. By implementing these prescribed methods, it is possible not only to determine whether individual floors meet the recommended standards but also to assess the relative safety and comfort of each floor.

Furthermore, the recommended values are based on permissible levels of safety and comfort deemed desirable. These levels serve as evaluation criteria and are compared against the evaluation indices to establish an acceptable range of performance values. In setting these permissible levels, comprehensive consideration was given to the general needs of building users and the feasibility of achieving a balance among multiple technically conflicting performance criteria. Specifically, the permissible levels are determined based on the following basic principles:

· For performance related to daily safety, the permissible criteria are set at a level described as "neither safe nor dangerous," representing the boundary between evaluations deemed "safe" and "dangerous."

· For performance related to comfort, the permissible criteria are established one level below "neither suitable nor unsuitable," assessed as "slightly unsuitable."

Thus, the recommended values specified in this recommendation merely represent the range that meets these predetermined permissible criteria. It is important to note that floors meeting these recommended values are not guaranteed to be absolutely safe or necessarily optimal from the perspective of safety and comfort.

Table 1.1.1 Performance items required for floors

Classifications	Performance items
Performance in terms of daily safety and comfort for building users	Hardness in daily motions
	Resiliency, hardness, and shock-absorbing properties during exercise
	Hardness of the surface layer
	Hardness in accidental collisions
	Non-vibration property
	Slipperiness
	Surface temperature
	Thermal insulation
	Roughness
	Flatness
	Color, gloss, pattern, and texture
	Stain resistance
	Dust-resistant property
	Antistatic property
	Non-condensation property
	Non-biodegradability
	Water absorption, hygroscopicity, and waterproofness
	Cleanability
	Sound absorption property
	Sound emission property
	Sound insulation property
	Non-odor/gas-generating property
	Non-toxic gas-generating property
Performance in terms of serviceability of equipment, articles, etc.	Hardness
	Non-vibration property
	Slipperiness
	Thermal insulation
	Flatness
	Stain resistance
	Dust-resistant property
	Non-dust-generating property
	Antistatic property
	Non-condensation property
	Non-biodegradability
	Water absorption, hygroscopicity, and waterproofness
	Sound absorption property
	Sound emission property
	Sound insulation property
	Non-odor/gas-generating property
	Electromagnetic shielding property
	Wiring and piping capability
	Air permeability
Performance in terms of durability and service life	Static load-bearing capacity
	Seismic resistance
	Impact resistance
	Local deformation resistance
	Deformation recovery capability
	Abrasion resistance
	Scratch resistance
	Water resistance
	Heat resistance
	Fire resistance
	Weather resistance
	Chemical resistance
	Peeling and blistering resistance
	Expansion and shrinkage resistance
	Insect and fungal resistance
Performance in terms of constructability	Ease of construction
	Construction accuracy
	Construction period
Performance in terms of economic efficiency	Material cost
	Construction cost
	Maintenance and management costs
Others	Environmental conservation

Note: This table was created by Hidenori Ono (Professor Emeritus, Tokyo Institute of Technology, Professor Emeritus, Tohoku Institute of Technology, Dr. Eng.).

Section 2: Performance Items

> The performance items targeted by this recommendation are as follows:
> a. Performance items for floor hardness
> · Hardness of floors in daily motions
> · Resiliency of gymnasium and Kendo hall floors
> · Shock-absorbing property of Judo hall floors
> · Hardness of aerobics floors
> · Hardness of outdoor sports surfaces (Japanese version only)
> · Hardness of floors in accidental collisions
> · Non-vibration property (Japanese version only)
> b. Performance items for floor slipperiness
> · Slipperiness of floors for footwear use
> · Slipperiness of floors for barefoot use
> · Slipperiness of stairway treads
> · Slipperiness of ramps (inclined floors)
> · Slipperiness for bicycles (Japanese version only)
> · Slipperiness for wheelchairs (Japanese version only)

To effectively implement frameworks such as performance specifications, performance design, and performance procurement, it is essential to utilize performance evaluation methods that satisfy the following three requirements:

· Methods capable of quantitatively representing the quality of floors from the perspective of building users.
· Methods that apply uniformly, irrespective of the material or construction technique used for the floor.
· Methods that evaluate the performance of the floor in its actual state of use—i.e., the performance of the installed floor—rather than just the material or component.

The first requirement aligns with the definition of performance as outlined in Section 1 of this chapter. The second requirement ensures a uniform comparison of floors constructed from different materials and by various methods, which is critical for a framework that offers building users freedom of choice. The third requirement acknowledges the complex relationship between floor performance and the properties of the materials or components used, which complicates predictions based solely on those properties.

In this recommendation, the selected performance evaluation methods are based on clear and valid academic evidence. Additionally, considerations such as the societal necessity of the performance, the practicality of the measurement methods, and the establishment of acceptable criteria corresponding to specific evaluation levels such as "neutral" or "slightly unsuitable" were taken into account. However, performances for which recommended values have already been provided by organizations such as the Architectural Institute of Japan are excluded from this document.

Among the selected performance characteristics, the resiliency of gymnasium and Kendo hall floors, the shock-absorbing property of Judo hall floors, the hardness of aerobics floors, and the hardness of outdoor sports surfaces correspond to the “resiliency, shock-absorbing property, and hardness during physical activities” category from “Performances from the perspective of daily safety and comfort of building users” as listed in Table 1.1.1. Similarly, the categories “slipperiness when wearing footwear, slipperiness for bare feet, slipperiness of stairway treads, slipperiness of ramps, slipperiness for bicycles, and slipperiness for wheelchairs” fall under the “slipperiness” category detailed under the same section in Table 1.1.1.

In this recommendation, the terminology used to describe performance attributes strictly adheres to that found in the supporting academic literature. This practice ensures the retention of the original nuances associated with these performance attributes, avoiding any subtle shifts in meaning. Thus, the same term, such as “hardness,” may relate to distinct performance values, such as the hardness experienced during daily motions versus hardness during accidental collisions. However, because both instances are categorized under “hardness” from the building users’ perspective, this recommendation employs the term “hardness” consistently across different contexts.

Moreover, within this document, “hardness” broadly encompasses several aspects: the hardness of floors during daily motions, the resiliency of gymnasium and Kendo hall floors, the shock-absorbing property of Judo hall floors, the hardness of aerobics floors, the hardness of outdoor sports surfaces, and the hardness during accidental collisions. Specifically, the resiliency evaluated for gymnasium and Kendo hall floors includes perceived hardness during movement, rebound characteristics, and vibration persistence. Additionally, the shock-absorbing property assessed for Judo hall floors is considered a component of perceived hardness during movement.

The Japanese version of this recommendation also outlines evaluation methods and recommended values for the hardness of outdoor sports surfaces, the non-vibration properties of floors, and the slipperiness of floors for bicycles and wheelchairs.

Chapter 2: Hardness

Section 1: Background, Scope, and Objectives

> This chapter aims to provide methods and recommended values for evaluating the hardness and non-vibration properties of floors.

Hardness and non-vibration properties are critical performance items; insufficient levels can render floors uncomfortable and difficult to work on, potentially leading to user fatigue and, in severe cases, serious injury accidents.

When evaluating floors' hardness and non-vibration properties, the following factors should be thoroughly considered:

Floor usage: This includes habitable rooms, sports surfaces, medical facilities, and facilities for older people and infants.

User motion: This encompasses everyday activities such as walking and turning, as well as more intense movements typical in sports settings

Type of footwear: This ranges from casual shoes and slippers to bare feet and specialized sports footwear.

Given these variables, different evaluation methods and indices of hardness are necessary for each type of floor usage and its associated factors. Therefore, this chapter will detail the performance items, including the hardness of floors during daily motions, the resiliency of gymnasium and Kendo hall floors, the shock-absorbing property of Judo hall floors, the hardness of aerobics floors, the hardness of outdoor sports surfaces, the hardness in situations involving accidental falls, and the non-vibration property of floors.

The evaluation methods discussed in this chapter utilize similar measuring apparatuses. These apparatuses function by dropping a weight of specified mass from a predetermined height onto designated rubber springs, measuring the dynamic behavior of the target floor under specific dynamic loading conditions.

The target evaluation methods include assessing the hardness of floors for daily motions, the resiliency of gymnasium and Kendo hall floors, the shock-absorbing property of Judo hall floors, the hardness of floors for aerobics, and the hardness of outdoor sports surfaces. The criteria for these apparatuses include the following:

· Mass and dropping height of the weight

· Size and shape of the dynamic loading area

· Maximum value of the dynamic load acting on a rigid floor

· Duration of dynamic load acting on a rigid floor: Measured from the beginning to the peak of the dynamic load

A rigid floor is defined as a floor that exhibits minimal deformation under a dynamic load, such as a concrete slab ground floor. If the dynamic load's maximum value or duration time falls outside the acceptable range, adjustments should be made to the rubber springs. While the fundamental components of these measuring apparatuses remain the same, the dropping weights, sets of rubber springs, and loading plates vary significantly among them.

Section 2: Hardness of Floors in Daily Motions

2.2.1 Purpose and Significance

> This section outlines methods and recommended values for evaluating the hardness of floors during everyday activities, with the aim of ensuring specified levels of hardness for comfort.

The hardness experienced by individuals during daily movements is a critical performance attribute that significantly influences everyday comfort. This section details a method and provides recommended values for assessing the hardness of floors in daily motions.

2.2.2 Scope of Application

> The evaluation method described in this section is applicable to all types of flooring used in daily life, without specific restrictions on the materials or construction techniques used.

The method addresses the evaluation of floor hardness as perceived during typical daily motions, including walking, standing, sitting directly on the floor, sitting in the seiza style, and lying down and rolling over. Perception of hardness varies with different body parts—the soles of the feet during walking and standing, the buttocks and palms while sitting on the floor, the knees and shins when sitting in seiza, and the back, shoulders, and hips during lying and rolling activities. The hardness perceived is influenced not only by the floor's surface materials but also by the deformation characteristics of the underlying base. The evaluation methods and recommended values are universally applicable regardless of the floor materials and construction methods.

2.2.3 Evaluation Perspective

> The primary focus of evaluating floor hardness is to ensure comfort in daily life.

Although several factors may affect this comfort, this section specifically introduces an evaluation method and recommended values based on the appropriateness of the hardness perceived during various motions.

2.2.4 Performance Evaluation Method

2.2.4.1 Performance Value Measurement Method

To measure and calculate the performance value of hardness, log (U_F / 9.8 − 8 D_R·D_R·T_R^{-1}) for floors in daily motions, a specific measuring apparatus is employed.

The apparatus, which has been validated in prior studies[1), 2)], is capable of dropping a weight from a predetermined height onto a set of rubber springs and measuring the dynamic behavior of the target floor under specific loading conditions. The following specifications are required for the apparatus:

· Mass of the weight: 40 kg

· Dropping height of the weight: 0 mm (the weight should drop from a position where the bottom surface of the weight just contacts the top surface of the rubber springs without compression)

· Size and shape of the dynamic loading area: A circle with a diameter of 70 mm

· Maximum value of the dynamic load: 706 ± 39 N (72 ± 4 kgf)

· Duration of the dynamic load: The time from the onset to the peak of the dynamic load is 0.15 ± 0.02 s

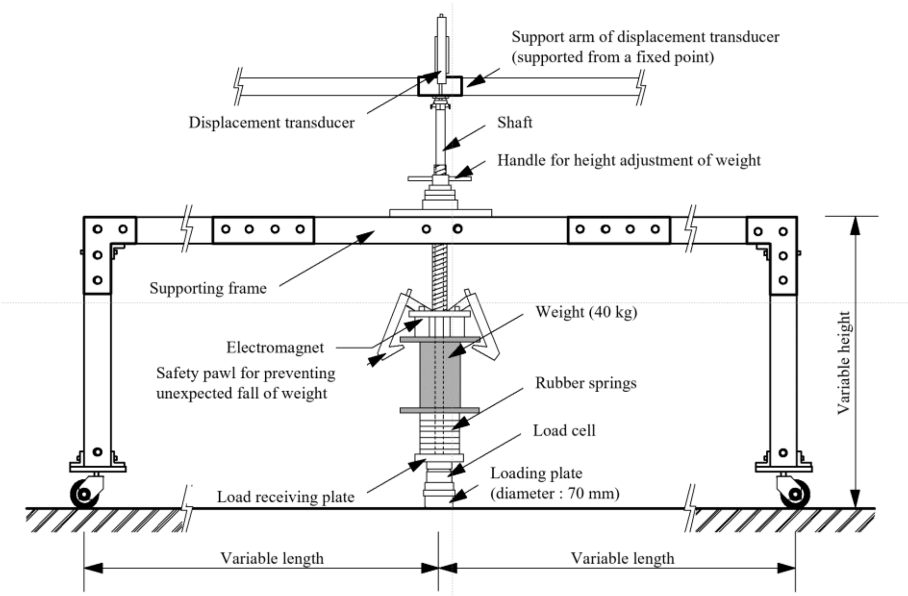

Fig. 2.2.1 Overview of the measuring apparatus for evaluating hardness of floors in daily motions (example)

Figure 2.2.1 provides an overview (example) of a measuring apparatus for evaluating the hardness. This apparatus suspends a weight at a predetermined height using an electromagnet, then releases the weight onto the rubber springs, thereby simulating the dynamic load experienced when a user walks on a floor. The dynamic load and floor deformation are measured using a load cell and a displacement transducer, which are mounted on the top of the guide pipe.

Figure 2.2.2 presents typical load-over-time and deformation-over-time curves as recorded by the apparatus, while Figure 2.2.3 illustrates the load–deformation curve from the initial to the maximum point of deformation. Key measurements include the following:

D_R (cm): Difference between the maximum deformation point and the highest rebound point of floor deformation

T_R (s): Time from the maximum deformation point to the highest rebound point

U_F (N·cm): Deformation energy from the initial point to the maximum point of floor deformation

The performance value for hardness evaluation is expressed by Equation (2.2.1), using U_F and $D_R \cdot D_R \cdot T_R^{-1}$, which indicates the intensity of the rebound and is composed of D_R and T_R.

$$\log\left(U_F / 9.8 - 8\, D_R \cdot D_R \cdot T_R^{-1}\right) \qquad \cdots \text{Equation (2.2.1)}$$

Here, a larger value of the log (U_F / 9.8 − 8$D_R \cdot D_R \cdot T_R^{-1}$) implies the target floor is softer, while a smaller value indicates the floor is harder.

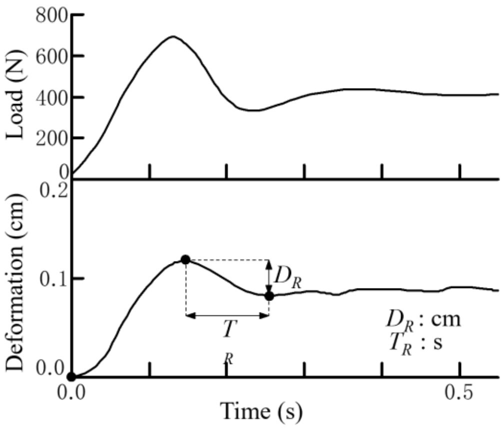

Fig. 2.2.2 Examples of load–time and deformation–time curves

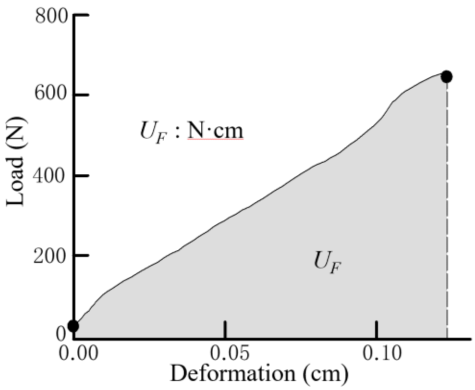

Fig. 2.2.3 Example of load–deformation curve

2.2.4.2 Evaluation Method

This method evaluates the hardness of a target floor by comparing the measured hardness performance value, log (U_F / 9.8 − 8D_R·D_R·T_R^{-1}), obtained in Section 2.2.4.1, with evaluation indices that describe the relationships between psychological evaluations and the log function.

These indices express the relationships between the psychological scales for hardness evaluation and log (U_F / 9.8 − 8D_R·D_R·T_R^{-1}). These psychological scales indicate the perceived suitability of hardness and are derived from sensory test methods.

Figure 2.2.4 illustrates an example of the evaluation procedures. In this figure, seven dotted lines with numbers (①–⑦) represent the evaluation levels on the scale. For instance, in the scenario of "a man walking on a floor," if the measurement result of log (U_F / 9.8 − 8D_R·D_R·T_R^{-1}) is 0.8, the hardness of the target floor should be evaluated as "⑤ A little suitable." Further details of the evaluation indices are described in Figure 2.2.5 in Section 2.2.5.

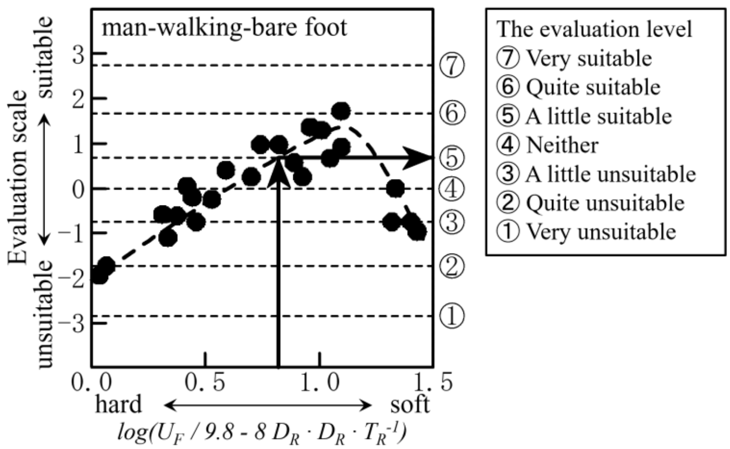

Fig. 2.2.4 Example of an evaluation index and evaluation procedures

2.2.5 Recommended Performance Values

Table 2.2.1 presents the recommended values of log (U_F / 9.8 − 8D_R·D_R·T_R^{-1}).

Table 2.2.1 Recommended values of log (U_F / 9.8 − 8D_R·D_R·T_R^{-1})
(X represents log (U_F / 9.8 − 8D_R·D_R·T_R^{-1}))

Types of floors	Types of motions	Recommended values
Floors where the hardness for daily motions should be considered	Walking, standing, etc. (bare feet, socks, etc.)	$0.4 \leq X \leq 1.3$
	Walking, standing, etc. (wearing slippers, shoes, etc.)	$0.2 \leq X \leq 1.3$
	Sitting, seiza, lying down and rolling over the floor, etc.	$0.6 \leq X$

Measurement positions of log (U_F / 9.8 − 8D_R·D_R·T_R^{-1}) are chosen from several representative spots likely to be used during actual floor usage.

Figure 2.2.5 shows evaluation indices of hardness for daily motions, showing that for activities such as walking and standing, both excessive hardness and softness lead to lower floor evaluations, whereas for sitting, seiza, and lying down and rolling over, a softer floor generally receives higher evaluations.

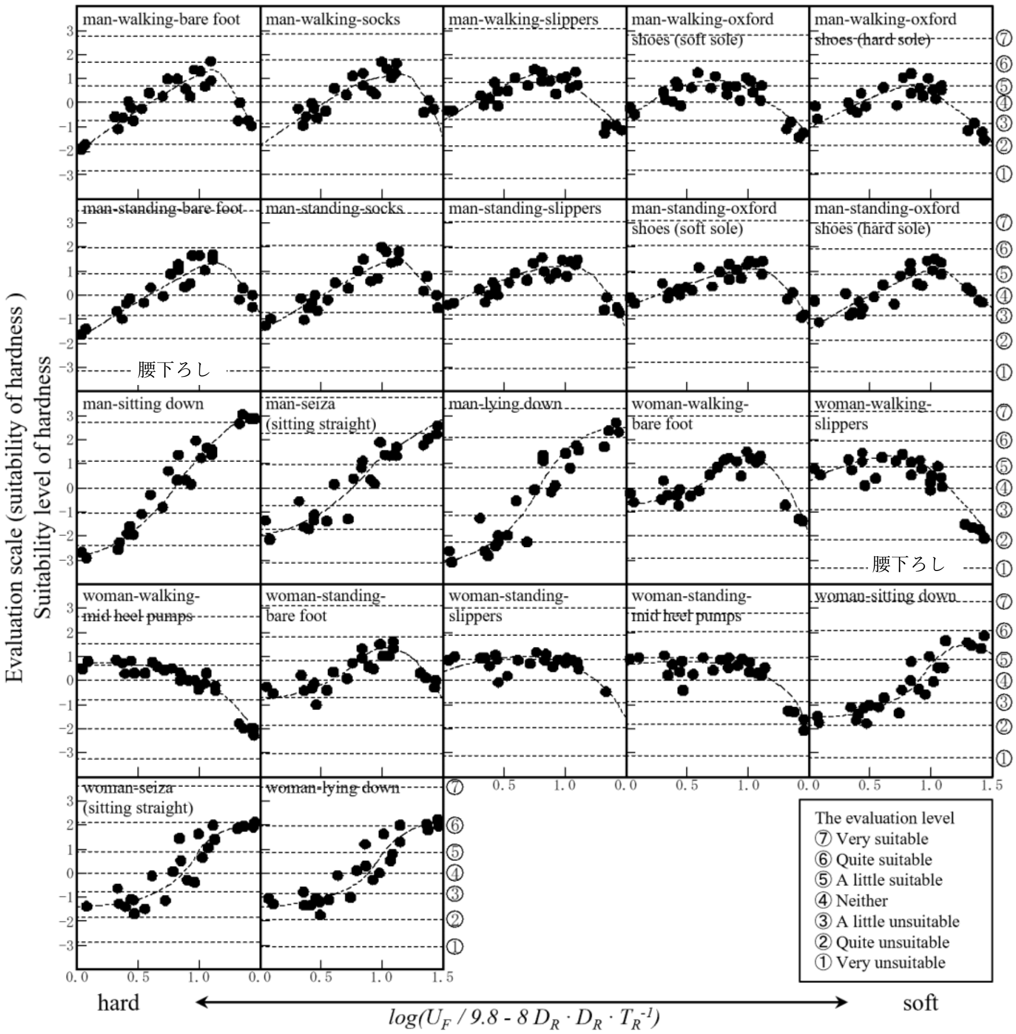

Fig. 2.2.5 Evaluation indices of hardness in daily motions[2)]

Figure 2.2.6 provides a summary derived from each diagram in Figure 2.2.5, showing the optimal values of log (U_F / 9.8 − 8D_R·D_R·T_R^{-1}) for walking and standing and the acceptable range when the evaluation level "③ Slightly unsuitable" is used as a provisional criterion.

The recommended values of log (U_F / 9.8 − 8D_R·D_R·T_R^{-1}) in Table 2.2.1 are based on the acceptable range corresponding to the evaluation level "③ Slightly unsuitable" as shown in Figure 2.2.6. This criterion was set lower than that for safety-related performance items to avoid overly restricting design freedom while considering comfort in daily motions.

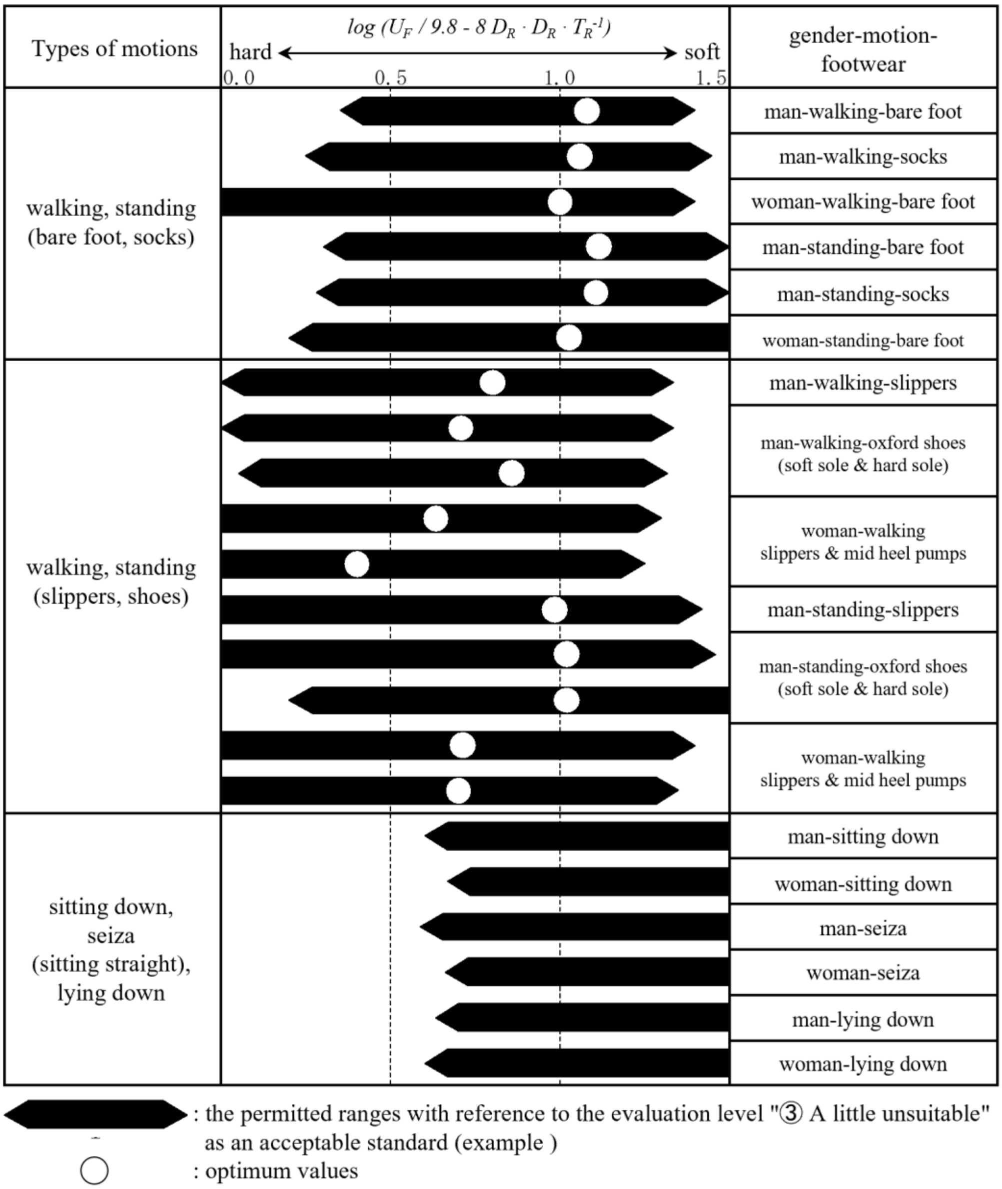

Fig. 2.2.6 Optimal values and allowable ranges of hardness in daily motions[2)] (example)

For framed floors consisting of struts, sleepers, joists, etc., log (U_F / 9.8 − 8$D_R \cdot D_R \cdot T_R^{-1}$) varies depending on the measurement position. Therefore, representative measurement positions should be determined based on the floor configuration.

References

1) Ono, H., Yokoyama, Y. and Ohno, R.: Study on hardness of building floors and its method of evaluation from the viewpoint of comfortableness, Part 1 The scaling of human senses on the hardness of building floors, vol. 358, pp. 1–9, 1985.12 (in Japanese)

2) Ono, H., Yokoyama, Y.: Study on Hardness of building floors and its method of evaluation from the viewpoint of comfortableness, Part 2 Design and development of a tester and presentation of the evaluation method of the hardness of building floors, Transactions of the Architectural Institute of Japan, vol. 373, pp. 1–8, 1987.03 (in Japanese)

Applied Standards

1) Japan Acoustic & Laminated Flooring Manufacturers Association: Standard test method for measuring properties of soundproof flooring materials

Section 3: Resiliency of Gymnasium and Kendo Hall Floors

2.3.1 Purpose and Significance

> This section outlines methods and recommended values for evaluating the resiliency of gymnasium and Kendo hall floors to ensure they meet a specified level of resiliency suitable for various sports and Kendo activities.

The resiliency of these floors is a critical performance item that includes hardness, intensity of rebound, and duration of vibration damping[1)–5)]. Insufficient resiliency can lead to increased strain on users' legs and lower backs and increase the risk of injuries. Therefore, determining the appropriate resiliency values is essential for ensuring the safety of sports activities.

2.3.2 Scope of Application

> The evaluation method for resiliency detailed in this section is applicable to both gymnasium and Kendo hall floors, with no specific restrictions regarding the materials or construction techniques used.

Given that gymnasium floors often host a variety of sports such as badminton, volleyball, and basketball, each requiring different optimal resiliency levels, and that these floors are generally used for multiple sports, the need for versatile performance criteria is evident. Additionally, because gymnasium floors are frequently used for Kendo practice—alongside dedicated Kendo halls—this evaluation encompasses both settings. The recommended values and evaluation methods are universally applicable, irrespective of floor composition or construction methods.

2.3.3 Evaluation Perspective

> The primary focus of this resiliency evaluation is safety.

Sports activities in gymnasiums typically involve intense physical exertion, necessitating floors designed to prevent injuries. While a harder floor may enhance performance by facilitating quicker movements, such as jumps or dashes, it can also contribute to quicker exhaustion and increase the risk of injuries from intense landings, which must be absorbed by the athletes' bodies, legs, and lower backs. The potential for fatigue and injury highlights the critical need for suitable flooring, particularly given the significant variability in skills and physical strength between trained athletes and recreational users. This section, therefore, emphasizes recommended resiliency values considering the safety needs of general users, who make up the majority of participants in these environments.

2.3.4 Performance Evaluation Method

2.3.4.1 Performance Value Measurement Method

Initially, three performance values are measured and calculated for the target floor using a specialized apparatus for evaluating the resiliency of gymnasium and Kendo hall floors:

· Hardness value: U_F / 9.8 − 1.1 $D_R \cdot D_R \cdot T_R^{-1}$

· Intensity of rebound: $D_R \cdot D_R \cdot T_R^{-1}$

· Duration of vibration damping: T_{VD}

Subsequently, a comprehensive performance value Y is calculated using the hardness value U_F / 9.8 − 1.1 $D_R \cdot D_R \cdot T_R^{-1}$ and the intensity of rebound value $D_R \cdot D_R \cdot T_R^{-1}$.

To assess the resiliency of gymnasium and Kendo hall floors accurately, it is essential to utilize a proven measurement apparatus[1)–5)]. This apparatus is designed to drop a weight of a specific mass from a predetermined height onto a set of rubber springs, thus measuring the dynamic behavior of the floor under specific dynamic loading conditions. The apparatus must meet the following specifications:

· Mass of the weight: 5 kg

· Dropping height of the weight: 800 mm

· Size and shape of the dynamic loading area: A circle with a diameter of 50 mm

· Maximum value of the dynamic load acting on a rigid floor: 2107 ± 49 N (215 ± 5 kgf)

· Duration of the dynamic load: The time from the onset to the peak of the dynamic load is 0.03 ± 0.005 s

· Distance between wheels: 600 mm or more

Figure 2.3.1 provides an overview of the measurement apparatus used for evaluating the resiliency of gymnasium and Kendo hall floors. This apparatus employs an electromagnet to suspend a weight at a specified height, which is then dropped onto rubber springs, simulating the dynamic load experienced when an athlete lands after jumping. The dynamic load acting on the floor and the dynamic deformation of the floor are measured using a load cell and a displacement transducer mounted atop the guide pipe.

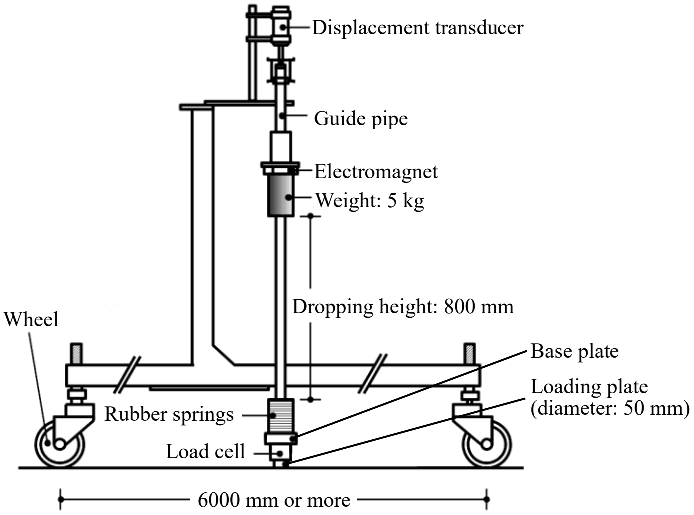

Fig. 2.3.1 Overview of the measurement apparatus for evaluating resiliency of gymnasium and Kendo hall floors (example)

Figure 2.3.2 presents typical load-over-time and deformation-over-time curves as measured by the apparatus. The load–deformation curve, depicted from the initial to the maximum deformation point, is illustrated in Figure 2.3.3. Each measured value is defined as follows:

D_R (cm): Difference between the maximum point and the highest rebound point of floor deformation

T_R (s): Time from the maximum point to the highest rebound point of floor deformation

U_F (N·cm): Deformation energy from the initial point to the maximum point of floor deformation

T_{VD} (s): Duration until the total amplitude of floor vibration dampens to 0.02 cm

The performance value for hardness, which influences resiliency, is expressed by Equation (2.3.1) as follows, using U_F and $D_R{\cdot}D_R{\cdot}T_R^{-1}$, which denotes the intensity of rebound and is composed of D_R and T_R.

$$U_F / 9.8 - 1.1D_R{\cdot}D_R{\cdot}T_R^{-1} \qquad \cdots\text{Equation (2.3.1)}$$

A larger value of U_F / 9.8 − $1.1D_R{\cdot}D_R{\cdot}T_R^{-1}$ indicates that the target floor is softer, while a smaller value indicates that the floor is harder. The comprehensive performance value Y is expressed by Equation (2.3.2) using the performance value for hardness $U_F / 9.8 - 1.1D_R{\cdot}D_R{\cdot}T_R^{-1}$ and another performance value $D_R{\cdot}D_R{\cdot}T_R^{-1}$.

$$Y = -0.0016(U_F / 9.8 - 1.1D_R{\cdot}D_R{\cdot}T_R^{-1} - 17.25)^2 - 0.0028(D_R{\cdot}D_R{\cdot}T_R^{-1} - 24.28)^2 + 1.378 \qquad \cdots\text{Equation (2.3.2)}$$

For framed floors consisting of struts, sleepers, joists, etc., performance values may vary depending on the measurement position. Therefore, representative measurement positions should be determined based on the floor configuration. In this context, if the measurement positions for framed floors are set according to JIS A

6519, which utilizes the same measurement method as this index, there will be four positions labeled A to D, as shown in Figure 2.3.4.

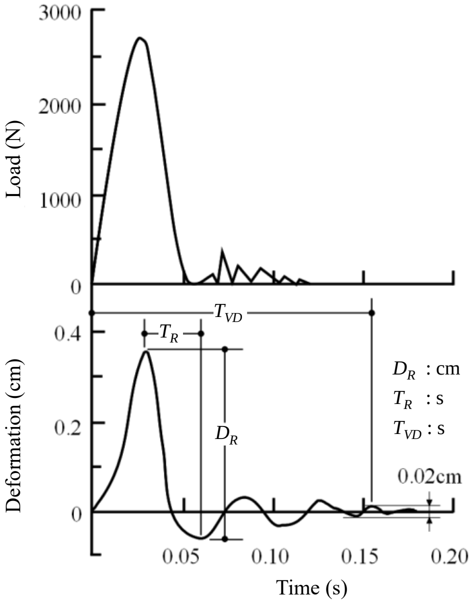

Fig. 2.3.2 Typical curves depicting the load over time and the corresponding deformation

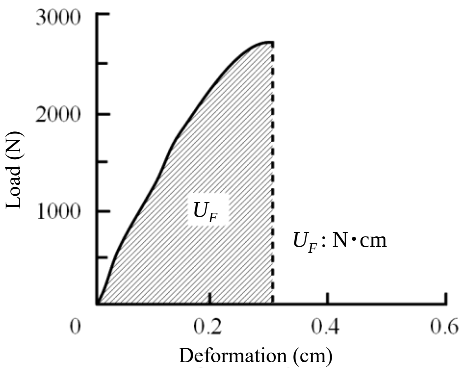

Fig. 2.3.3 Typical load–deformation curve

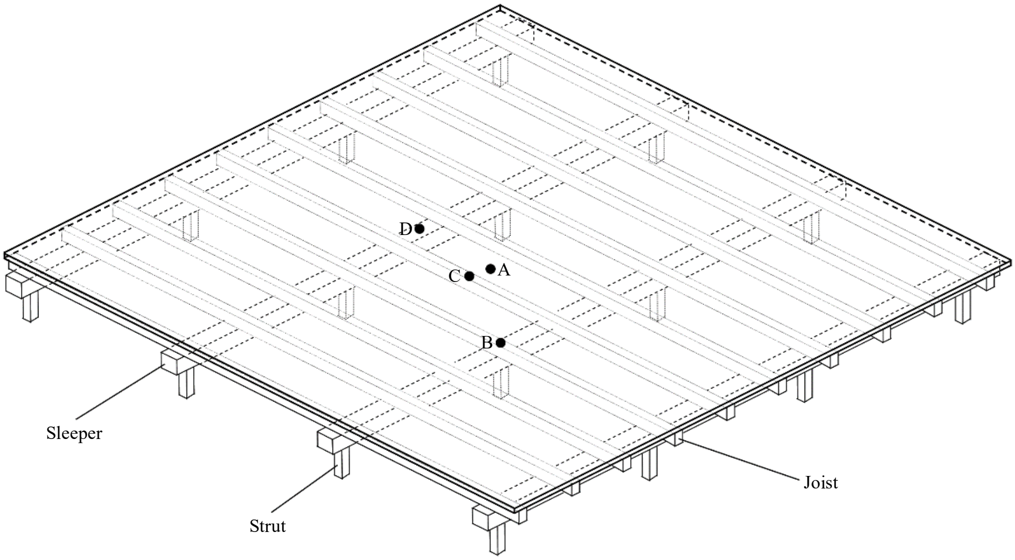

Fig. 2.3.4 Measurement positions per JIS A 6519

2.3.4.2 Evaluation Method

> The resiliency of the target floor is evaluated using the measurements obtained in Section 2.3.4.1 for U_F / 9.8 − 1.1$D_R \cdot D_R \cdot T_R^{-1}$, T_{VD}, and Y.

The comprehensive performance value Y is determined by Equation (2.3.2) using the performance values of hardness U_F / 9.8 − 1.1$D_R \cdot D_R \cdot T_R^{-1}$ and the intensity of rebound $D_R \cdot D_R \cdot T_R^{-1}$. The key evaluation points are as follows:

· Identifying the optimum value (17.25) for the performance value of hardness U_F / 9.8 − 1.1$D_R \cdot D_R \cdot T_R^{-1}$.

· Identifying the optimum value (24.28) for the performance value of the intensity of rebound $D_R \cdot D_R \cdot T_R^{-1}$.

· Preferring a higher comprehensive performance value Y, which combines the values for hardness and intensity of rebound. The maximum value (1.378) of Y occurs when both performance values are optimal.

Additionally, because prolonged vibration can disrupt subsequent motions or disturb nearby individuals, a shorter duration of vibration damping, indicated by the performance value T_{VD}, is preferable.

2.3.5 Recommended Performance Values

Table 2.3.1 presents the recommended values for U_F / 9.8 − 1.1 $D_R \cdot D_R \cdot T_R^{-1}$, T_{VD}, and Y.

Table 2.3.1 Recommended values of U_F / 9.8 − 1.1 $D_R \cdot D_R \cdot T_R^{-1}$, T_{VD}, and Y

Types of floors	Types of sports	Recommended values		
		U_F / 9.8 − 1.1 $D_R \cdot D_R \cdot T_R^{-1}$	T_{VD}	Y
Gymnasium floor	Badminton, Volleyball, Basketball, etc.	15–40	0.45 s or less	Maximum: 0.0–1.378, Minimum: −0.2–1.378
Kendo hall floor	Kendo		0.60 s or less	

In 1985, JIS A 6519 was published concerning the resiliency of gymnasium and Kendo hall floors. While the primary focus of this standard is the steel furring components for gymnasium floors, the research studies[1)–5)] that form the basis of this standard are applicable to all gymnasium and Kendo hall floors, regardless of construction and material differences. The standard values specified in JIS A 6519 have been effectively used for approximately 30 years. Therefore, the recommended values in this section align with this JIS.

Per this standard, each performance value measured at the four positions indicated in Figure 2.3.4 must meet the following criteria:

· The performance value U_F / 9.8 − 1.1$D_R \cdot D_R \cdot T_R^{-1}$ at all four positions must fall within the range of 15 to 40.

· The performance value T_{VD} at all four positions must be 0.45 s or less for gymnasium floors and 0.60 s or less for Kendo hall floors.

· The performance value Y at all four positions must be −0.2 or higher and at least 0.0 or higher at any one position.

References

1) Ono, H.: A study of resiliency of gymnasium floor (part 1), Transactions of the Architectural Institute of Japan, vol. 181, pp. 7–14, 1971.3 (in Japanese)

2) Ono, H. and Yoshioka, M.: A study of resiliency of gymnasium floor (part 2), Transactions of the Architectural Institute of Japan, vol. 187, pp. 27–34, 1971.9 (in Japanese)

3) Ono, H. and Yoshioka, M.: A study of resiliency of gymnasium floor (part 3), Transactions of the Architectural Institute of Japan, vol. 188, pp. 1–10, 1971.10 (in Japanese)

4) Ono, H. and Yoshioka, M.: A study of resiliency of gymnasium floor (part 4), Transactions of the Architectural Institute of Japan, vol. 226, pp. 9–19, 1974.12 (in Japanese)

5) Ono, H. and Yoshioka, M.: A study of resiliency of gymnasium floor (part 5), Transactions of the Architectural Institute of Japan, vol. 227, pp. 1–11, 1975.1 (in Japanese)

Applied Standards

1) JIS A 6519: 2018 (Steel furring components for gymnasium floors)

Section 4: Shock-Absorbing Property of Judo Hall Floors

2.4.1 Purpose and Significance

> This section outlines methods and recommended values for evaluating the shock-absorbing properties of Judo hall floors, with the aim of ensuring these floors meet specified levels appropriate for Judo activities.

The shock-absorbing property of Judo hall floors is critical as it mitigates the impact between a Judo athlete's body and the floor[1), 2)]. Inadequate shock absorption raises concerns about injuries from impacts experienced by athletes during falls in Judo. Therefore, it is crucial to maintain an optimal level of shock absorption to ensure safety during Judo practice.

2.4.2 Scope of Application

> The evaluation method for shock-absorbing properties outlined in this section is applicable to floors in Judo halls. There are no specific restrictions regarding the materials or construction methods of the target floors.

The scope extends not only to floors specifically designed for Judo halls but also to any flooring used for Judo activities. The evaluation method and recommended values are designed to be applicable across various floor materials and construction techniques.

2.4.3 Evaluation Perspective

> The primary focus of evaluating shock-absorbing properties is safety.

Owing to the nature of Judo, where collisions between athletes and the floor are frequent, it is essential to have a floor that promotes safe practices to prevent injuries. For example, a considerably hard floor increases the risk of injury when an athlete is thrown, while an overly soft floor can hinder the practice of Judo techniques.

There is often a considerable difference in skill and physical abilities between highly skilled athletes who have undergone specialized training and general athletes participating in school classes or less competitive environments. As such, the floor that might be optimal for highly trained athletes to perfect their techniques may not be the best choice for ensuring safety and minimizing injury risks for less experienced athletes.

This section provides recommended values for the shock-absorbing properties of floors that are suited for general athletes, prioritizing safety considerations.

2.4.4 Performance Evaluation Method

2.4.4.1 Performance Value Measurement Method

> Using a specialized measuring apparatus, we calculate the deformation energy, U_J, of Judo hall floors until they reach maximum deformation.

The evaluation is crucial for assessing the shock-absorbing properties of the floors, ensuring they are appropriate for Judo activities. This section utilizes a proven measurement apparatus for evaluating the shock-absorbing properties of Judo hall floors[1), 2)]. This apparatus is designed to drop a weight from a predetermined height onto a set of rubber springs, measuring the dynamic behavior of the floor under specific loading conditions. The specifications for the apparatus are as follows:

· Mass of the weight: 10.5 kg

· Dropping height of the weight: 1,140 mm

· Size and shape of the dynamic loading area: A circle with a diameter of 200 mm

· Maximum value of the dynamic load acting on a rigid floor: 17,934 ± 588 N (1,830 ± 60 kgf)

· Duration of the dynamic load: The time from the onset to the peak of the dynamic load is 0.015 ± 0.003 s

· Distance between wheels: 600 mm or more

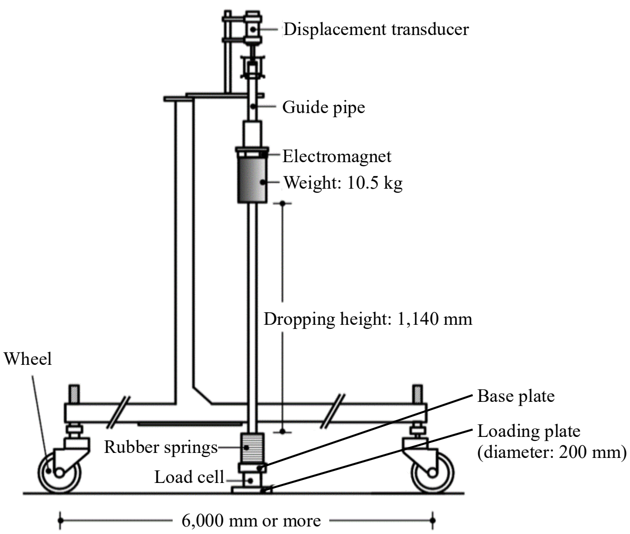

Fig. 2.4.1 Overview of the measurement apparatus for evaluating shock-absorbing property of Judo hall floors (example)

Figure 2.4.1 provides an overview of the measurement apparatus used for evaluating the shock-absorbing property of Judo hall floors. This apparatus suspends a weight at a specified height using an electromagnet, then releases it onto rubber springs, simulating the dynamic load experienced when an athlete is thrown onto the floor. The dynamic load and floor deformation are recorded using a load cell and a displacement transducer mounted on top of the guide pipe.

Figure 2.4.2 presents typical load-over-time and deformation-over-time curves as recorded by the apparatus. The load–deformation curve, from the initial point to the maximum deformation point, is illustrated in Figure 2.4.3. The measured value U_J, which represents the deformation energy of the floor until maximum deformation (N·cm), is indicated by the area enclosed by the shaded region in Figure 2.4.3.

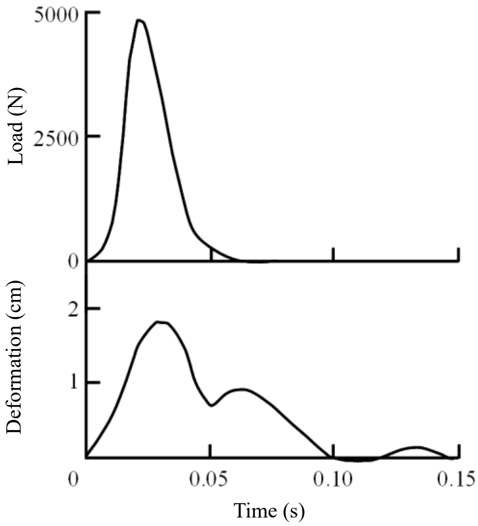

Fig. 2.4.2 Typical curves depicting the load over time and the corresponding deformation

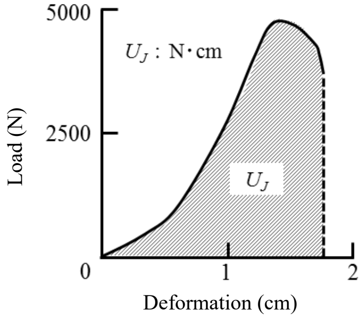

Fig. 2.4.3 Typical load–deformation curve

2.4.4.2 Evaluation Method

> The shock-absorbing property of the target floor is assessed using the U_J measurement obtained in Section 2.4.4.1.

A higher U_J value indicates that the floor has a significant shock-absorbing capacity and is relatively soft. A lower U_J value suggests that the floor has minimal shock-absorbing properties and is comparatively hard.

2.4.5 Recommended Performance Values

Table 2.4.1 presents the recommended values of U_J.

Table 2.4.1 Recommended values of U_J
(X represents U_J in the table)

Types of floors	Types of sports	Recommended values
Judo hall floor	Judo	$5{,}635 \leq X \leq 7{,}350$ (N·cm) ($575 \leq X \leq 750$ (kgf·cm))

Measurement positions for evaluating the shock-absorbing property are chosen from several representative spots within the area where Judo activities typically occur, ensuring that the measurements reflect real-use scenarios.

The Architectural Institute of Japan has established the recommended values, focusing on safety for general athletes, as discussed in Section 2.4.3. These values are also standard for beginners according to JIS A 6519: 2018 and have been used effectively without issues.

For floors specifically designed for skilled athletes, JIS A 6519 outlines the shock-absorbing property values as follows:

· For skilled athletes, U_J should range from 3,920 N·cm to 7,350 N·cm (from 400 kgf·cm to 750 kgf·cm)

Given the variety in construction, such as floors made up of struts, sleepers, joists, and other components, performance values can differ based on where they are measured. It is necessary to select several representative measurement positions to accommodate differences in floor configuration. According to the methods specified by JIS A 6519, designated measurement positions for framed floors are set at two points labeled A and B, as depicted in Figure 2.4.4.

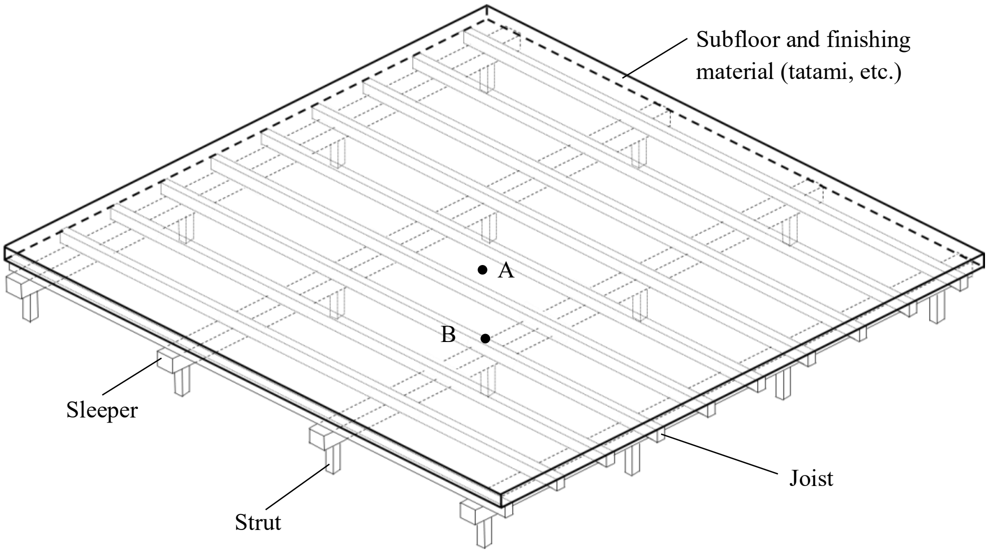

Fig. 2.4.4 Measurement positions per JIS A 6519

References

1) Ono, H., Shibasaki, H., Kawamura, S., and Yoshioka, M.: Study on the shock-absorbing effect of judo hall floors (part 1), Transactions of the Architectural Institute of Japan, vol. 293, pp. 21–28, 1980.7 (in Japanese)

2) Ono, H., Shibasaki, H., Kawamura, S. and Yoshioka, M.: Study on the shock-absorbing effect of judo hall floors (part 2), Transactions of the Architectural Institute of Japan, vol. 304, pp. 11–19, 1981.6 (in Japanese)

Applied Standards

1) JIS A 6519: 2018 (Steel furring components for gymnasium floors)

Section 5: Hardness of Aerobics Floors

2.5.1 Purpose and Significance

> This section outlines methods and recommended values for evaluating the hardness of aerobics floors, which are crucial when users engage in aerobic exercises.

The hardness of aerobics floors, typically felt by athletes performing aerobics in sports gyms and similar venues, significantly affects performance and safety. Inappropriately hard or soft floors can increase stress on the feet, legs, and lower back, potentially leading to injuries. Thus, ensuring the appropriate hardness is vital for safe aerobics activities.

2.5.2 Scope of Application

> The evaluation method described herein applies specifically to floors used for aerobics. There are no restrictions concerning the materials or construction methods of these floors.

This section covers the evaluation of hardness for all floors used in aerobics. The evaluation method and the recommended values are designed to be universally applicable, regardless of the floor materials and construction techniques.

2.5.3 Evaluation Perspective

> The primary focus of hardness evaluation is safety, considering that aerobic exercises typically involve long periods of continuous activity.

It is necessary to ensure that the floors are suitably hard to minimize the risk of injury over prolonged exercise sessions.

2.5.4 Performance Evaluation Method

2.5.4.1 Performance Value Measurement Method

> Using a specialized measuring apparatus for the hardness of aerobics floors, we measure and calculate the performance value of hardness, represented as $U_F / 9.8 - 1.1D_R \cdot D_R \cdot T_R^{-1}$, for the target floor.

To accurately assess the hardness of aerobics floors, it is essential to use a measurement apparatus that is appropriate for this specific evaluation. This section utilizes a proven apparatus for measuring the hardness of aerobics floors[1)]. This apparatus operates by dropping a weight of a specified mass from a set height onto rubber springs, thereby measuring the dynamic behavior of the floor under specified loading conditions. The apparatus must meet the following specifications:

· Mass of the weight: 15 kg

· Dropping height of the weight: 120 mm

· Size and shape of the dynamic loading area: A circle with a diameter of 70 mm

· Maximum value of the dynamic load acting on a rigid floor: 1274 ± 29 N（130 ± 3 kgf）

· Duration of the dynamic load: The time from the onset to the peak of the dynamic load is 0.05 ± 0.008 s

· Distance between wheels: 600 mm or more

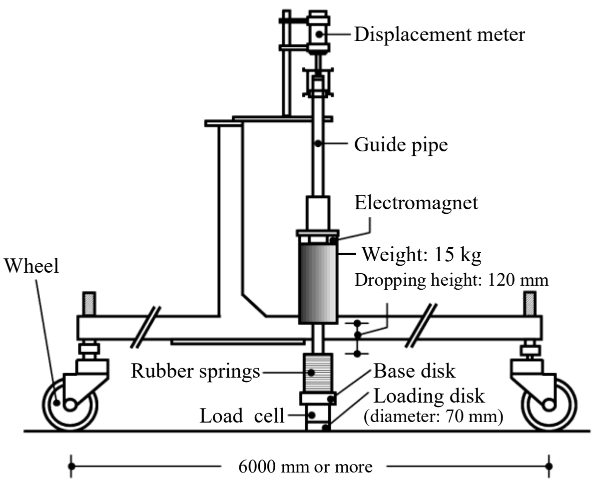

Fig. 2.5.1 Overview of the measurement apparatus for evaluating hardness of aerobics floors (example)

Figure 2.5.1 provides an overview of the measurement apparatus used for assessing the hardness of aerobics floors. This apparatus suspends a weight at a predetermined height using an electromagnet and then releases the weight onto a set of rubber springs. This setup simulates the dynamic load experienced when an athlete lands after jumping on a floor equipped with a load plate. Additionally, the apparatus measures the dynamic load acting on the floor and the dynamic deformation of the floor using a load cell and a displacement transducer mounted atop the guide pipe.

Figure 2.5.2 presents typical load-over-time and deformation-over-time curves as measured by the apparatus. The load–deformation curve, from the initial point to the maximum deformation point, is shown in Figure 2.5.3. Each measured value is defined as follows:

D_R (cm): Difference between the maximum point and the highest rebound point of floor deformation

T_R (s): Time from the maximum point to the highest rebound point of floor deformation

U_F (N･cm): Deformation energy from the initial point to the maximum point of floor deformation

The performance value for hardness evaluation is expressed by Equation (2.5.1), using U_F and $D_R{\cdot}D_R{\cdot}T_R^{-1}$, which indicates the intensity of rebound and is composed of D_R and T_R.

$$U_F \,/\, 9.8 - 1.1 D_R{\cdot}D_R{\cdot}T_R^{-1} \qquad \cdots \text{Equation (2.5.1)}$$

In this equation, a larger value of $U_F / 9.8 - 1.1D_R{\cdot}D_R{\cdot}T_R^{-1}$ indicates that the target floor is softer, whereas a smaller value suggests the floor is harder.

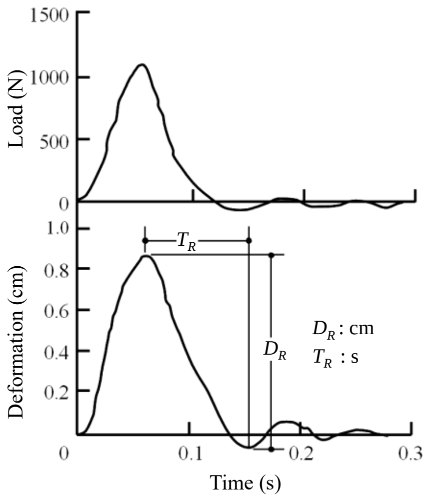

Fig. 2.5.2 Typical curves of the load and deformation over time

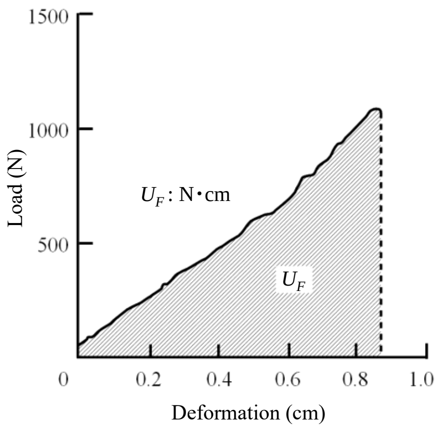

Fig. 2.5.3 A typical load–deformation curve

2.5.4.2 Evaluation Method

This method evaluates the hardness of a target floor by comparing the measured hardness performance value, U_F / 9.8 − 1.1D_R·D_R·T_R^{-1}, with the evaluation indices that correlate psychological evaluations to this value.

These indices express the relationships between psychological scales for hardness evaluation and U_F / 9.8 − 1.1D_R·D_R·T_R^{-1}, indicating psychological suitability for hardness based on sensory test methods.

Figure 2.5.4 illustrates an example of the evaluation method. In this figure, five dotted lines numbered ①–⑤ represent different levels on the scale. For instance, in a scenario of "aerobic dancing on a floor," if the result of U_F / 9.8 − 1.1D_R·D_R·T_R^{-1} calculated by Equation (2.5.1) is 33, the hardness of the target floor should be evaluated as "③ Neither likely nor unlikely." Details of the evaluation indices are further explained in Figure 2.5.5 in Section 2.5.5.

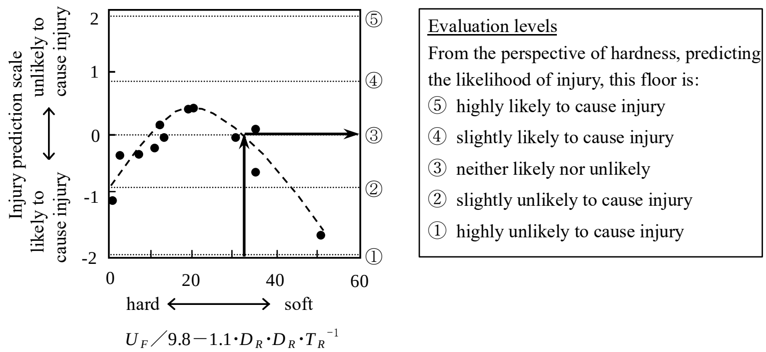

Fig. 2.5.4 Example of evaluation index and the outline of the evaluation method

2.5.5 Recommended Performance Values

Table 2.5.1 presents the recommended value of U_F / 9.8 − 1.1D_R·D_R·T_R^{-1}.

Table 2.5.1 Recommended values of U_F / 9.8 − 1.1D_R·D_R·T_R^{-1}
(X represents U_F / 9.8 − 1.1D_R·D_R·T_R^{-1} in the table)

Types of floors	Types of motion	Recommended values
Floors for aerobics	Aerobic exercises	$10 \leq X \leq 30$

Measurement points of U_F / 9.8 − 1.1D_R·D_R·T_R^{-1} should be set at representative points within the area used for aerobic exercises.

Figure 2.5.5 shows two types of evaluation indices of hardness, specifically from the perspectives of fatigue and injuries. This figure reveals that there are optimal values of hardness for aerobics, and the evaluation level of a floor will decrease if the hardness is excessively hard or soft. Table 2.5.1 lists the recommended values for U_F / 9.8 − 1.1D_R·D_R·T_R^{-1} derived from the acceptable range shown in Figure 2.5.5, corresponding to the evaluation level "③ Neither likely nor unlikely" and higher levels.

For framed floors consisting of struts, sleepers, joists, etc., U_F / 9.8 − 1.1D_R·D_R·T_R^{-1} may vary depending on the measurement position. It is essential to select representative measurement positions based on the floor configuration.

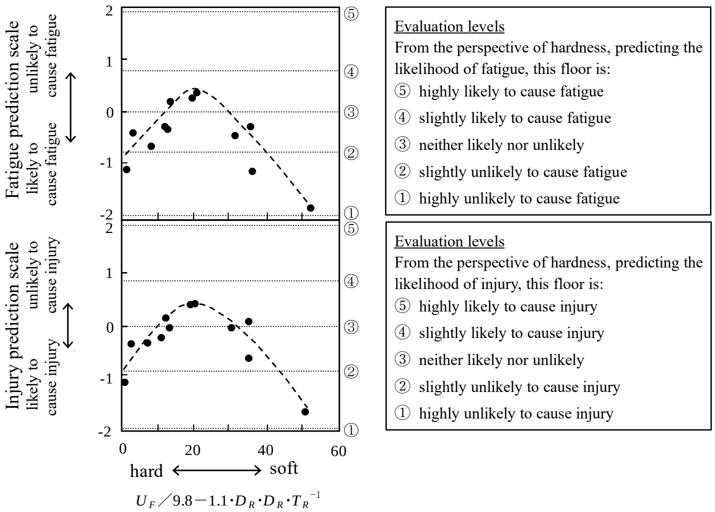

Fig. 2.5.5 Evaluation indices of the hardness of aerobics floors[1)]

[Reference Materials]

Evaluation Indices for Wearing Non-Cushioning Footwear

The evaluation of floor hardness is influenced by the cushioning (shock-absorbing) effect of the footwear sole. Accordingly, evaluation indices have been established for both non-cushioning footwear and aerobics shoes with cushioning, as shown in Figure 2.5.5. Figure 2.5.6 presents the evaluation indices for non-cushioned footwear. As shown in Figure 2.5.5, the evaluation peaks when the hardness performance value, U_F / 9.8 − 1.1D_R·D_R·T_R^{-1}, irrespective of the footwear type. This suggests that an optimal floor hardness value hovers around 20, regardless of the evaluation perspective. However, as denoted by the dotted line in the figure, the ease of fatigue does not surpass the evaluation level "③ Neither likely nor unlikely" even when the performance value reaches 20. This observation underscores the necessity of considering that appropriate floor hardness may still lead to increased fatigue levels, depending on the type of footwear worn.

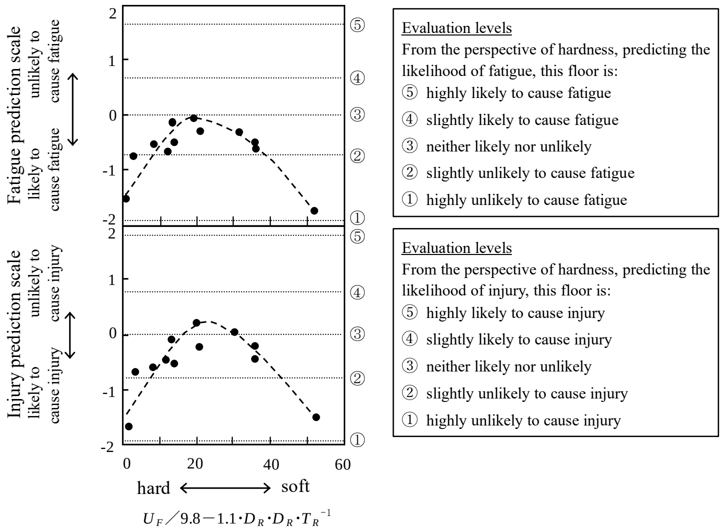

Fig. 2.5.6 Evaluation indices of the hardness of aerobics floors (when wearing shoes with hard soles)[1)]

References

1) Ono, H., Mikami, T., Iwasaki, Y., Yokoyama, Y.: Study on the evaluating method of hardness and slipperiness of aerobic dancing floors, Journal of Structural and Construction Engineering, Transactions of the Architectural Institute of Japan, vol. 385, pp. 1–7, 1988.3 (in Japanese)

Section 7: Hardness of Floors in Accidental Collisions

2.7.1 Purpose and Significance

> This section presents methods and recommended values for evaluating the hardness of floors in scenarios where users might accidentally fall and collide with the floor, aiming to ensure a specified level of hardness.

Accidental falls, especially those resulting in head impacts, can significantly influence the occurrence and severity of injuries. It is thus crucial to carefully assess the hardness of floors, particularly in environments frequented by individuals with lower impact resistance, such as young children and older adults. Priority should be given to evaluating floors in facilities such as kindergartens, nursery schools, hospitals, and senior care facilities. Additionally, in settings prone to frequent collisions, such as Judo halls, the hardness of the floor requires meticulous consideration to ensure appropriate safety measures are implemented.

2.7.2 Scope of Application

> This section is applicable to the evaluation of floor hardness in the context of accidental collisions, covering both indoor and outdoor floors of buildings, including sports surfaces. There are no specific restrictions regarding the materials or construction methods of the target floors.

The evaluation method described here is designed to be universally applicable, accommodating any floor material or construction technique.

2.7.3 Evaluation Perspective

> The focus of this evaluation is the safety of individuals, particularly the protection of the head during accidental collisions.

Here, safety refers to minimizing the risk of injury when the body, especially the head, impacts the floor. Hardness measurements and evaluations are conducted using a specialized apparatus designed to simulate head impacts. The recommended hardness values are set to ensure safety on floors categorized as “requiring consideration for accidental collisions” and “designed for anticipated accidental collisions” while ensuring that these values do not compromise other critical performance aspects beyond safety.

2.7.4 Performance Evaluation Method

2.7.4.1 Performance Value Measurement Method

This method involves using a specialized measuring apparatus to calculate the performance value of hardness, G_S, of the target floor in accidental collision scenarios.

It is imperative to use a measurement apparatus that is suitable for accurately evaluating floor hardness. This section utilizes a specific apparatus designed for assessing hardness in accidental collisions[1)]. The apparatus operates by dropping a head model of a predetermined mass from a set height onto the target floor, simulating the impact experienced when a human head collides with the floor. For this measurement, a rubber plate that mimics the scalp is placed on the floor. Equipped with an accelerometer, the head model records data during impact. The hardness of the floor during collisions is quantified by the maximum acceleration, denoted as G_S (in G unit). The specifications for this apparatus are as follows:

· Mass of the head model: 3.75 ± 0.1 kg
· Drop height of the head model: 200 mm
· Thickness of the rubber plate: 6 – 8 mm
· Hardness of the rubber plate: Shore A hardness 40 ± 3
· Maximum acceleration, G_S, on a rigid floor: 155 ± 5 G
· Duration of the acceleration on a rigid floor: 0.002 – 0.003 s

Figure 2.7.1 provides an overview of the measurement apparatus used for evaluating the hardness of floors in accidental collisions.

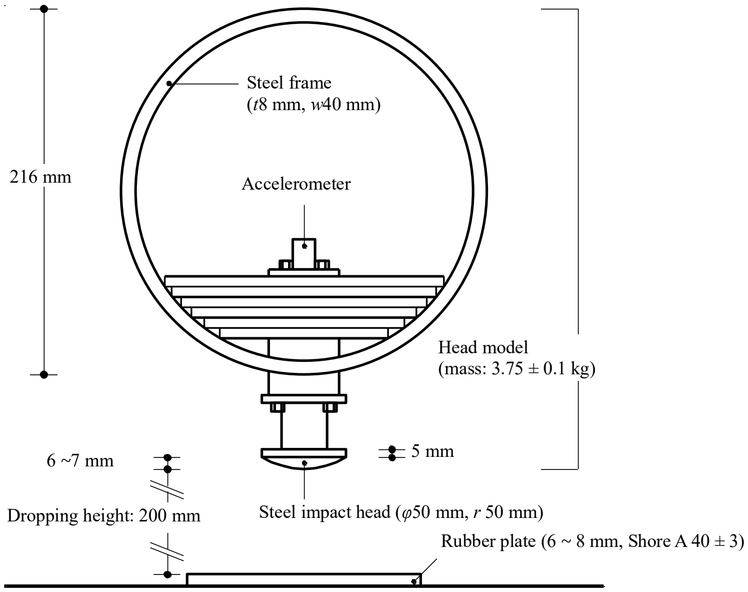

Fig. 2.7.1 Overview of the measurement apparatus for evaluating the hardness of floors in accidental collisions (example)

2.7.4.2 Evaluation Method

The hardness of the target floor is evaluated based on the performance value G_S, as measured in Section 2.7.4.1.

A lower G_S value indicates that the floor is softer and potentially safer.

2.7.5 Recommended Performance Values

Table 2.7.1 presents the recommended values of G_S.

Table 2.7.1 Recommended Values of G_S
(X represents G_S in the table)

Types of floors	Recommendation values	Remarks (example of floors)
Floors where safety in collision should be considered	$X \leq 100$ (G)	Floors of kindergartens, nursery schools, schools, hospitals, senior living facilities, sports facilities, etc.
Floors where safety in collision must be considered	$X \leq 65$ (G)	Judo hall floors, etc.

The measurement position for G_S is designated as the hardest point within the area where accidental collisions are likely to occur during actual use.

As per JIS A6519:2018, this standard G_S value is recommended to be adopted as the guideline in this recommendation. However, considering that lower G_S values are indicative of safer floors, efforts should be directed towards achieving the lowest possible value, taking into account the floor's usage, user demographics, and its relationship with other performance metrics.

References

1) Ono, H., Mikami, T., Watanabe, H.: Research study on hardness of school gymnasium floors from the viewpoint of safety, Transactions of the Architectural Institute of Japan, vol. 321, pp. 9–16, 1982.11 (in Japanese)

Applied Standards

1) JIS A 6519: 2018 (Steel furring components for gymnasium floors)

Chapter 3: Slipperiness

Section 1: Background, Scope, and Objectives

> This chapter aims to provide methods and recommended values for evaluating floor slipperiness, an essential performance characteristic of flooring surfaces.

Inadequate slipperiness can lead to slipping and falling, stumbling due to excessive slip resistance, or loss of control over bicycles and wheelchairs, potentially resulting in severe accidents.

Slipperiness involves more than just the friction between the floor and the contact surfaces—whether shoes, bare feet, or tire treads (hereafter referred to as “soles, etc.”). It also involves mechanical interactions such as the indentation of floor surface irregularities into the soles, etc.; thus, it cannot be solely understood as friction.

Moreover, floors and soles are rarely pristine and often contaminated with debris, dirt, rainwater, oil, detergents, or soapy water. The condition of floor surfaces also changes continually; short-term changes due to surface contaminants and long-term changes due to wear significantly affect slipperiness. Therefore, appropriate maintenance is crucial to minimize variations in slipperiness.

Generally, conditions of too low slip resistance are more likely to lead to serious accidents compared to those caused by high slip resistance. Particular attention should be given to scenarios where inadequate maintenance results in dangerously low slip resistance.

When evaluating slipperiness, it is standard to consider the actual soles and contaminants present on the floor. However, it is impractical to evaluate every potential combination of soles and contaminants. Thus, representative soles and contaminants must be chosen for evaluation, and the most slippery and hazardous combinations anticipated during actual use must be selected. For instance, soles without anti-slip treatments should be prioritized over those with such treatments, and harder soles that are less likely to indent into the floor’s irregularities should be preferred over softer ones. Additionally, measurements should consider expected contaminants, such as rainwater, during wet conditions.

Factors to consider when evaluating the slipperiness of floors are as follows:

- Floor-type: Horizontal floors, stairs, ramps, etc.
- Usage: Outdoor surfaces, indoor corridors and rooms, sports surfaces, water-prone areas such as bathrooms, etc.
- Activities: Everyday movements such as walking and turning, both indoors and outdoors, and vigorous activities such as sports.
- Footwear, etc.: Shoes, slippers, socks, bare feet, tires, etc.

Intervening substances: Dust, dirt, rainwater, snow, oil, detergents, soapy water, etc.

Given the numerous factors mentioned, various methods for evaluating slipperiness will be detailed in subsequent sections, covering conditions including footwear (including socks), barefoot scenarios, stairs, ramps, and surfaces used by bicycles and wheelchairs.

Section 2: Slipperiness of Floors for Footwear Use

3.2.1 Purpose and Significance

> This section outlines evaluation methods and recommended values for assessing the slipperiness of floors when performing various activities while wearing footwear, aiming to ensure a specified level of slipperiness.

Inadequate slip resistance can lead to serious incidents, such as slipping and falling or stumbling due to excessive slip resistance, potentially resulting in significant accidents. Therefore, it is critical that floors possess the appropriate level of slip resistance. This section details evaluation methods and recommended values for slipperiness experienced when walking or participating in physical activities while wearing footwear.

3.2.2 Scope of Application

> This section is applicable to evaluating slipperiness during activities such as walking, changing direction, or performing typical daily movements, as well as more vigorous physical activities on floors with footwear (including road surfaces, sports surfaces, etc.), both indoors and outdoors. There are no specific restrictions concerning the materials or construction methods of the target floors.

The methods and values presented here can be universally applied to any type of flooring material or construction technique.

3.2.3 Evaluation Perspective

> For common floors not specifically designed for sports activities, the evaluation of slipperiness focuses on safety and comfort. For sports surfaces, such as gymnasium floors, the evaluation prioritizes ease of movement during physical activities.

Safety considerations concerning common floors aim to minimize risks such as imbalance, stumbling, or falling and to reduce the incidence of accidents or injuries. Comfort pertains to factors such as ease of walking once safety is assured.

Ease of motion on sports surfaces not only facilitates gameplay but also ensures injury prevention and reduces the likelihood of disabilities. It is important to recognize that the criteria for evaluating ease of movement may vary between general users and professional athletes, particularly on sports surfaces. This section focuses on evaluating the ease of movement for general users.

3.2.4 Performance Evaluation Method

3.2.4.1 Performance Value Measurement Method

Using the slipperiness measuring apparatus "O-Y·PSM," we measure and calculate the coefficient of slip resistance (*C.S.R*) of the target floor.

It is crucial to use a measuring apparatus that is capable of accurately evaluating slipperiness. Among the various devices available both domestically and internationally, this section employs the "O-Y PSM,"[1)–6)] which is recognized for providing reliable evaluations and is incorporated into official standards. Fig. 3.2.1 provides an overview of the "O-Y·PSM" slipperiness measuring apparatus. Detailed specifications of this apparatus are provided in the appendix under "Reference Materials (1): Specifications of the O-Y PSM Slipperiness Measuring Apparatus."

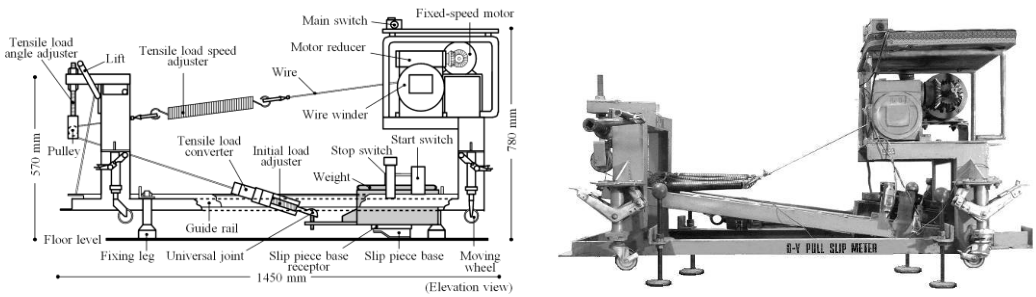

Fig. 3.2.1 Overview of the slipperiness measuring apparatus "O-Y·PSM" (example)

As discussed in Section 1 of this chapter, slipperiness involves more than just friction. The "O-Y·PSM" is designed to replicate the load conditions and contact dynamics between footwear soles and the floor during human movement accurately. When measuring slipperiness with footwear, a slip piece with an attached footwear sole is used. For measurements involving socks, a slip piece covered with a sock is used, featuring an underlayer of foam rubber to simulate the softness of the human foot sole (JIS K 6253-3:2012, Type A durometer hardness of 10, thickness of 10 mm). Fig. 3.2.2 and Photo 3.2.1 show examples of the slip pieces used.

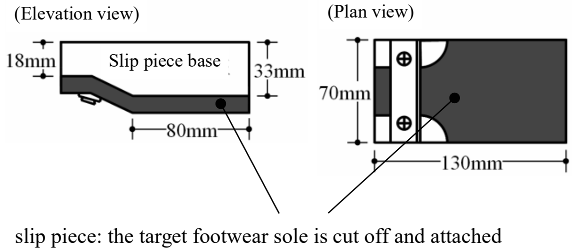

Fig. 3.2.2 Overview of a slip piece (example)

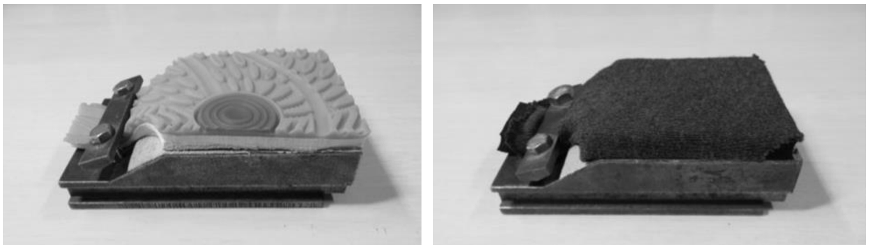

Photo 3.2.1 Examples of slip pieces (left: a shoe sole, right: a sock)

Fig. 3.2.3 shows an example of a tensile load–time curve measured by the "O-Y·PSM." The slipperiness of human motion is quantified by the coefficient of slip resistance (*C.S.R)*, calculated using the following formula, where P_{max} (N) is the maximum tensile load divided by the vertical load (784 N) applied to the slip piece:

$$C.S.R = P_{max} / 784 \quad \cdots \text{ Equation (3.2.1)}$$

This *C.S.R* value has been shown to correlate closely with the psychological scale of slipperiness, constructed using sensory test methods[1)–6)].

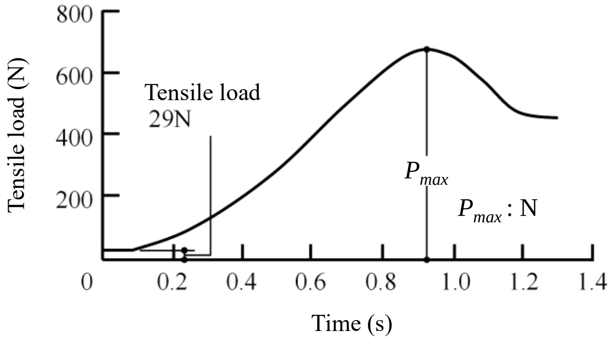

Fig. 3.2.3 Example of a tensile load–time curve

The *C.S.R* value can vary significantly based on the type of footwear and the presence of contaminants such as dust, water, and oil on the floor surface. It is necessary to select the appropriate slip pieces and contaminants for floor surface application during measurement[7)]. Examples of slip pieces and surface contaminant conditions are detailed in JIS A 1454:2010, as shown in Table 3.2.1.

Table 3.2.1 Examples of slip pieces and floor surface contaminant conditions as per JIS A 1454: 2010

Slip pieces	· Rubber sheet with hardness of 72–80 and thickness of 3–6 mm · Rubber sheet with hardness of 29–35 and thickness of 7–10 mm · Other: Actual shoe soles in use, etc. Note: Hardness is measured according to the durometer hardness test specified in JIS K 6253-3 (Type A durometer).
Floor surface contaminant conditions	· Clean and dry condition: The test piece surface is wiped with a clean cloth · Dust-sprinkled condition: The test piece surface is sprinkled with Test Powder 1, Class 7 (specified in JIS Z 8901) at a rate of 10 g/m^2 · Water + dust-sprinkled condition: A mixture of tap water and Test Powder 1, Classes 1 and 7, in a mass ratio of 20:9:1, sprinkled at a rate of 400 g/m^2 · Oil-sprinkled condition: Edible oil sprinkled at a rate of 40 g/m^2 · Others: As agreed between the parties involved.

3.2.4.2 Evaluation Method

> This method evaluates the slipperiness of the target floor by comparing the measured *C.S.R* from Section 3.2.4.1 with established evaluation indices.

The evaluation indices demonstrate the relationships between *C.S.R* and psychological scales related to slipperiness, which include factors such as safety, comfort, and ease of motion, all constructed through sensory test methods.

Figure 3.2.4 shows an example of this evaluation method. The evaluation levels shown in the figure correlate to positions on the sensory test-based evaluation scale. For instance, if the *C.S.R*, calculated using Equation (3.2.1) with the “O-Y·PSM” apparatus, is 0.4 when walking on a specific floor type while wearing slippers, this floor’s slipperiness is rated as “⑥ Considerably safe” according to Figure 3.2.4. More detailed evaluation indices are provided in Figures 3.2.5–3.2.10 in Section 3.2.5.

Note: In this document, we refer to Japanese-style indoor slippers simply as “slippers.”

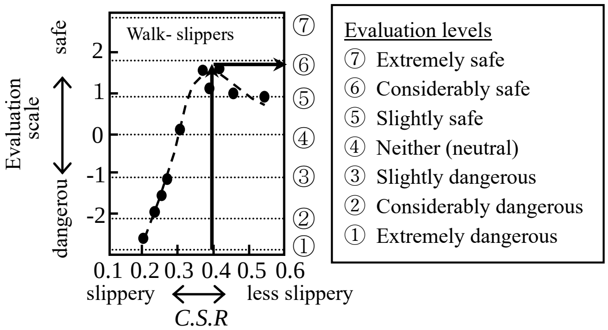

Fig. 3.2.4 Example of an evaluation index and the outline of evaluation procedures

3.2.5 Recommended Performance Values

Table 3.2.1 presents the recommended values of *C.S.R*.

Table 3.2.1 Recommended values of *C.S.R*
(X represents *C.S.R* in the table)

Types of floors	Types of motions	Recommended values	Remarks
Common floors used with footwear	Normal motions	$0.4 \leq X$	Including trot (brisk walking with small steps), etc.
	Slow motions	$0.3 \leq X$	
Gymnasium floors, etc.	Motions in Badminton, Volleyball, Basketball, etc.	$0.5 \leq X \leq 0.9$	
Outdoor sports surfaces	Motions in Baseball	$0.6 \leq X \leq 1.1$	
	Motions in Football	$0.5 \leq X \leq 0.9$	
	Motions in Rugby Football	$0.6 \leq X$	
	Motions in Tennis	$0.5 \leq X \leq 0.8$	

Measurement conditions for *C.S.R* (slip piece, floor surface contaminants): All conditions anticipated during actual use are applicable.

Figures 3.2.5 to 3.2.10 detail the evaluation indices for slipperiness. Notably, Figure 3.2.10 uses a vertical axis representing the evaluation scale derived from sensory test results involving elderly participants[8]. These figures illustrate that there is an optimal value for slipperiness; both excessive and insufficient slipperiness result in lower evaluations of floor quality.

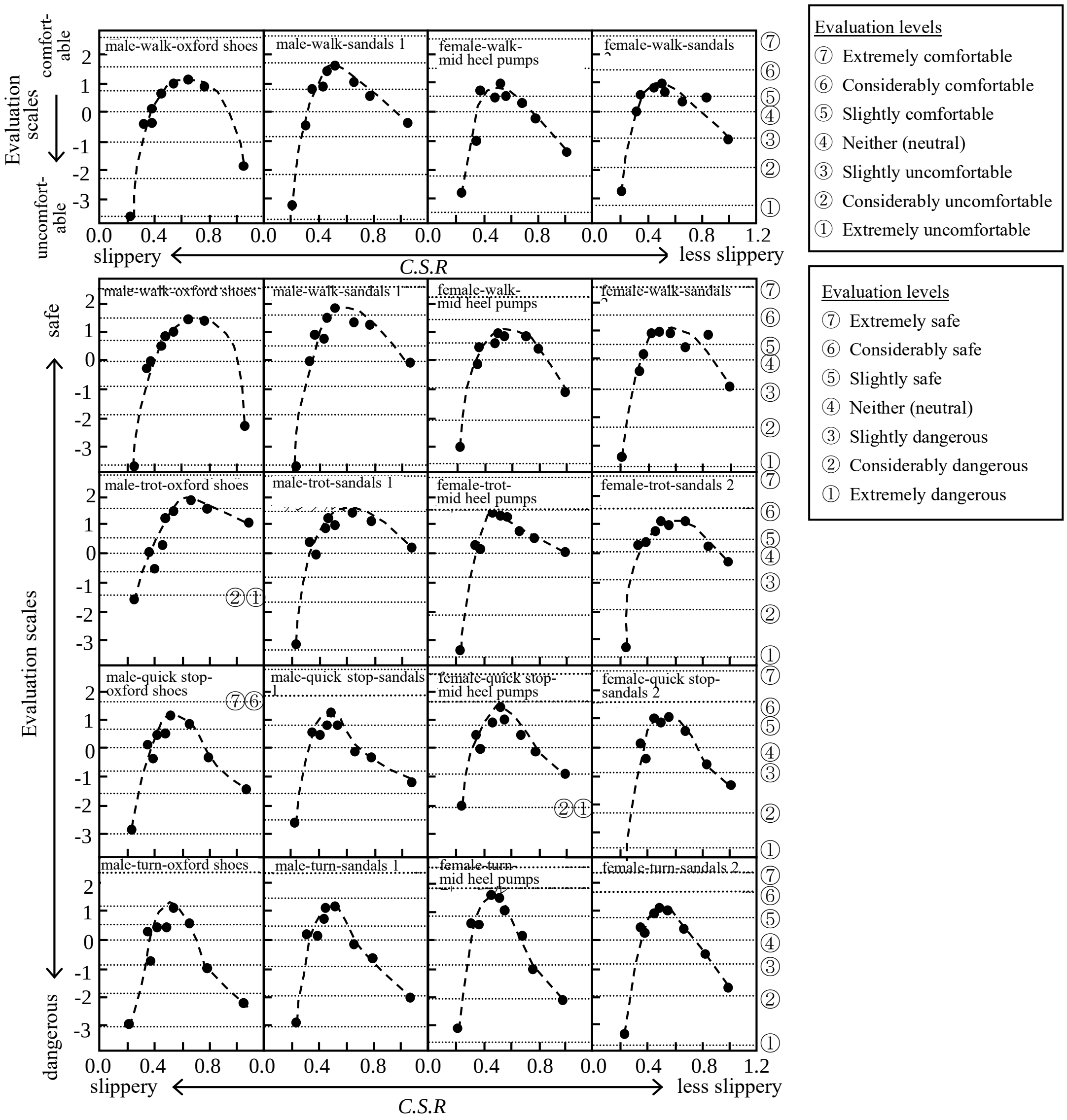

Fig. 3.2.5 Evaluation indices of the slipperiness of common floors used with shoes and sandals, etc.[4)]

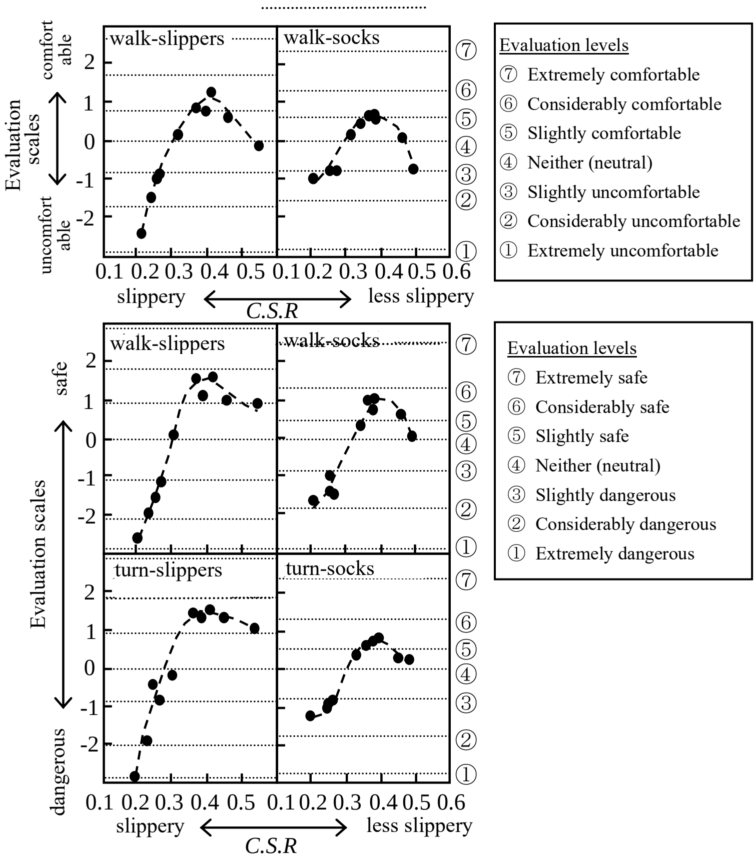

Fig. 3.2.6 Evaluation indices of the slipperiness of common residential floors used with slippers and socks, etc.[4)]

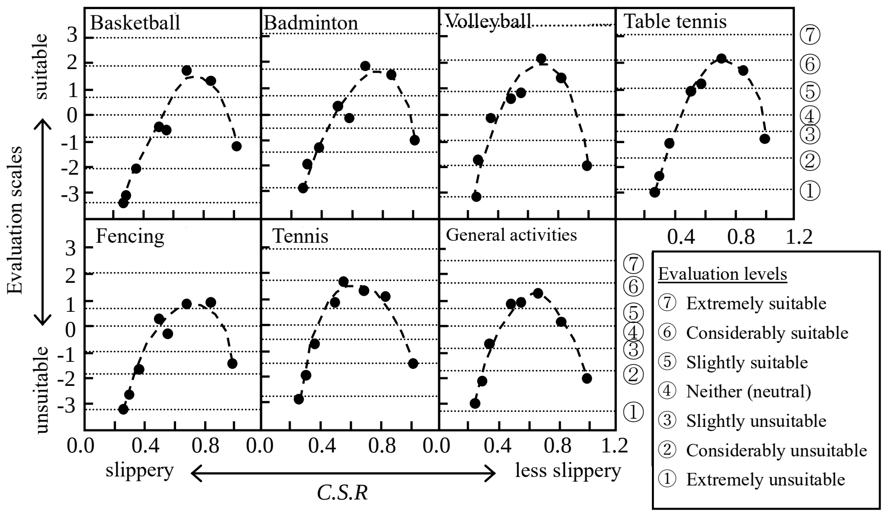

Fig. 3.2.7 Evaluation indices of the slipperiness of gymnasium floors[5)]

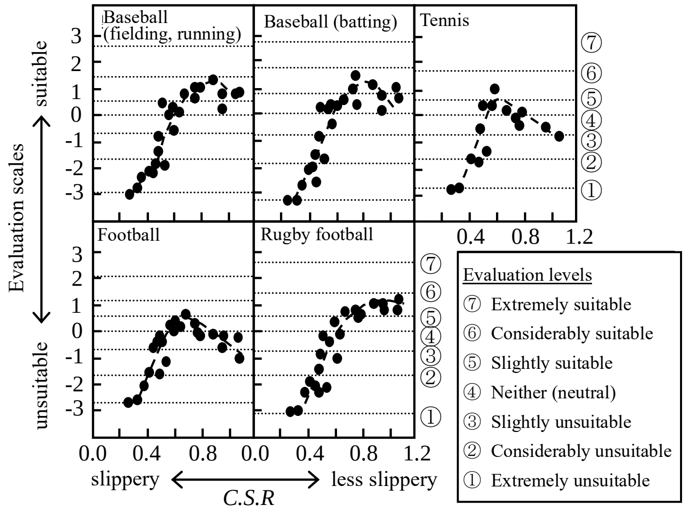

Fig. 3.2.8 Evaluation indices of the slipperiness of outdoor sports surfaces[5)]

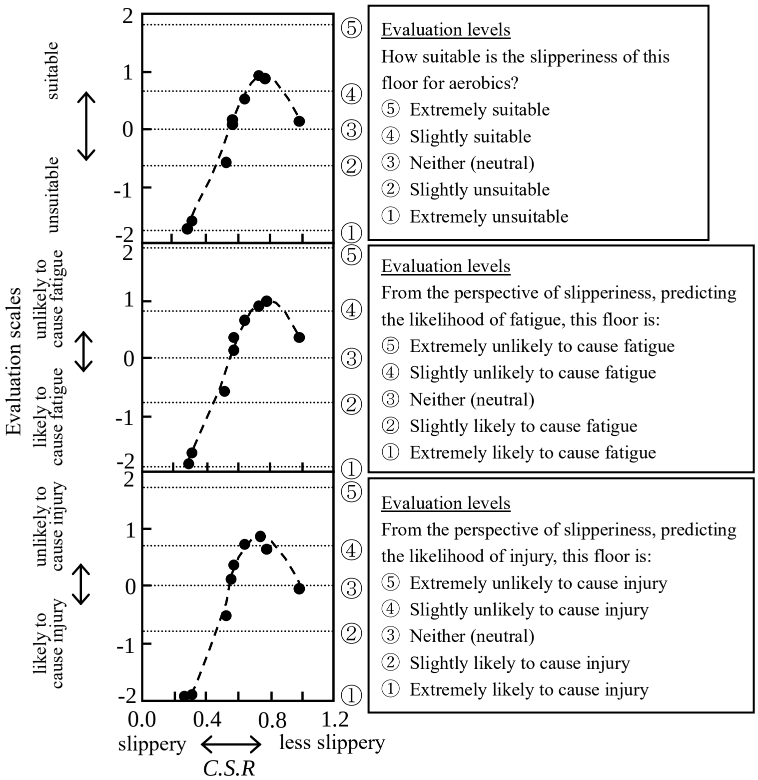

Fig. 3.2.9 Evaluation indices of the slipperiness of aerobics floors[6)]

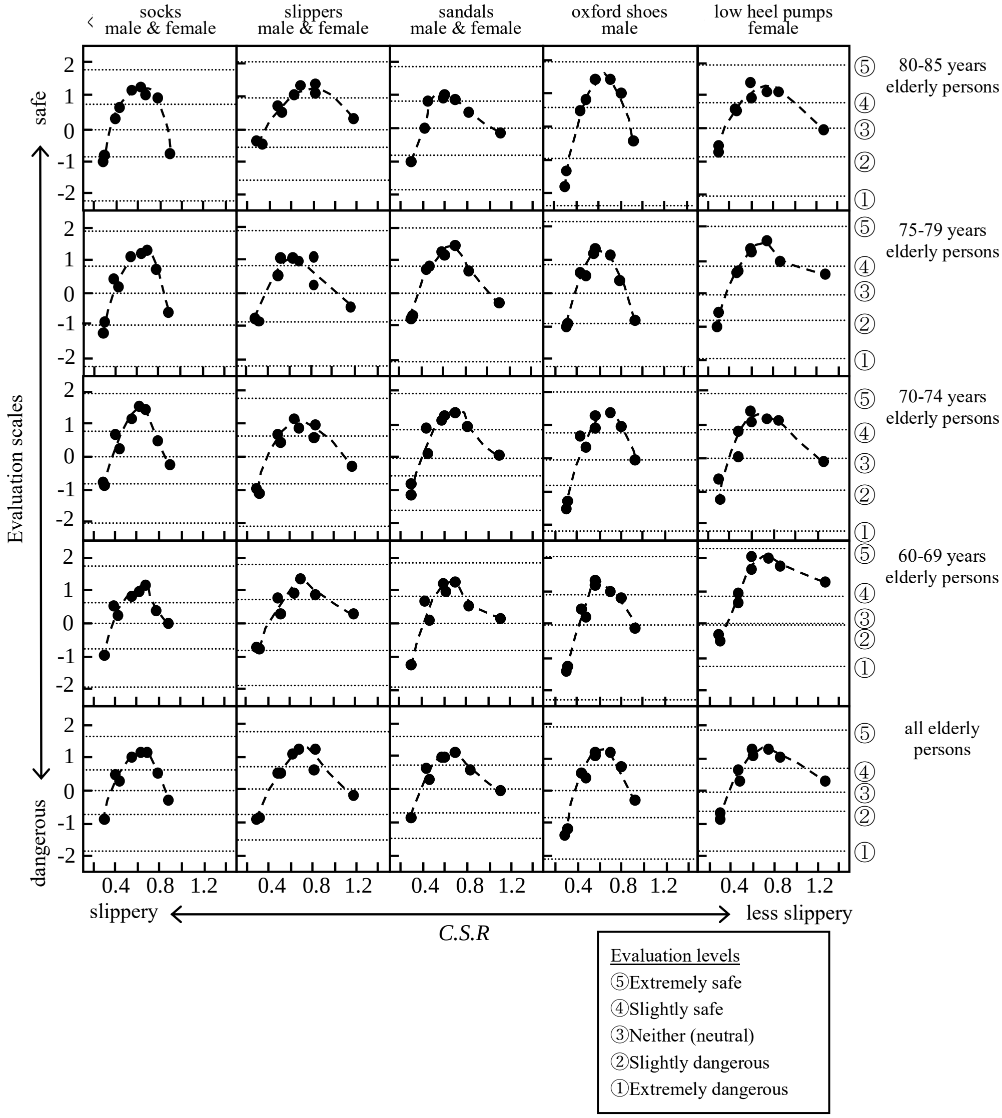

Fig. 3.2.10 Evaluation indices of the slipperiness of floors for elderly persons with footwear[8)]

Figures 3.2.11–3.2.16 derive and present optimal *C.S.R* values and the allowable ranges of *C.S.R* using the evaluation levels "④ (or ③) Neither" as tentative acceptance criteria, based on Figures 3.2.5–3.2.10.

The recommended values for *C.S.R* listed in Table 3.2.1 are established using the allowable ranges of *C.S.R* from Figures 3.2.11–3.2.16 as foundational data.

In the table, the lower limit of *C.S.R* is set for floors used with footwear to mitigate the risk of excessive slipperiness. In principle, it is important to establish an upper limit for *C.S.R* as excessively non-slip floors can also pose dangers. However, at this initial stage, only the lower limit has been set, with the establishment of an upper limit reserved as a future task.

Given that non-slip floors pose a higher risk during exercise compared to everyday motions, an upper limit for the *C.S.R* is generally established for gymnasium floors and outdoor sports surfaces. Specifically for gymnasium floors, where managing slipperiness is critical, recommended values are set based on the acceptance criterion of evaluation level "⑤ Slightly suitable" in Figure 3.2.7 for floors requiring special consideration.

The recommended values in Table 3.2.1 for "common floors used with footwear during slow motions" are intended for floors that do not provide sufficient space for movements at normal speed, typically found in standard-sized residential homes.

As mentioned in Section 1 of this chapter, the slipperiness of the same floor material can vary over time owing to factors such as surface contaminants and wear. Thus, regular maintenance is essential to preserve the initial performance values of slipperiness and prevent significant deterioration. Abrasion testing apparatuses that can quickly replicate the changes in floor slipperiness due to wear from walking have also been developed[9), 10)].

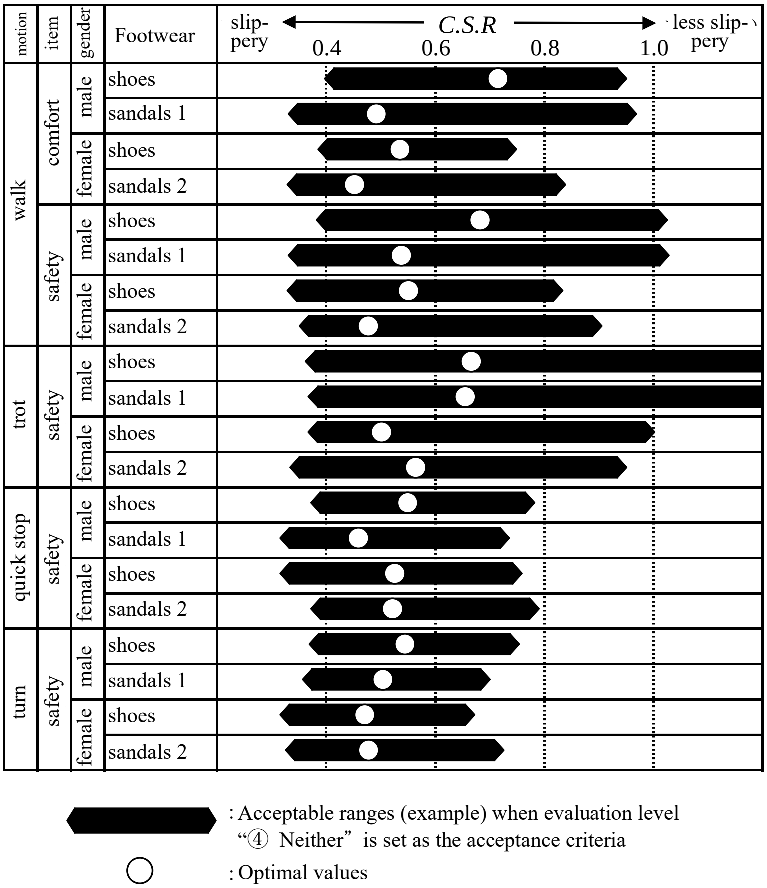

Fig. 3.2.11 Examples of optimal values and acceptable ranges of *C.S.R* for common floors used with shoes and sandals, etc.4)

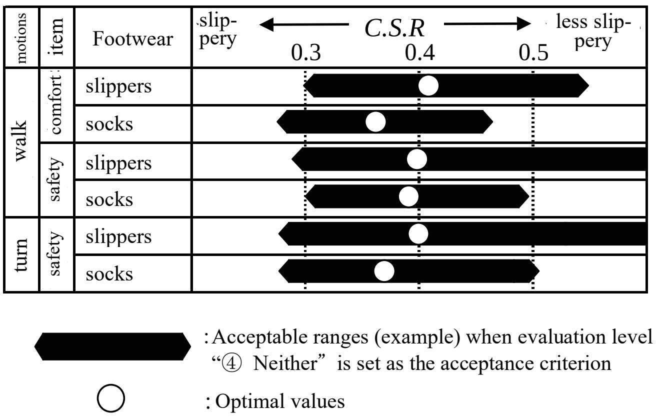

Fig. 3.2.12 Examples of optimal values and acceptable ranges of *C.S.R* for residential floors used with slippers and socks, etc.4)

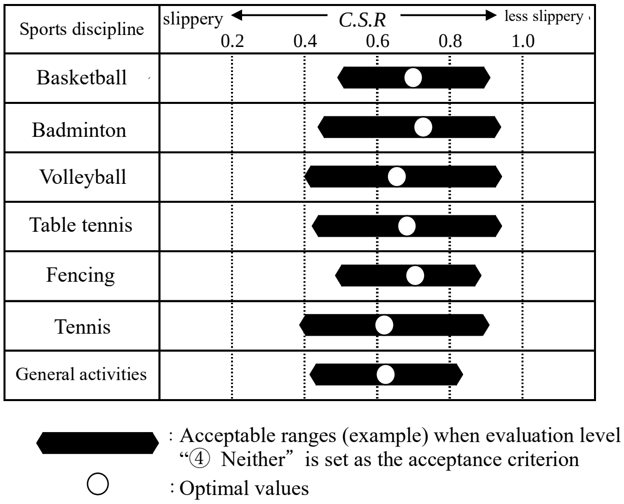

Fig. 3.2.13 Examples of optimal values and acceptable ranges of *C.S.R* for gymnasium floors[5)]

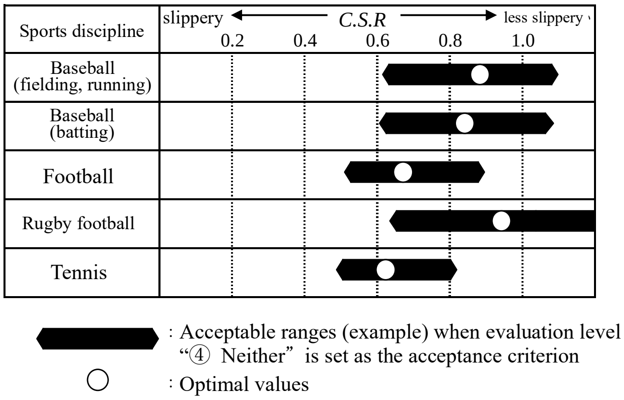

Fig. 3.2.14 Examples of optimal values and acceptable ranges of *C.S.R* for outdoor sports surfaces[5)]

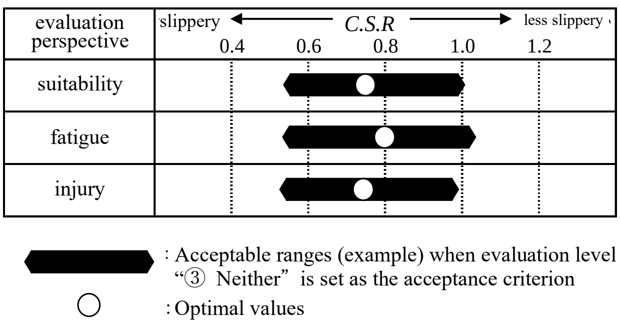

Fig. 3.2.15 Examples of optimal values and acceptable ranges of *C.S.R* for aerobics floors[6)]

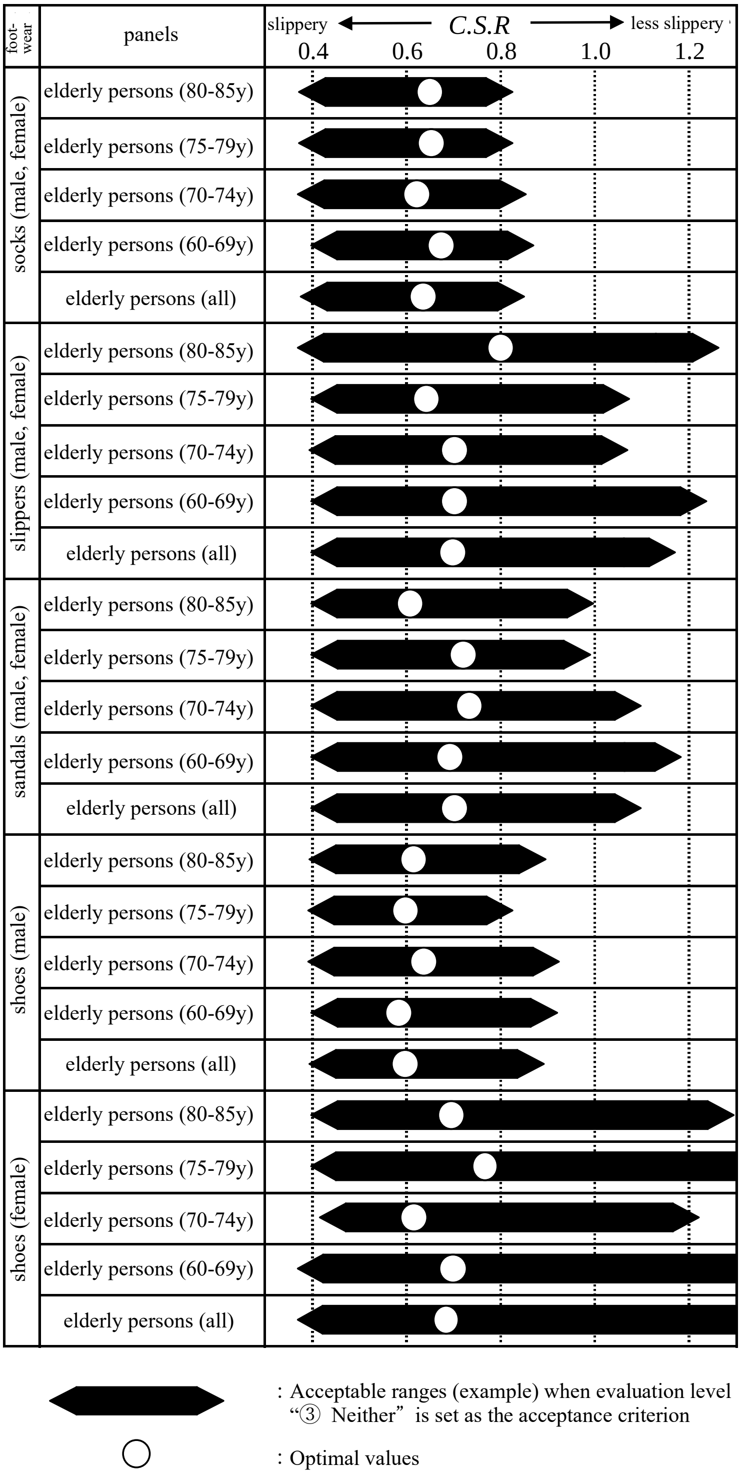

Fig. 3.2.16 Examples of optimal values and acceptable ranges of *C.S.R* for common floors for elderly persons used with footwear such as shoes and socks, etc.[8)]

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Applied Standards

1） JIS A 1454: 2010 (Test methods – Resilient floorcoverings)

2）JIS A 1509-12: 2014 (Test methods for ceramic tiles – Part 12: Determination of slip resistance)

Section 3: Slipperiness of Floors for Barefoot Use

3.3.1 Purpose and Significance

> This section aims to provide evaluation methods and recommended values for assessing the slipperiness of floors when moving barefoot, thereby ensuring an adequate level of slipperiness.

Inadequate slipperiness can lead to slipping and falling, potentially resulting in significant accidents. Thus, it is crucial for floors to possess appropriate slipperiness. This section introduces evaluation methods and recommended values for the slipperiness experienced while walking or engaging in exercise barefoot.

3.3.2 Scope of Application

> This section applies to evaluating the slipperiness of floors for barefoot use both inside and outside buildings under various conditions. There are no specific limitations regarding the materials or construction methods of the target floors. The floors considered include the following:
> a. Bathroom floors, etc.: Floors in bathrooms, bathtubs, poolside areas, and other surfaces where significant liquid contaminants may be present.
> b. Sports facility floors, etc.: Floors in martial arts facilities and sports facilities used for activities such as Judo, Kendo, Shorinji Kempo, among others.
> c. Common floors: Floors in residences or other areas where everyday activities are performed.

This section addresses the slipperiness experienced under the following scenarios:

a. Bathroom floors, etc.: Slipperiness during motions such as entering or exiting a bathtub, walking, or turning on floors where significant liquid contaminants such as water and soapy water are present.

b. Sports facility floors, etc.: Slipperiness during barefoot motions in sports facilities.

c. Common floors: Slipperiness during everyday motions such as walking and turning in residences or other general settings.

Evaluation methods and recommended values applicable to any floor material or construction method are presented.

3.3.3 Evaluation Perspective

The evaluation of slipperiness varies based on the type of floor and intended use:

a. For bathroom floors, safety

b. For sports facility floors, ease of exercise motions

c. For common floors, safety and comfort

a. Bathroom floors: The primary concern is safety, owing to the increased risk of imbalance or falls from liquid contaminants compared to other floor types.

b. Sports facility floors: In line with Section 2 of this chapter, the evaluation focuses on the ease of exercise motions.

c. Common floors: Consistent with Section 2, the evaluation prioritizes both safety and comfort.

3.3.4 Performance Evaluation Method

3.3.4.1 Performance Value Measurement Method

a. For evaluating the slipperiness of barefoot conditions on bathroom floors, the "O-Y·PSM" equipped with a specialized barefoot slip piece for bathroom floors is used to measure and calculate the slipperiness performance value, *C.S.R·B* (coefficient of slip resistance·bath), of the target floor.

b. For the slipperiness of barefoot conditions on sports facility floors, the "O-Y·PSM" equipped with a barefoot slip piece common to both sports facility floors and common floors is used to measure and calculate the performance value of slipperiness, *C.S.R·BF* (coefficient of slip resistance·bare feet), of the target floor.

c. The same measurement method described above (b) for sports facility floors is also applied to evaluate the slipperiness of barefoot conditions on common floors.

The slipperiness measuring apparatus "O-Y·PSM," as described in Section 3.2.4.1, is employed across these evaluations. Figure 3.3.1 provides an overview of the "O-Y·PSM."

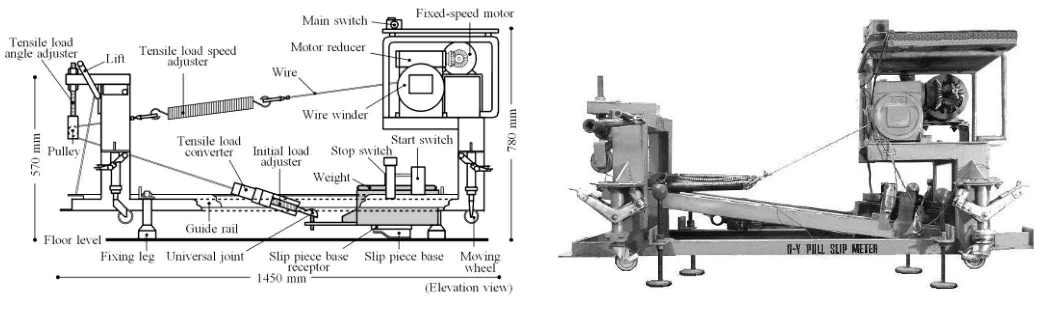


Fig. 3.3.1 Overview of the slipperiness measuring apparatus "O-Y·PSM"

For barefoot slipperiness, the measurement methods can be broadly categorized into two groups: one for bathroom floors and the other for both sports facility floors and common floors.

a. When measuring the slipperiness of barefoot conditions on bathroom floors, where significant liquid contaminants are present, we utilize the specific slip piece shown in Figure 3.3.2 and perform the test with the "O-Y·PSM," as outlined in Section 3.2.4.1.

An example of the measured tensile load–time curve is shown in Figure 3.3.3. The slipperiness performance value for barefoot on bathroom floors, *C.S.R·B* (coefficient of slip resistance·bath), is calculated using the following equation, which sums the maximum tensile load P_{max} (N) and the first minimum load P_{min} (N) following the maximum load, each divided by the vertical load applied to the slip piece (784 N), as shown in Figure 3.3.3.

$$C.S.R{\cdot}B = P_{max} / 784 + P_{min} / 784 \quad \cdots\text{Equation (3.3.1)}$$

C.S.R·B represents a specific slipperiness performance value for barefoot conditions on bathroom floors and is applicable only when liquid contaminants such as water or soapy water are present. When conducting measurements, it is crucial to select the appropriate type of liquid contaminants (such as water or soapy water) to sprinkle between the slip piece and the floor surface, based on the intended use of the floor.

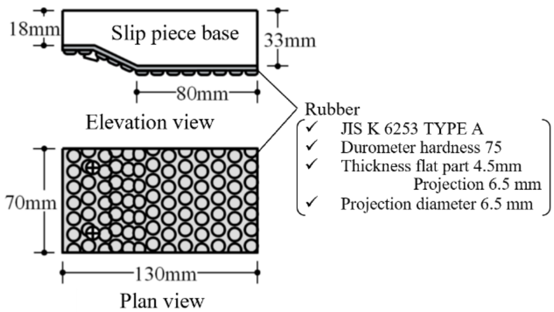


Fig. 3.3.2 Slip piece for barefoot on bathroom floors

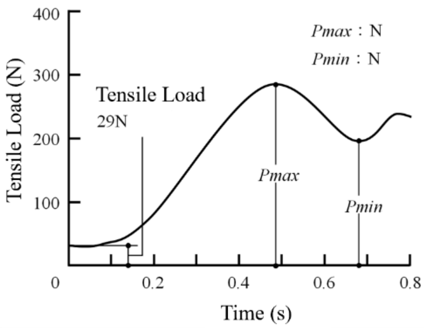


Fig. 3.3.3 Example of a tensile load–time curve of slipperiness for barefoot on bathroom floors

b. For evaluating the slipperiness of barefoot on sports facility floors, we utilize the slip piece shown in Figure 3.3.4 and conduct the test with the "O−Y·PSM" as described in Section 3.2.4.1.

Figure 3.3.5 shows an example of the measured tensile load–time curve. The slipperiness performance value for barefoot on sports facility floors, denoted as *C.S.R·BF* (coefficient of slip resistance·bare feet), is calculated using the following equation, which represents the maximum tensile load P_{max} (N) divided by the vertical load applied to the slip piece (784 N).

$$C.S.R{\cdot}BF = P_{max} / 784 \qquad \cdots\text{Equation (3.3.2)}$$

The $C.S.R{\cdot}BF$ is influenced by factors such as dust, water, and sweat on the floor surface. Therefore, when conducting measurements, it is crucial to appropriately select the contaminants to be applied between the slip piece and the floor surface. Examples of such contaminants are detailed in Table 3.2.1 of Section 3.2.4.1.

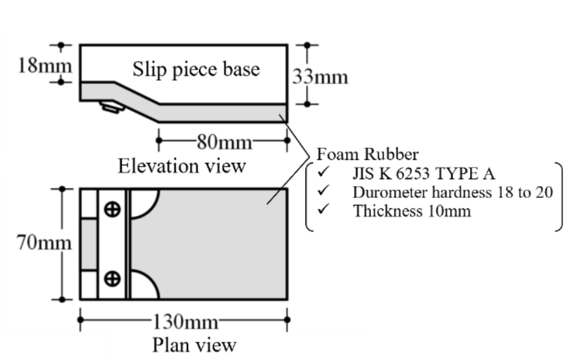


Fig. 3.3.4 Slip piece for barefoot on sports facility floors and common floors

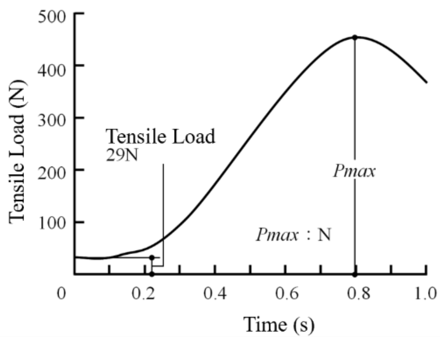


Fig. 3.3.5 Example of a tensile load–time curve of slipperiness for barefoot on sports facility floors and common floors

c. The procedure for measuring the slipperiness performance value of barefoot on common floors is identical to that described for sports facility floors in part b.

3.3.4.2 Evaluation Method

a. For bathroom floors and similar surfaces, the slipperiness performance value, $C.S.R{\cdot}B$, as measured in Section 3.3.4.1 a., is compared with the barefoot slip evaluation index specific to bathroom floors. This index delineates the relationship between the evaluation of slipperiness and $C.S.R{\cdot}B$. This comparison facilitates the evaluation of the target floor's slipperiness.

b. For sports facility floors and similar surfaces, the slipperiness performance value, $C.S.R{\cdot}BF$, as measured in Section 3.3.4.1 b., is compared with the barefoot slip evaluation index specific to sports facility floors. This index illustrates the relationship between the evaluation of slipperiness and $C.S.R{\cdot}BF$, aiding in the assessment of the target floor's slipperiness.

c. For common floors, the slipperiness performance value, $C.S.R{\cdot}BF$, measured in Section 3.3.4.1 c., is compared with the barefoot slip evaluation index specific to common floors. This index shows the relationship between the evaluation of slipperiness and $C.S.R{\cdot}BF$, which is used to evaluate the target floor's slipperiness.

The evaluation index reflects the relationship between psychological scales (evaluation scales) concerning safety, comfort, and ease of movement related to slipperiness, all constructed using sensory test methods, and the slipperiness performance values *C.S.R·B* and *C.S.R·BF*.

a. An example of the evaluation method for barefoot slipperiness on bathroom floors is shown in Figure 3.3.6. The evaluation levels shown represent judgment categories used in sensory tests to construct the vertical axis of the evaluation scale. The plots illustrate the relationship between the safety evaluation scale for slipperiness when walking barefoot on bathroom floors and *C.S.R·B*. For example, if the slipperiness performance value, calculated using Equation (3.3.1) with the "O-Y·PSM" apparatus, is 0.9, Figure 3.3.6 indicates that the floor's slipperiness is evaluated as "⑥ quite safe."

Details of the evaluation indices are provided in Figure 3.3.9 in Section 3.3.5.

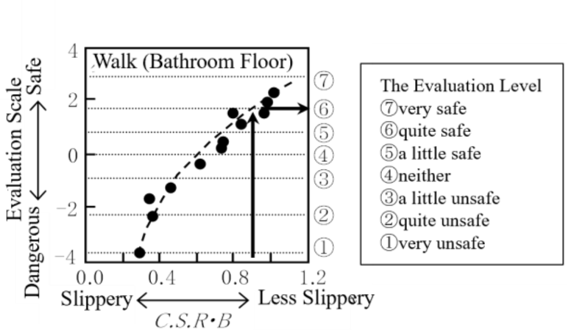


Fig. 3.3.6 Example of the evaluation index and the outline of evaluation procedures for barefoot slipperiness of bathroom floors

b. An example of the evaluation procedures for barefoot slipperiness on sports facility floors is shown in Figure 3.3.7. The evaluation levels represented correspond to judgment categories used in sensory tests to construct the vertical axis of the evaluation scale. The plots demonstrate the relationship between the ease of exercise motion during Kendo and *C.S.R·BF*. For instance, if the slipperiness performance value, calculated using Equation (3.3.2) with the "O-Y·PSM" apparatus, is 0.5, Figure 3.3.7 indicates that the floor's slipperiness falls within the range of "③ neither" to "④ suitable."

Details of the evaluation indices are available in Figure 3.3.10 in Section 3.3.5.

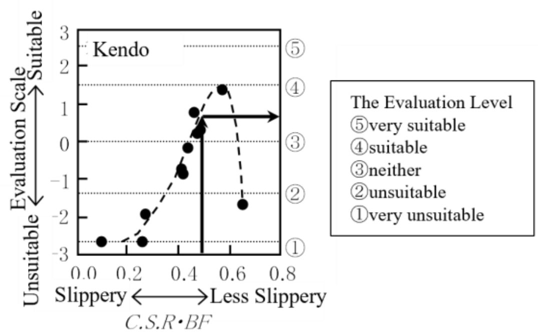


Fig. 3.3.7 Example of the evaluation index and the outline of evaluation procedures for barefoot slipperiness of sports facility floors

c. An example of the evaluation procedures for barefoot slipperiness on common floors is shown in Figure 3.3.8. The evaluation levels depicted in the figure correspond to the positions of judgment categories, which were established through sensory tests to construct the vertical axis of the evaluation scale. The plots demonstrate the relationship between the safety evaluation scale for slipperiness when walking barefoot on common floors and *C.S.R·BF*. For instance, if the slipperiness performance value measured using the "O-Y·PSM" apparatus and calculated according to Equation (3.3.2) is 0.5, Figure 3.3.8 suggests that the slipperiness of the floor is categorized between "③ neither" and "④ safe."

Details of the evaluation indices are provided in Figure 3.3.11 in Section 3.3.5.

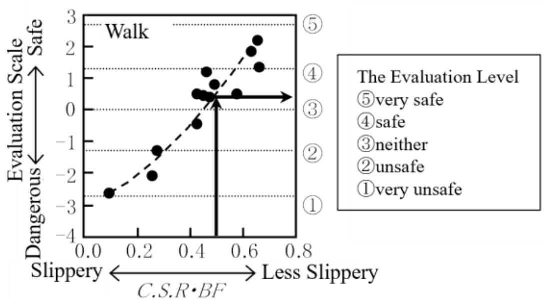


Fig. 3.3.8 Example of an evaluation index and the outline of evaluation procedures for barefoot slipperiness of common floors

3.3.5 Recommended Performance Values

Tables 3.3.1 and 3.3.2 present the recommended values of *C.S.R·B* and *C.S.R·BF*, respectively.

Table 3.3.1 Recommended values of *C.S.R·B*
(X represents *C.S.R·B* in the table)

Types of floors	Types of motions	Recommended values	Remarks
a. bathroom floors and similar surfaces	Normal motions	$0.7 \leq X$	Large bathrooms, poolside areas, etc.
	Slow motions	$0.6 \leq X$	

Measurement conditions for *C.S.R·B* (floor surface contaminants): All conditions anticipated during actual use are applicable.

Table 3.3.2 Recommended values of *C.S.R·BF*
(X represents *C.S.R·BF* in the table)

Types of floors	Types of motions	Recommended values	Remarks
b. Floors of sports facilities and similar surfaces	Motions in Kendo, Judo, and Shorinji Kempo, etc.	$0.4 \leq X \leq 0.6$	
c. Common floors	Normal motions	$0.5 \leq X$	Including trot, etc.
	Slow motions	$0.4 \leq X$	

Measurement conditions of *C.S.R·BF* (floor surface contaminants): All conditions anticipated during actual use are applicable.

Figure 3.3.9 shows the evaluation indices for barefoot slipperiness on bathroom floors and similar surfaces. From this figure, it is evident that for bathroom floors and similar surfaces, the less slippery they are, the higher their rating across all corresponding curves. Utilizing evaluation level "④ Neither" as the criterion, it is inferred that in large bathrooms or poolside areas where ordinary movements, including trotting, are expected, a *C.S.R·B* of approximately 0.7 or higher would meet evaluation level ④ even when trotting. Moreover, in smaller bathroom areas within residential units where only slow movements are performed, a *C.S.R·B* of approximately 0.6 or higher would suffice to meet evaluation level ④. These insights have informed the recommended values listed in Table 3.3.1.

Note that in Figure 3.3.9, terms such as "safe bath," "general bath," and "unsafe bath" refer to simulated baths utilized in sensory tests in previous studies[1), 2)], with the cross-sectional dimensions shown in Figure 3.3.10. Their designations are as follows:

· Safe bath: Bath with cross-sectional dimensions that facilitate easy entry and exit.

· General bath: Bath with typical cross-sectional dimensions.

· Unsafe bath: Bath with cross-sectional dimensions that make entry and exit challenging.

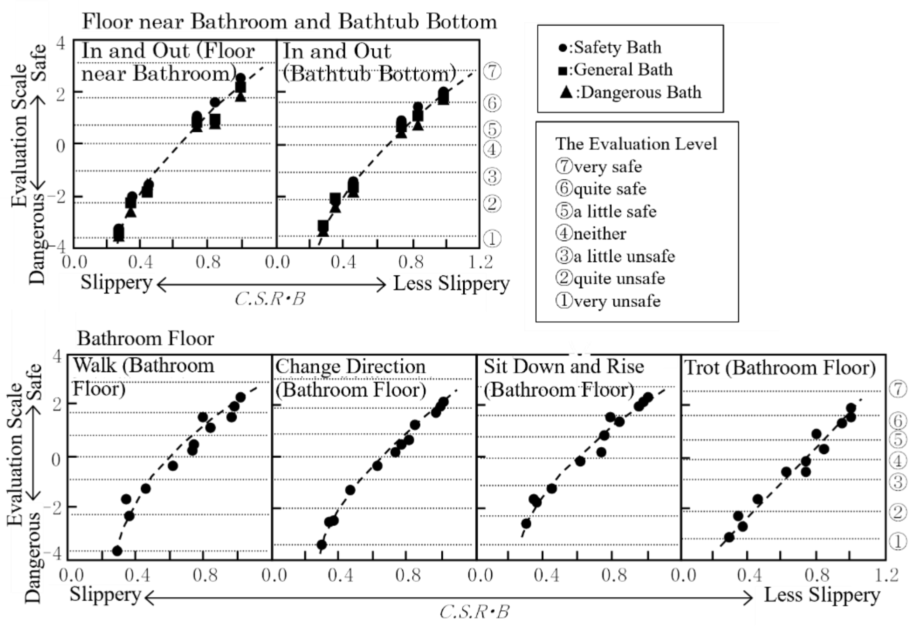


Fig. 3.3.9 Evaluation indices for barefoot slipperiness on bathroom floors[2)]

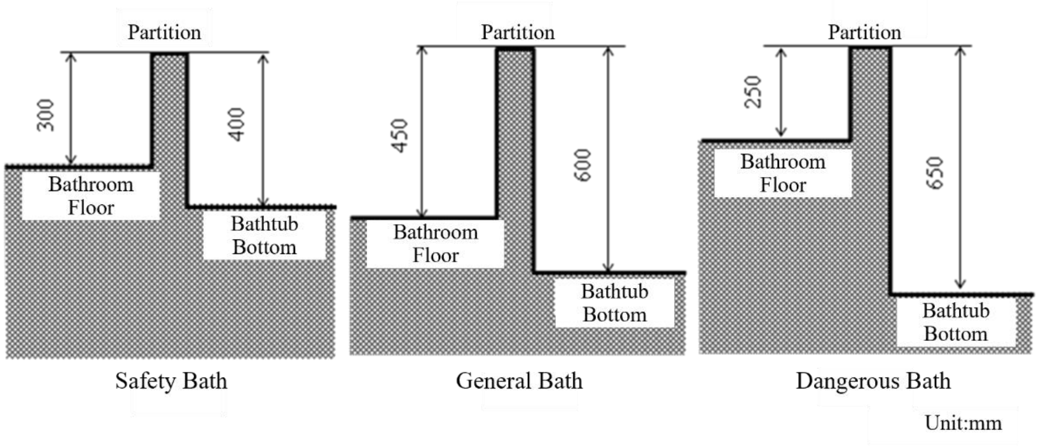


Fig. 3.3.10 Cross-sectional dimensions of the simulated baths used for sensory tests[1)]

Figure 3.3.11 depicts the evaluation indices for barefoot slipperiness on sports facility floors. The data presented in Figure 3.3.11 suggest that there is an optimal value of slipperiness for each corresponding curve on sports facility floors, with performance declining both above and below this optimal value. By applying the evaluation level "③ Neither" as a criterion, it can be inferred that a *C.S.R·BF* value ranging from approximately 0.4 to 0.6 would meet the requirements of this evaluation stage.

The recommended values outlined in part b. of Table 3.3.2 were established based on these findings.

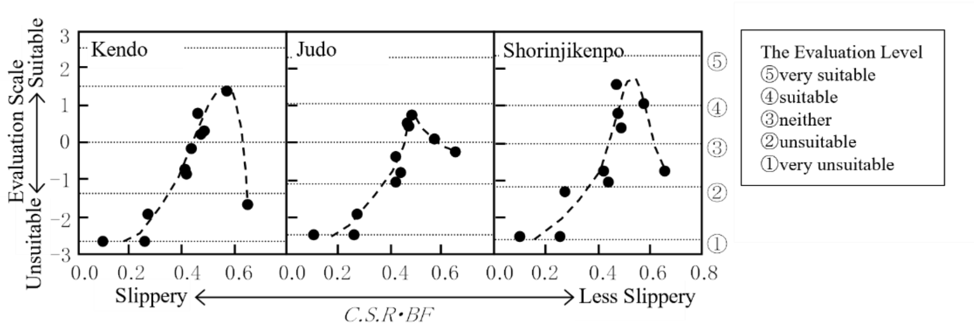


Fig. 3.3.11 Evaluation indices for barefoot slipperiness on sports facility floors 3)

Figure 3.3.12 presents the evaluation indices for barefoot slipperiness on common floors. Analysis of Figure 3.3.12 indicates that for common floors, a lower slipperiness is generally safer, with all corresponding curves favoring less slippery surfaces. Using the evaluation stage "③ Neither" as a criterion, it can be inferred that for floors where activities such as starting to run or making sudden stops are common, a *C.S.R·BF* value of approximately 0.5 or higher would satisfy the evaluation level ③ during these activities. Additionally, for scenarios involving only slow movements on common floors, a *C.S.R·BF* value of approximately 0.4 or higher would be adequate.

The recommended values outlined in part c. of Table 3.3.2 were established based on these insights.

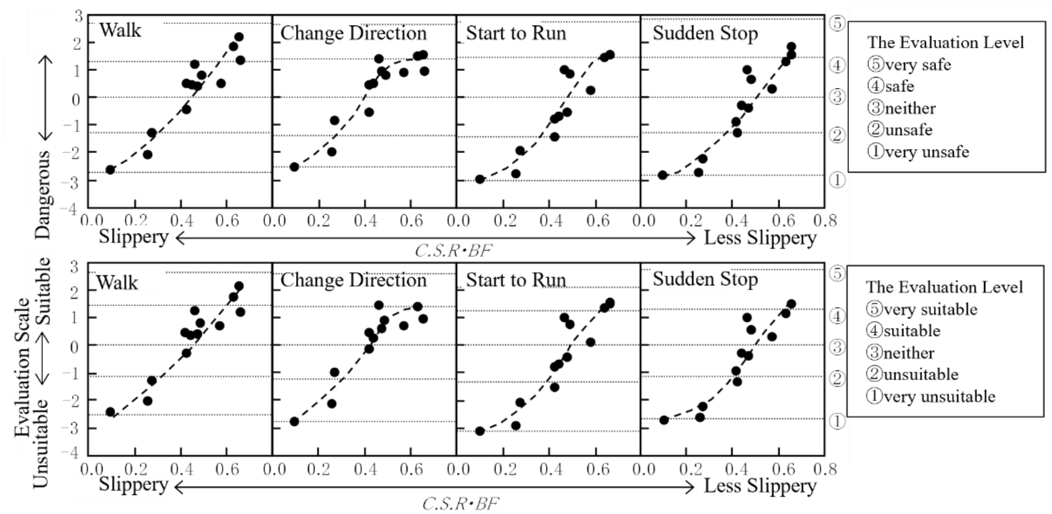


Fig. 3.3.12 Evaluation indices for barefoot slipperiness on common floors3)

References

1) Ono, H., Ueno, S., Yokoyama, Y., Ohno, R. and Mikami, T.: Study on the evaluation method of slipperiness of bathroom floors and bathtub bottoms from a viewpoint of safety, Part 1 Study on the measuring method of slip resistance between the easiness to cross the bathtub's edge and its sectional proportion, Transactions of the Architectural Institute of Japan, vol. 384, pp. 26–33, 1988.2 (in Japanese)

2) Ono, H., Mikami, T., Ohno, R., Yokoyama, Y., Ueno, S., and Takaki, S.: Study on the evaluation method of slipperiness of bathroom floors and bathtub bottoms from a viewpoint of safety, Part 2 Presentation of the evaluating indexes and the evaluating method of slipperiness of bathroom and bathtub bottoms, Transactions of the Architectural Institute of Japan, vol. 387, pp. 1–7, 1988.5 (in Japanese)

3) Ono, H. and Ochiai, N.: Study on the evaluation method of slipperiness of floors with bare feet, Transactions of the Architectural Institute of Japan, vol. 537, pp. 21–26, 2000.11 (in Japanese)

Applied Standards

1) JIS A 1509-12: 2014 (Test methods for ceramic tiles – Part 12: Determination of slip resistance)

Section 4 Slipperiness of Stairway Treads

3.4.1 Purpose and Significance

> This section outlines methods and recommended values for evaluating the slipperiness of stairway treads during ascent and descent while wearing footwear, aiming to ensure a specified level of slipperiness.

Inadequate slipperiness on stairway treads can lead to slipping and falling, potentially resulting in serious injuries. Therefore, it is crucial for stairway treads to possess appropriate slipperiness. This section provides methods and recommended values for assessing the slipperiness experienced while ascending and descending stairs with footwear.

3.4.2 Scope of Application

> This section is dedicated to evaluating slipperiness when ascending and descending stairs in both indoor and outdoor building environments while wearing footwear. There are no specific limitations regarding the materials or construction methods of the stairs.

The section focuses on the evaluation of slipperiness on the treads and nosing of stairs used with footwear, offering methods and recommended values that are applicable irrespective of the stairs' materials and construction techniques.

3.4.3 Evaluation Perspective

> The primary concern regarding the slipperiness of stairway treads is safety.

In contrast to common floor surfaces, stairs consist of small, discontinuous treads, and individuals ascending or descending these stairs may not always place their entire foot on the tread, often resulting in part of the foot overhanging the edge. This characteristic makes stairs inherently less stable than continuous floors, thereby increasing the risk of balance loss and subsequent falls. Therefore, the focus of evaluating the slipperiness of stairway treads is on safety.

3.4.4 Performance Evaluation Method

3.4.4.1 Performance Value Measurement Method

> To evaluate the slipperiness of stair treads, the slipperiness measuring apparatus "O-Y PSM" is used to measure the coefficient of slip resistance at different parts of the stair: on the tread (C_1), the horizontal part of the nosing (C_2), and the angled part of the nosing (C_3). Then, the stair slipperiness performance value, $C.S.R{\cdot}S$ (coefficient of slip resistance for stairs) is calculated.

The "O-Y PSM," the same apparatus used as detailed in Section 3.2.4.1, is used for these measurements. Figure 3.4.1 provides an overview of this apparatus. The slipperiness of the stairs is quantified by $C.S.R{\cdot}S$, derived from the slip resistance values C_1, C_2, and C_3, representing the tread part, horizontal part of the nosing, and angled part of the nosing, respectively.

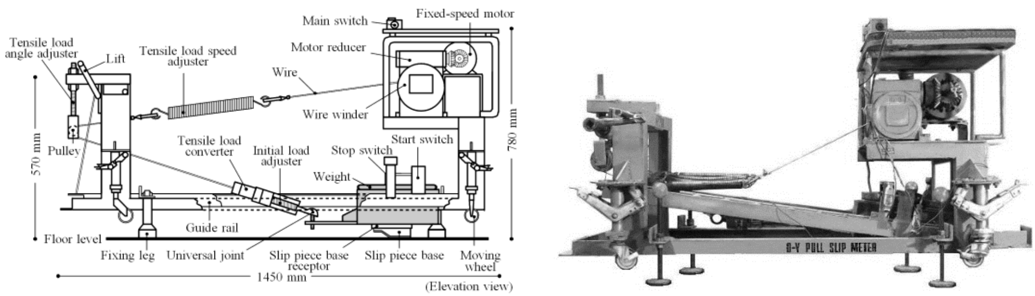


Fig. 3.4.1 Overview of the slipperiness measuring apparatus "O-Y·PSM"

Table 3.4.1 shows the measurement procedures for C_1, C_2, and C_3. Figure 3.4.2 presents an example of a tensile load–time curve measured using the method described in Table 3.4.1. C_1, C_2, and C_3 are calculated from the maximum tensile load value P_{max} (N) and the vertical load acting on the slip piece, as follows:

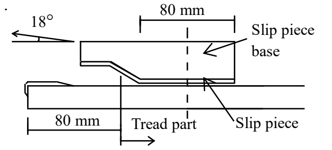
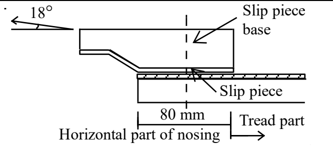
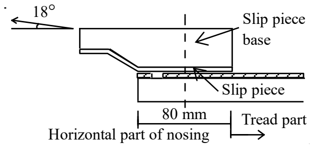
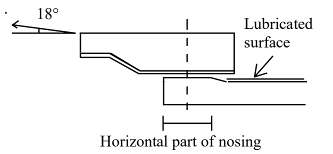
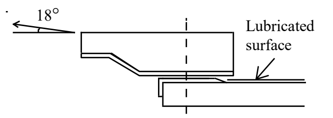
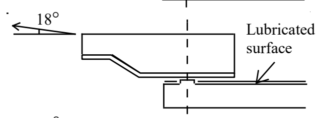
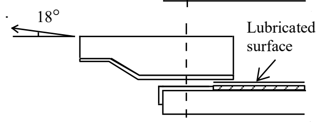
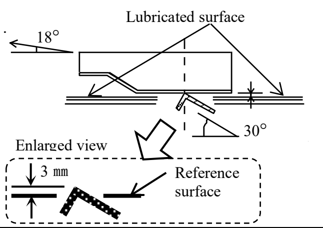
C_1: P_{max} (maximum tensile load value on the tread part) / 784 ···Equation (3.4.1)

C_2: P_{max} (maximum tensile load value on the horizontal part of the nosing) / 784 ···Equation (3.4.2)

C_3: P_{max} (maximum tensile load value on the angled part of the nosing) / 588 ···Equation (3.4.3)

Here, the vertical load acting on the slip piece is 784 N for C_1 and C_2, and 588 N for C_3, as detailed in Table 3.4.1.

Table 3.4.1 Measurement methods for C_1, C_2, and C_3

Part	Coefficient of slip resistance	Measurement conditions with O-Y·PSM	Setting condition of the slip piece	Overview
Tread part	C_1	Vertical load: 784 N Tensile load speed: 784 N/s Initial tensile load: 29 N Tensile angle: 18° Lead time: 0 s $C_1 = (Pmax\ (\mathrm{N}))/(784\ (\mathrm{N}))$		Set a slip piece at least 80 mm behind the nosing.
Horizontal part of nosing	C_2	Vertical load: 784 N Tensile load speed: 784 N/s Initial tensile load: 29 N Tensile angle: 18° Lead time: 0 s $C_2 = (Pmax\ (\mathrm{N}))/(784\ (\mathrm{N}))$	When the horizontal part of nosing and the tread part are made of the same material and the horizontal part of the nosing has no protrusion  	Align the edge of the slip piece with the tip of the nosing.
			When the horizontal part of the nosing and the tread part are made of the same material and the horizontal part of the nosing has some protrusions 	Align the center of the slip piece with the center of the nosing material, protrusion, non-stop tape, etc. Apply lubricating surface* to areas other than the nosing, protrusions, and non-slip tape. *Lubricating surface: Surface where *C.S.R* is 0.04 or less using the slip piece
			When the horizontal part of the nosing and the tread part are made of different materials   	
Corner part of nosing	C_3	Vertical load: 588 N Tensile load speed: 784 N/s Initial tensile load: 29 N Tensile angle: 18° Lead time: 0 s $C_3 = (Pmax\ (\mathrm{N}))/(588\ (\mathrm{N}))$		Set the corner of the nosing to the center of the slip piece and place the corner 3 mm above the reference plane. Apply a lubricating surface to areas other than the nosing corner.

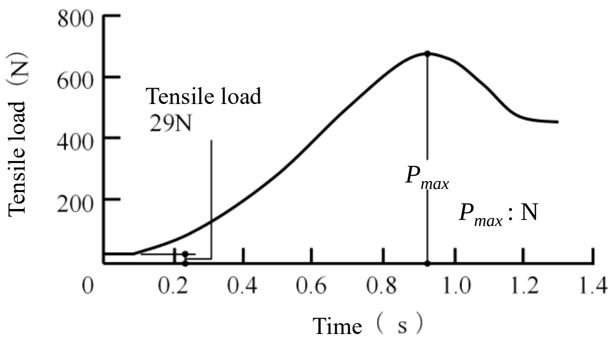


Fig. 3.4.2 Example of a tensile load–time curve measured by the method shown in Table 3.4.1

C_4 is calculated from C_1, C_2, and C_3 using the following equation:

$$C_4 = \frac{|C_1 - (C_2 + C_3) / 2|}{\mathrm{Min}\ \{C_1, (C_2 + C_3) / 2\}} \quad \cdots \text{Equation (3.4.4)}$$

C_4 represents the contrast in slipperiness between the tread and nosing parts of the stairway.

The overall slipperiness of the stairway treads, indicated by "$C.S.R{\cdot}S$," is calculated from C_1, C_2, C_3, and C_4 according to the following equation:

$$C.S.R{\cdot}S = \mathrm{a}{\cdot}C_1 + \mathrm{b}{\cdot}C_2 + \mathrm{c}{\cdot}C_3 - \mathrm{d}{\cdot}C_4 \quad \cdots \text{Equation (3.4.5)}$$

Here, the coefficients a through d are adjusted based on the gender of the users and the types of footwear, as shown in Figures 3.4.4 and 3.4.5. For footwear not listed, coefficients for similar types of footwear should be used.

It is important to note that $C.S.R{\cdot}S$ is highly dependent not only on the type of footwear but also on the presence of surface contaminants such as dust, water, and oil on the tread and nosing. Thus, when conducting measurements, it is crucial to carefully select the appropriate contaminants to apply between the slip piece and the stair surfaces. For standard slip pieces and surface contaminants, refer to Table 3.2.1 in Section 3.2.4.1.

3.4.4.2 Evaluation Method

> The slipperiness of the target stairway tread is assessed by comparing the measured slipperiness performance value, *C.S.R·S*, with evaluation indices that delineate the relationship between slipperiness and *C.S.R·S*.

The evaluation indices are psychological scales related to the safety of stair slipperiness, constructed through sensory test methods and correlate with *C.S.R·S*.

Fig. 3.4.3 shows an example of these evaluation indices. In this figure, circle symbols (●) represent the relationship between the evaluation scale and *C.S.R·S* for safe stairs (tread: 290 mm, riser: 170 mm), which are within the recommended dimensions for safety, ease of ascent and descent, and energy efficiency based on prior research. Triangle symbols (▲) depict the relationship for dangerous stairs (tread: 160 mm, riser: 240 mm), aligning with the marginal dimensions considered dangerous by the Enforcement Order of the Building Standards Act of Japan.

For instance, if the *C.S.R·S* calculated using Equation (3.4.5) is 0.8 for safe stairs with soft-soled dress shoes, the slipperiness would be evaluated as "⑥ Quite safe" according to Figure 3.4.3. For dangerous stairs, a *C.S.R·S* of 0.8 would place the slipperiness marginally below "④ Neither" on the evaluation scale. Further details of the evaluation indices are provided in Figures 3.4.4 and 3.4.5 in Section 3.4.5.

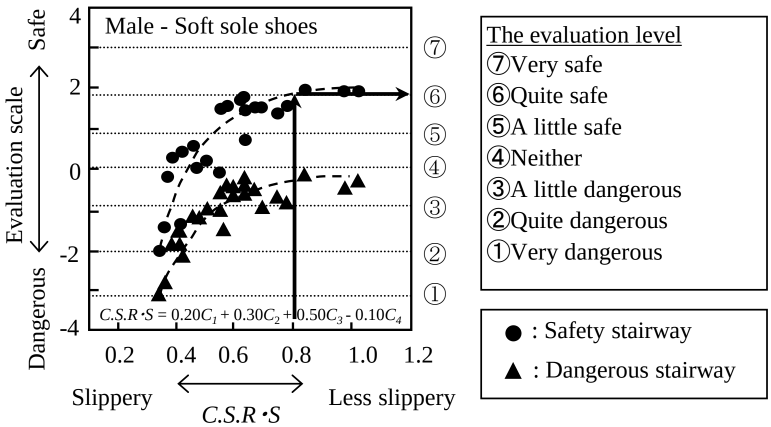


Fig. 3.4.3 Example of evaluation indices and the outline of evaluation procedures

3.4.5 Recommended Performance Values

Table 3.4.2 presents the recommended values of *C.S.R·S*.

Table 3.4.2 Recommended values of *C.S.R·S*
(X represents *C.S.R·S* in the table)

Types of floors	Types of motions	Recommended values
Stairs	Ascending and descending	$0.7 \leq X$

Measurement conditions for *C.S.R·S* (slip piece, floor surface contaminants): All conditions anticipated during actual use are applicable.

Figure 3.4.4 shows the evaluation indices for the slipperiness of stairs, illustrating the performance across different conditions. Figure 3.4.5 presents the evaluation indices for the slipperiness of stairs from the perspective of elderly people, employing a vertical axis based on psychological scales constructed from sensory test results targeted at this demographic.

Analysis of Figure 3.4.4 reveals that a *C.S.R·S* of 0.7 or higher maintains a nearly constant evaluation for stair slipperiness, applicable for both safe and hazardous stair conditions. This consistency indicates the importance of maintaining a minimum *C.S.R·S* of 0.7 to ensure adequate safety. Figure 3.4.5 demonstrates that evaluations remain relatively stable at values of 0.4 or higher, which likely reflects the slower movement speeds of elderly individuals, leading them to perceive lower *C.S.R·S* values as safer. Therefore, for enhanced safety, especially concerning elderly users, maintaining a *C.S.R·S* of 0.7 or higher is recommended.

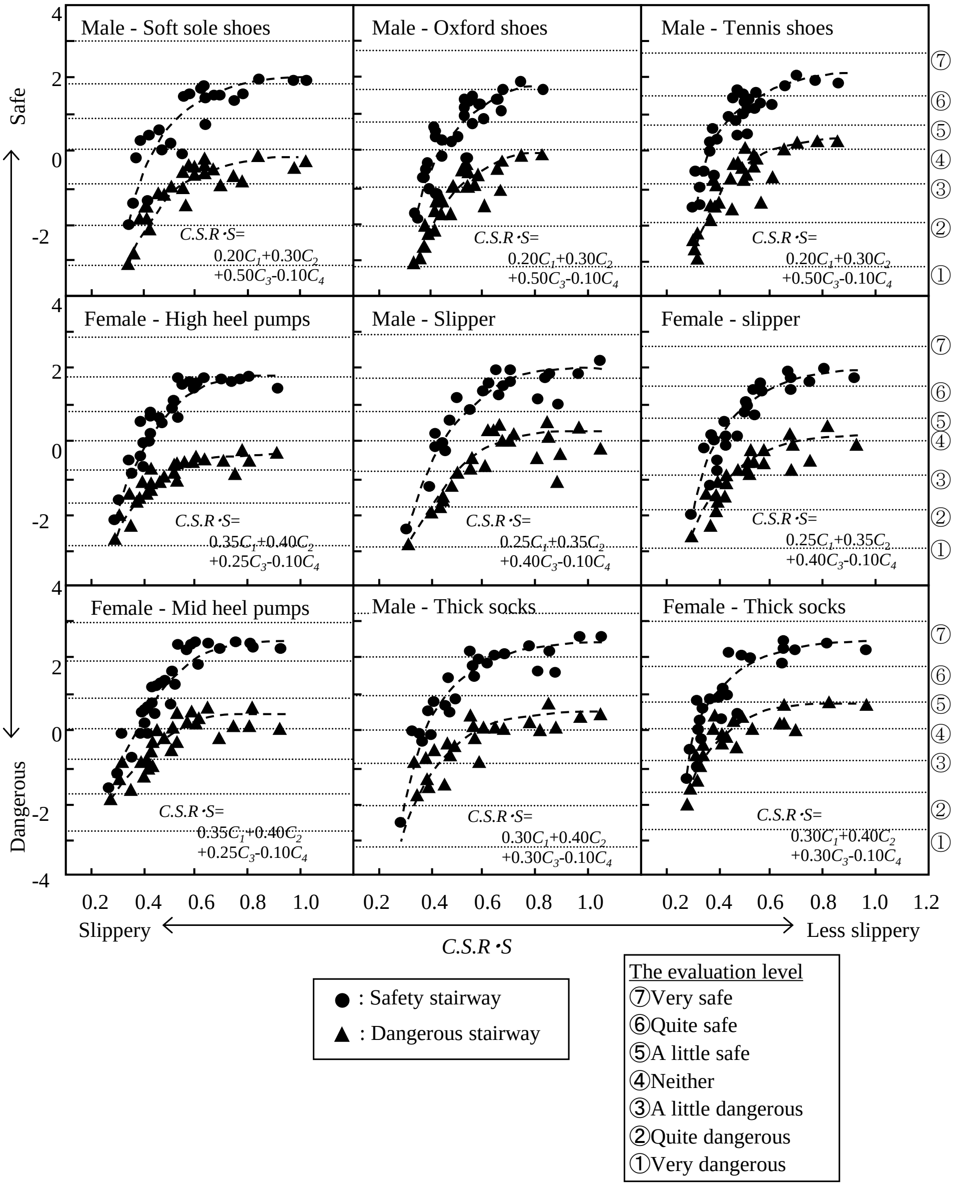


Fig. 3.4.4 Evaluation indices for the slipperiness of stairway treads

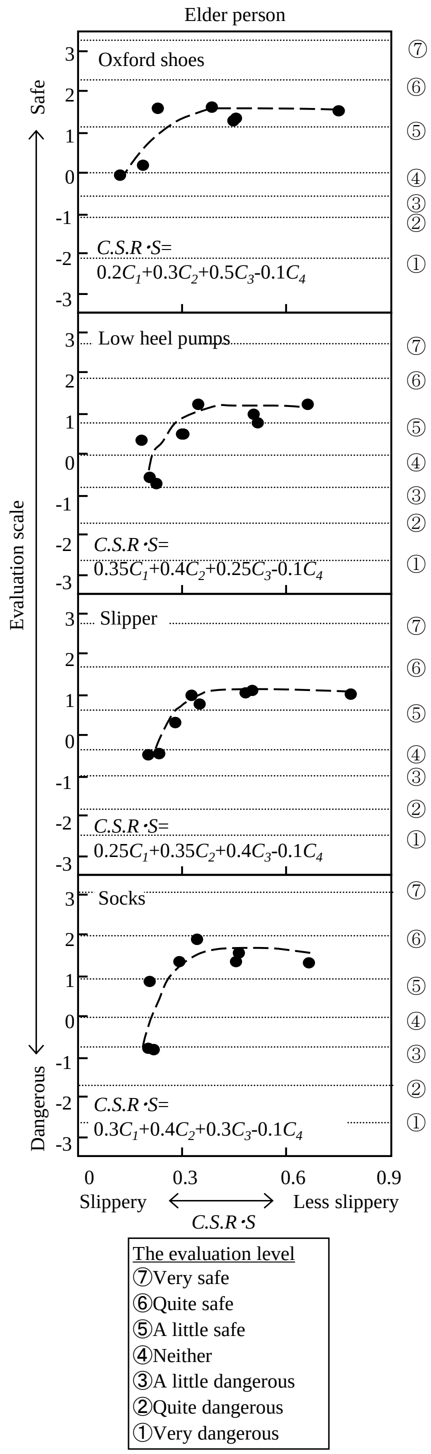


Fig. 3.4.5 Evaluation indices for the slipperiness of stairway treads for elderly persons

References

1) Ono, H., Sudoh, T., and Mikami, T.: Fundamental approach to evaluating method of slip resistance of stairway treads from a viewpoint of safety, Evaluating method of slip resistance of stairway treads from a viewpoint of safety (Part 1), Transactions of the Architectural Institute of Japan, vol. 362, pp. 1–10, 1986.4 (in Japanese)

2) Ono, H., Takeda, K., and Nagata, H.: Measuring method of slip resistance of each part of a stairway tread, Evaluating method of slip resistance of stairway treads from a viewpoint of safety (Part 2), Transactions of the Architectural Institute of Japan, vol. 373, pp. 19–26, 1987.3 (in Japanese)

3) Ono, H., Takeda, K., Mikami, T., and Ohno, R.: Presentation of evaluating indexes and method of slip resistance of stairway treads from a viewpoint of safety, Evaluating method of slip resistance of stairway treads from a viewpoint of safety (Part 3), Transactions of the Architectural Institute of Japan, vol. 383, pp. 1–7, 1988.1 (in Japanese)

4) Ono, H., Izumi, J., Takahashi, H., Isoda, N., Idogawa, J., and Ueda, H.: Relative evaluation method on slipperiness of stairway treads from a viewpoint of safety of the aged, Study on evaluation method on slipperiness of stairway treads from a viewpoint of safety (Part 4), Transactions of the Architectural Institute of Japan, vol. 490, pp. 27–33, 1996.12 (in Japanese)

Section 5 Slipperiness of Ramps (Inclined Floors)

3.5.1 Purpose and Significance

> This section presents methods and recommended values for evaluating the slipperiness when ascending and descending ramps (inclined floors) while wearing footwear.

The goal is to ensure a specified level of slipperiness to prevent accidents. If ramps do not have the appropriate level of slipperiness, there is an increased risk of slipping and falling or stumbling due to excessive slip resistance, which can lead to serious injuries. This section outlines evaluation methods and recommended values for assessing slipperiness as experienced when using ramps in footwear.

3.5.2 Scope of Application

> This section applies to the evaluation of slipperiness on relatively long ramps (hereafter referred to as “long inclined floors”) with an incline of 30° or less, which accommodate more than several steps of movement, both indoors and outdoors. There are no specific restrictions regarding the materials or construction methods of these floors.

While there are shorter ramps, such as threshold ramps that do not allow full-foot contact owing to their length, this section focuses on long inclined floors considering their greater relevance. The applicable incline angle for these floors is 30° or less[1)–3)]. The methods and recommended values presented can be generally applied regardless of the floor materials and construction techniques.

3.5.3 Evaluation Perspective

> The primary concern in evaluating the slipperiness of ramps is safety.

On ramps (inclined floors), the force acting perpendicular to the surface of the ramp is reduced, while the force in the direction of the slope is increased. Additionally, the physical effort required to ascend and descend ramps places a greater burden on the body, makes posture more unstable compared to movement on a horizontal surface, and thereby increases the likelihood of balance loss or falls. Thus, the evaluation of ramp slipperiness is primarily focused on safety.

3.5.4 Performance Evaluation Method

3.5.4.1 Performance Value Measurement Method

> The performance value of slipperiness for long inclined floors, denoted as $C.S.R{\cdot}L_i$ (coefficient of slip resistance for long inclined floors), is measured using the "O-Y·PSM."

This slipperiness measuring apparatus, as detailed in Section 3.2.4.1, is used for assessing the slipperiness of long inclined floors.

Figure 3.5.1 provides an overview of the "O-Y·PSM" slipperiness measuring apparatus.

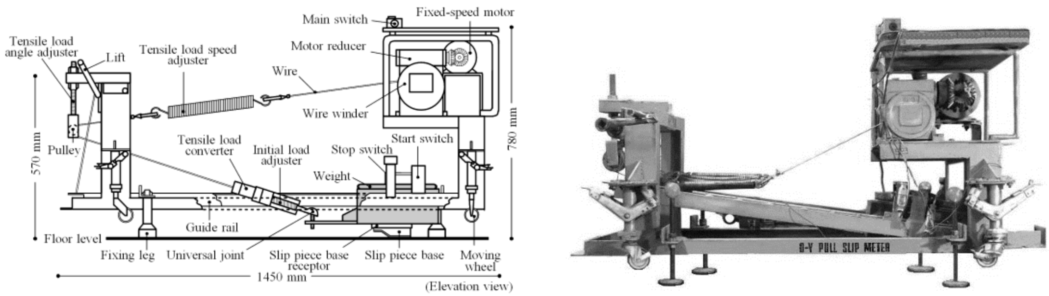


Fig. 3.5.1 Overview of the slipperiness measuring apparatus "O-Y·PSM"

Figure 3.5.2 shows an example of a tensile load–time curve measured using this apparatus when the ramp flooring materials are set horizontally. The slipperiness of the ramp is quantified as $C.S.R{\cdot}L_i$ (coefficient of slip resistance for long inclined floors), which is calculated using the following equation, where P_{max} (N) represents the maximum tensile load shown in the figure and 784 N is the vertical load acting on the slip piece. The inclination angle θ of the ramp is shown in Figure 3.5.3.

$$C.S.R{\cdot}L_i = P_{max} / 784 - \sin\theta \qquad \cdots\text{Equation (3.5.1)}$$

As indicated by the equation, even if P_{max} / 784 remains constant, the $C.S.R{\cdot}L_i$ decreases as the inclination angle θ increases.

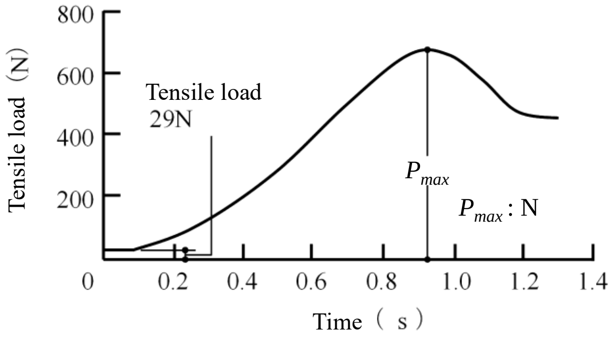


Fig. 3.5.2 Example of a measured tensile load–time curve

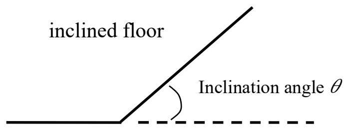


Fig. 3.5.3 Inclination angle θ

$C.S.R{\cdot}L_i$ is significantly influenced by various factors, including the type of footwear and the presence of contaminants on the floor surface, such as dust, water, or oil. Therefore, when conducting measurements, it is essential to select appropriate slip pieces and contaminants for application on the floor surface. For reference, standard slip pieces and surface contaminants are described in Table 3.2.1 in Section 3.2.4.1.

3.5.4.2 Evaluation Method

> The slipperiness performance value $C.S.R{\cdot}L_i$, measured in Section 3.5.4.1, is evaluated by comparing it with evaluation indices that indicate the relationship between the evaluation of slipperiness and $C.S.R{\cdot}L_i$.

The evaluation indices are psychological scales related to the safety of slipperiness, constructed using sensory test methods, and illustrate their relationship with $C.S.R{\cdot}L_i$.

Figure 3.5.4 shows an example of the evaluation procedures. The evaluation levels indicated in the figure correspond to the positions of judgment categories used in sensory tests to construct the vertical evaluation scales. If the $C.S.R{\cdot}L_i$ calculated using Equation (3.5.1) from measurements taken with the “O-Y·PSM” is 0.4 while descending a long inclined floor in dress shoes, then Figure 3.5.4 indicates that the slipperiness of the long inclined floor is evaluated as “⑥ Quite safe.” Additional details of the evaluation indices are provided in Figures 3.5.5–3.5.7.

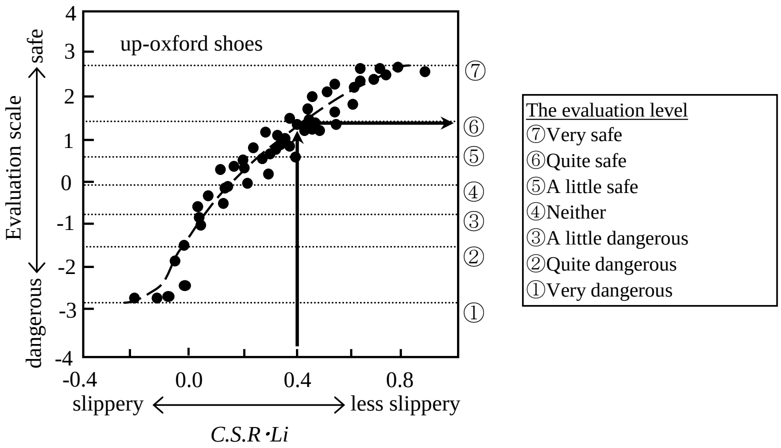


Fig. 3.5.4 Example of an evaluation index and the outline of evaluation procedures

3.5.5 Recommended Performance Values

Table 3.5.1 presents the recommended values of $C.S.R{\cdot}L_i$.

Table 3.5.1 Recommended values of $C.S.R{\cdot}L_i$

(X represents $C.S.R{\cdot}L_i$ in the table)

Types of floors	Types of motions	Recommended values
Inclined floors	Ascending and descending ramps	$0.4 \leq X$

Measurement conditions for $C.S.R{\cdot}L_i$ (slip piece, floor surface contaminants): All conditions anticipated during actual use are applicable.

Figures 3.5.5–3.5.7 show the evaluation indices for the slipperiness of long inclined floors.

For horizontal floors, the general policy for setting recommended slipperiness values from a safety perspective involves using the performance values corresponding to the central evaluation stage (④ in Figure 3.5.5). However, for inclined floors, given the increased likelihood of accidents and injuries due to slipperiness, the recommended value for ramp slipperiness is set two stages higher than the central stage (⑥ in Figure 3.5.5), which is 0.4 or higher. For instance, with a slope of 7° (approximately 1/8), sinθ is 0.12, thus reducing the $C.S.R{\cdot}L_i$ value by 0.12. This requires P_{max} / 784 to be at least 0.52 to meet the recommended value. Because P_{max} / 784 corresponds to the $C.S.R$ for a horizontal floor, special caution is advised when using flooring materials designed for horizontal applications on ramps.

Figure 3.5.6 shows evaluation indices constructed using sensory test results targeting elderly individuals. Figure 3.5.7 presents evaluation indices based on sensory test results for crossing a ramp (moving in a direction perpendicular to the slope). The recommended value of 0.4, when compared to Figures 3.5.6 and 3.5.7, corresponds to evaluation levels above the central stage in each of these indices.

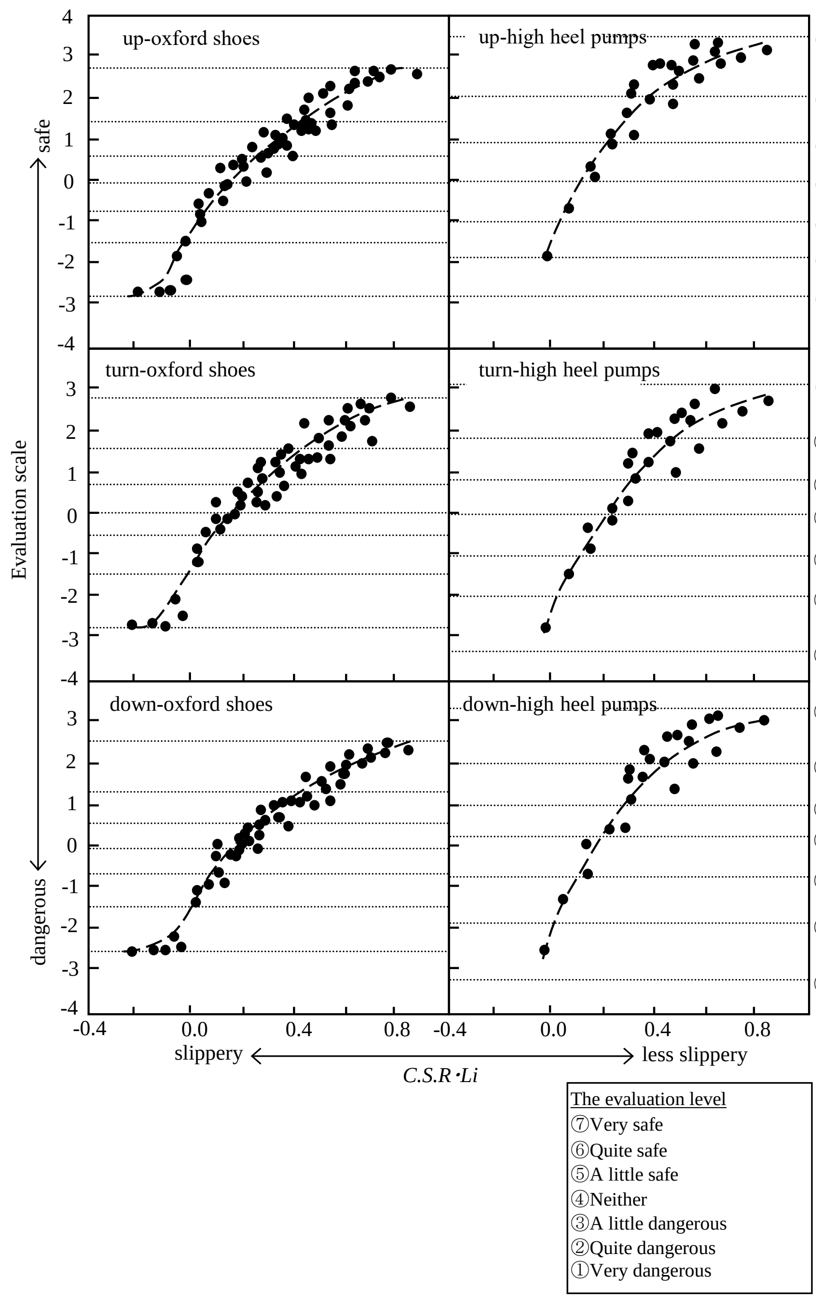


Fig. 3.5.5 Evaluation indices for the slipperiness of long inclined floors[1)]

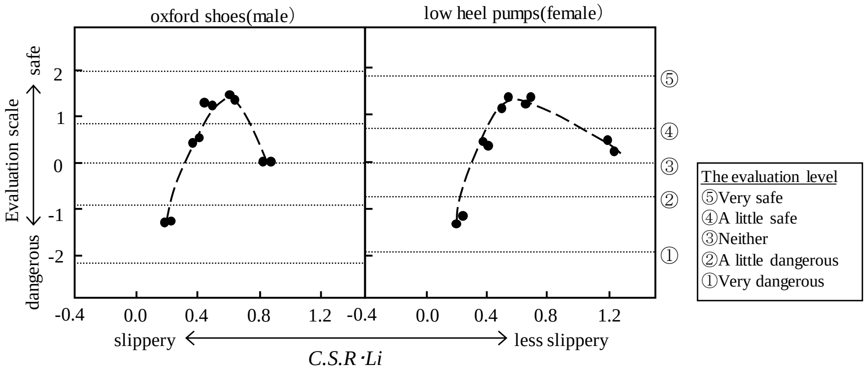


Fig. 3.5.6 Evaluation indices for the slipperiness of long inclined floors for elderly persons[2)]

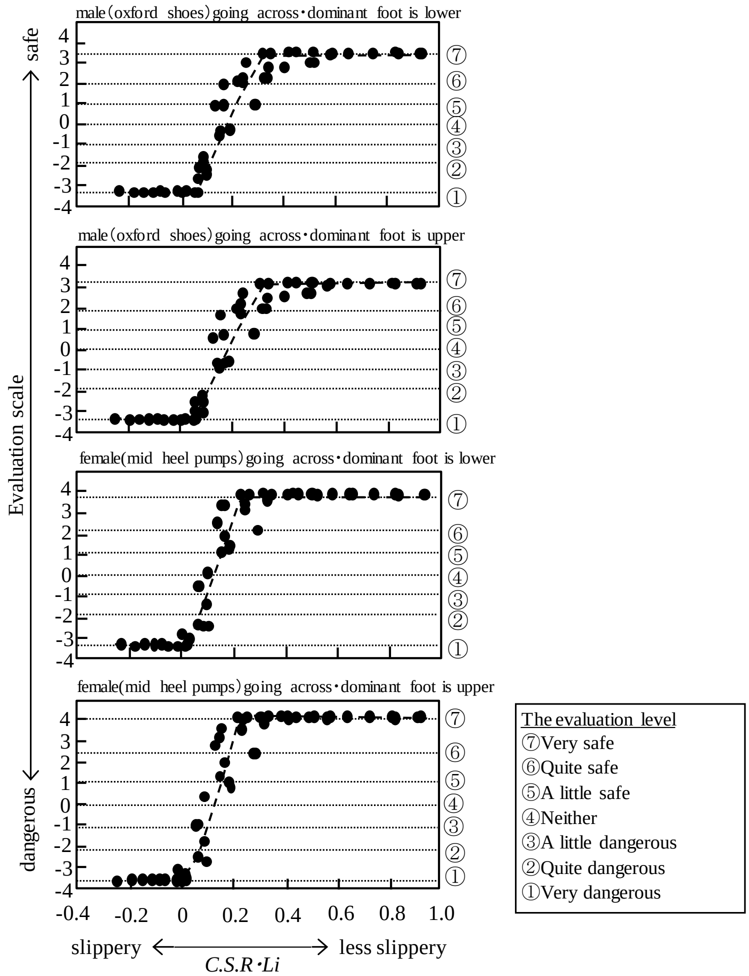


Fig. 3.5.7 Evaluation indices for the slipperiness during crossing of long inclined floors[3)]

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