A SUPER HIGH-RISE ESCALATOR WITH A HORIZONTAL MID-SECTION

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ABSTRACT

This paper describes an escalator having a horizontal section in the middle of its 42m rise. Details of studies on technical issues such as motor starting circuit, load distribution among multi drive units, synchronization of steps and handrails, step pulsation and handrail de-railment, which were considered throughout the designing of the escalator, are described herein.

1. INTRODUCTION

In recent years, with the increasing development of large-scale resort and transportation centers, demand for high-rise escalators has been growing as the means of pedestrian access in their facilities. The advantages of escalators, such as, no-waiting time before boarding and spacious atmosphere in the open air, have enhanced the growth of needs toward the escalators that can operate even in higher rise.

While the demand for high-rise escalators grows, consideration to the specific aspects of escalators, besides the basic functions required for the transportation means, such as, improvement of psychological effect by enhancing the pleasure of travel and by reducing the passengers' fear of height, preservation of scenic views, harmonization with the surrounding environment, flexibility in architectural layout, provision of safety features, has also been growing. As a means to satisfy the demands derived from such consideration, an escalator with a section of horizontal travel can be applied.

A super high-rise escalator with a horizontal mid-section was developed based on the high-rise escalator technology which is applied to the modular drive system (shown in Fig.1). The super high-rise escalator was delivered to "REOMA WORLD" which opened in Kagawa Prefecture, Japan in April, 1991 (shown in Fig.2). The escalator has a unique horizontal mid-section which can rarely be seen in the world and its rise of 42m is the highest in the East. The outline of this super high-rise escalator is presented in this paper.

2. INSTALLATION BACKGROUND AND SPECIFICATIONS

"REOMA WORLD" is a large recreation and resort facility with a total land area of 690,000m^2. In the early stage of its development, a super high-rise escalator was proposed as a means of transportation to carry a large number of visitors between the ground level and the top of the hill that is 42m high. Since the amusement and resort facilities are located in a beautiful forest by a lake, the escalator had to be installed along the surface of the mountain to preserve the scenic views of nature. In order to eliminate the passengers' fear of height, a horizontal mid-section of 10m long is provided at the height of 12m from its landing entrance. For passengers' convenience, the escalator is covered by a transparent open-type dome. The specifications of the escalator are shown in Table 1 and the escalator layout is shown in Fig.3.

3. FEATURE OF SUPER HIGH-RISE ESCALATOR WITH A HORIZONTAL MID-SECTION

Until quite recently, escalators exceeding 20m in rise had been rare in Japan. In order to prepare an escalator as a transportation means to connect the differences in elevation over 40m,

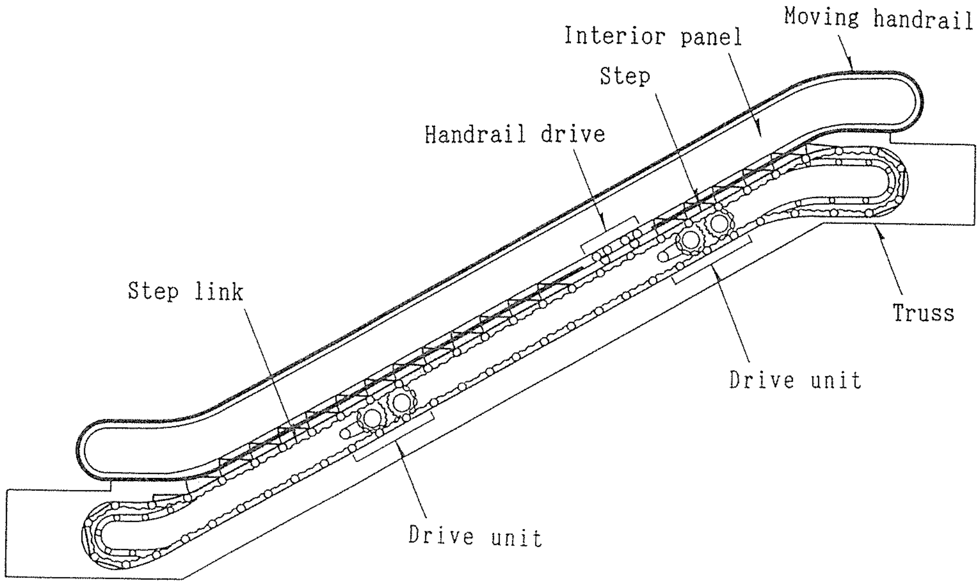


Fig.1 Structure of Modular escalator.

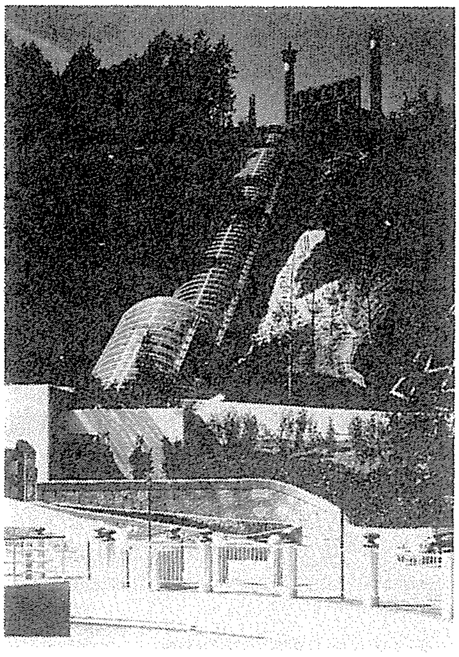


Fig.2 Escalator installed at "REOMA WORLD"

Table 1 Specifications.

Type	1200AP-J
Balustrade	Stainless-steel panel
Balustrade width	1.2m
Environment	Outdoor(with dome)
Speed	30m per minute
Inclination angle	30°
Carrying capacity	9000 passengers per hour
Total rise	42m
Upper rise	30m
Lower rise	12m
Midsection length	10m
Power supply	440VAC,60Hz
Motor capacity	5.5kW×10

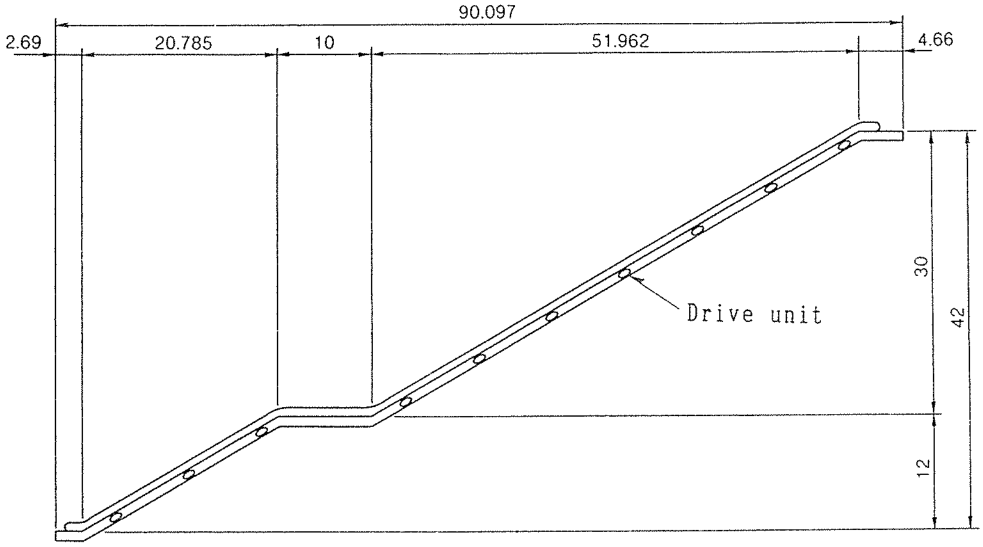


Fig.3 Escalator layout (dimensions in meters).

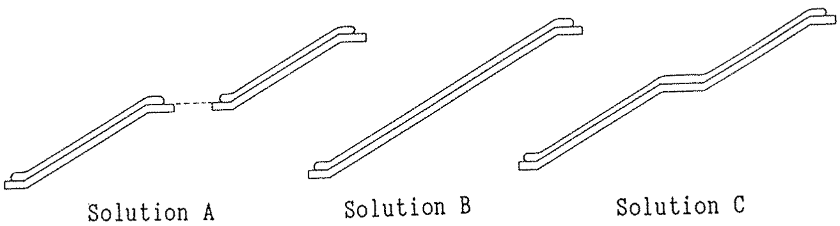


Fig.4 Three high-rise escalator layouts.

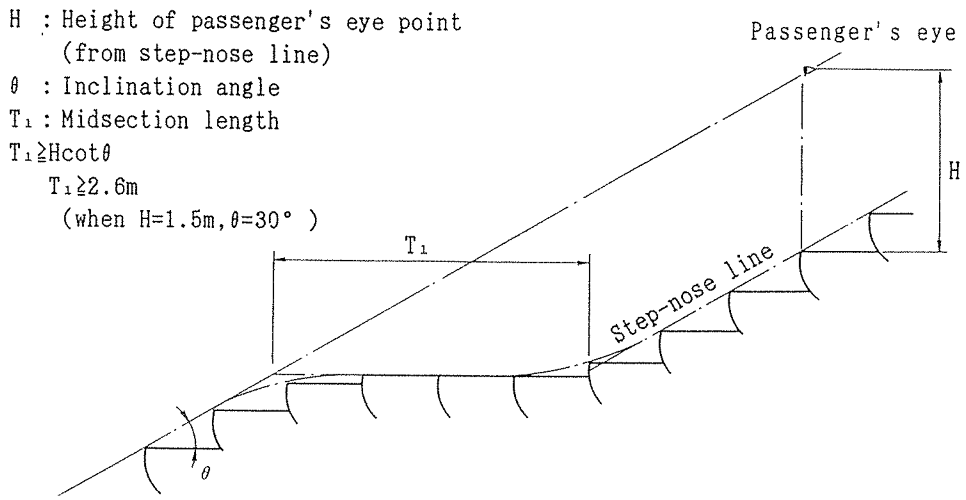


Fig.5 Required midsection length.

we studied the technology for the hard-ware, as well as other factors in all aspects such as passenger's safety, convenience, psychological effect and architectural layout of the escalator. Three possible configurations shown in Fig.4 were studied as the high-rise escalator transportation system.

Use of two low-rise escalators (Solution A) is functional but inconvenient because the passengers must get off and reboard the escalator in the middle. The additional boarding and alighting is also undesirable in terms of safety because there have been many passengers involved accidents in the landing zones of escalator. In addition, architectural considerations require certain excess space around the landing area, which layout flexibility may preclude.

On the other hand, use of one super-high rise escalator (Solution B) eliminates the shortenings of the two low-rise escalator system, but the descending passengers may have acrophobia upon boarding or during the ride. In addition, passengers may find the ride irritating and tiring since they stand in the same posture during the long ride.

Solution C avoids the problems associated with Solutions A and B. The horizontal mid-section of Solution C breaks the monotony of a single long rise. It also blocks the view of the lower escalator section, avoiding the appearance of a long drop that could be unsettling to descending passengers. The length of landing necessary to block the view is shown in Fig.5. The horizontal mid-section provides a fresh, attention-getting variation on linear escalators that makes the ride enjoyable, while allowing greater flexibility in facility layout.

4. TECHNOLOGY OF SUPER HIGH-RISE ESCALATORS

4. 1 MOTOR-STARTING CIRCUIT

The steps are driven by the multi-drive system in which ten (10) individual drive units are located (Fig.3). Each drive unit motor is supplied with a Kondorfer starting circuit with an auto-transformer that limits the large starting current and lowers the mechanical shock delivered to the escalator equipment when the motors are energized (Fig.6). Prevention of starting shock is effective to protect the escalator equipment and also to prevent mis-detection of the safety devices.

The following is the comparison of Kondorfer starting circuit with other types of starting circuits (shown in Table 2).

(1) Comparison with sequential motor-starting circuit

In case of sequential motor-starting circuits, the escalator is started with only a few motors and afterwards the other motors are energized. The starting of the escalator equipped with Kondorfer starting circuits is smoother, because the circuits evenly generates the torque in all motors simultaneously.

(2) Comparison with 人-△ motor-starting circuit

For 人-△ motor-starting circuits, wiring in the multi-drive unit becomes more complicated as six (6) wires are needed in each motor. Furthermore contactors for changing the circuit in the same number as that of motors are necessary, and thus the control circuits also become more complicated.

(3) Comparison with invertor motor-starting circuit

Auto-transformers are more reliable than invertors as they consist of simple parts and the maintenance of auto-transformers is easier.

(4) Comparison with reactor motor-starting circuit

Kondorfer starting circuits can limit the starting current to lower level than reactor starting circuits.

The comparison indicates that Kondorfer starting circuits are the most suitable circuits for multi-drive system.

4. 2 LOAD DISTRIBUTION TO EVERY DRIVE UNIT

In multi-drive system, the drive units must be so positioned that the load to each drive unit and the tension on each step link become even, since uneven load and tension will cause over-load to some motors and degrade the ride quality.

Positioning method called "spacing", in which drive units are positioned in the escalator's longitudinal direction, causes even distribution of load and tension to the drive units and the step links. A technique that makes the positioning in the "spacing" method simple and highly accurate was developed, and applied to the escalator delivered to the "REOMA WORLD".

Fig.7 shows the measurement of power consumption of the motors which are positioned in the "spacing" method.

The dotted line and the solid line in Fig.7 show the theoretical step link tension and the measurement of tension after the positioning in the "spacing" method respectively. It is characteristic of the modular drive system that compression of the step link exists on the upper side of each drive unit.

Although the measurement which was made on an escalator with no-load (equivalent to about 20% of the motor rating load) varies depending on the characteristics of each motor, we obtained excellent results of power consumption and step link tension.

4. 3 SYNCHRONIZATION OF HANDRAILS AND STEPS

One of the technical concerns regarding the handrail drive is the synchronization of handrails and steps. Generally, the moving handrails are driven by a traction drive system which is different from the drive system for the steps. This system involves slight slippage during operation, which can vary depending on a number of factors. In the case of a long handrail such as that of a super high-rise escalator, small difference in speed between the steps and the moving handrail which can be ignored for low-rise escalators, will accumulate, causing the gap in the positions between the passengers and the handrails.

The synchronization data of handrail in dry and wet conditions are shown in Fig.8. When the driving force for the handrail is not sufficient, the speed difference between dry condition (the running resistance is low) and wet condition (the running resistance is high) will became greater. This means that the handrail speed will differ from the step speed due to the change of the handrail condition, even when the handrail speed is designed to be synchronized with the step speed. Therefore it is necessary to reduce the running resistance of the moving handrail (especially in wet condition) and to increase the handrail drive capacity in order to continuously synchronize the moving handrails and the steps.

As a countermeasure to reduce the running resistance of the handrail, idler rotation rings were installed at the upper and the lower newels (reversal portion of the moving handrail), and many rollers were provided along the handrail guide on the passenger side and the return side. As a result, the handrail running resistance was reduced to the same level as that of a low-rise escalator, this is surprisingly low for a super high-rise escalator with a horizontal mid-section. In addition to raising the handrail drive capacity, the number of handrail drive units were increased. As a result, the handrail drive capacity became 10 times as much as that of a low-rise escalator.

Due to the application of the above countermeasures, the synchronization between the moving handrails and the steps both in dry and wet conditions was greatly improved.

5. TECHNOLOGY OF HORIZONTAL MID-SECTION
5. 1 HANDRAIL DE-RAILMENT COUNTERMEASURES

Though the handrail tension in the lower concave portion (B part) of a low-rise escalator is low, there is a large amount of tension in the inter-mediate concave portion (A part) of an escalator with horizontal mid-section. As shown in FIG 9, this high tension creates a force in a

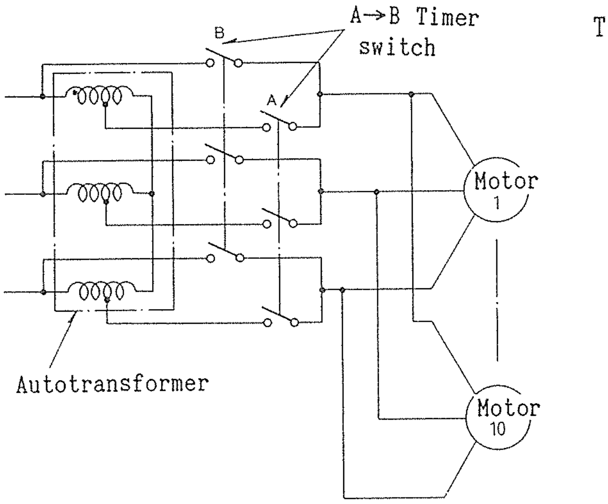
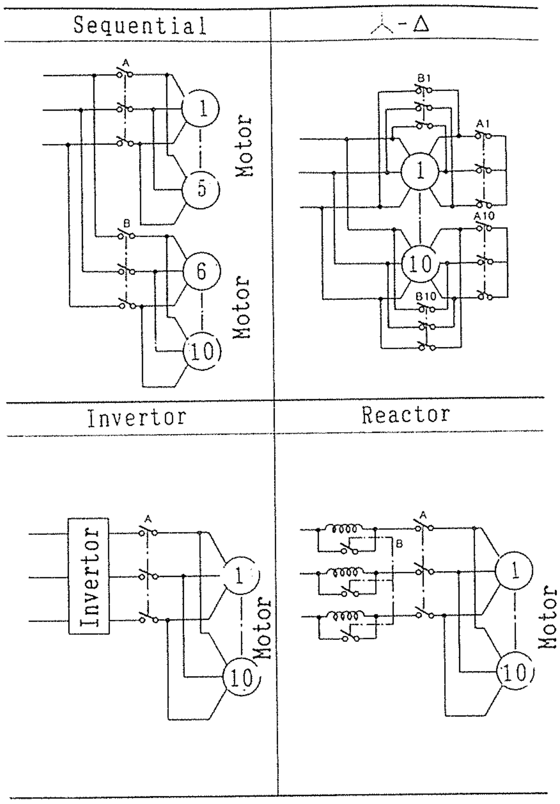


Fig.6 Kondorfer motor-starting circuit.

Table 2 Other motor-starting circuits.



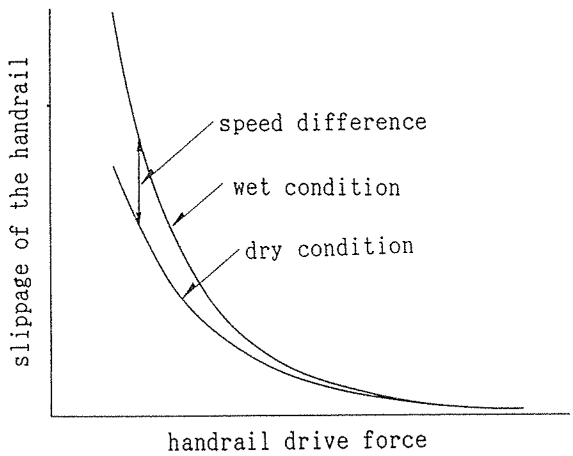


Fig.8 Relation between slippage of handrail and handrail drive force.

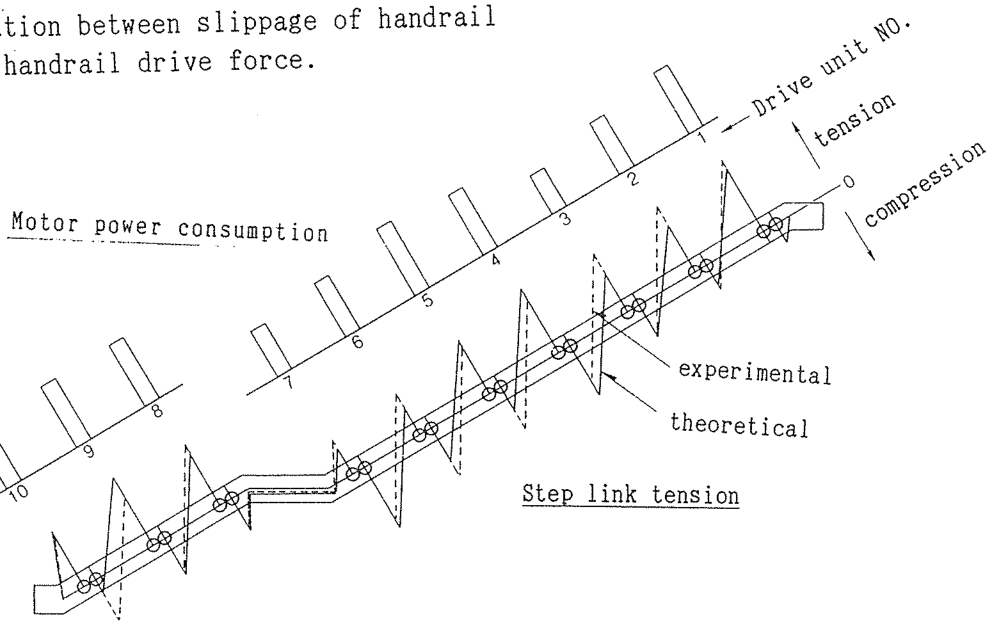


Fig.7 Motor power consumption and distribution of step link tension.

direction which tense to pull this handrail off. In addition the handrail in this portion of the escalator is subject to external forces from various direction by the passengers.

To prevent the handrail from coming off, we reduced that portion of the handrail force in the direction to pull the handrail off by applying a large-sized radius of curvature of the handrail guide. In addition we developed and provided a handrail de-railment safety device. The handrail de-railment safety device with a sensor, shown in Fig 10, detects the distance from the steel tape, located inside the handrail as the reinforce element.

5. 2 STEP PULSATION COUNTERMEASURES

As shown in Fig 11 the each step link forms a straight line against the curved track. Because of difference between straight line and curved line, the velocity of step roller located at the start of the curved track is always different from the velocity of at the exit of the curved track. That is to say, when roller Cx moves with constant velocity, roller Cy moves with uncertain velocity. A pulsation is produced at a frequency determined by the step link pitch.

In the case of the modular drive system the drive units engages to the step link at the incline portion before and behind the horizontal mid-section, and the riding comfort over the drive unit gets worse and step pulsation increases.

The distance from normal line A to roller Cx is assumed to be X, the distance from normal line B to roller Cy located the other side of the curved track is assumed to be Y, as shown in Fig 11.

The pulsating quantity $\triangle Z$ is the total change quantity of $Z=(X+Y)$ when value of X is changed. If the value of Z is constant, pulsation does not occur. The radius of curved track is assumed to be R, escalator incline angle is assumed to be θ, the step link pitch is assumed to be P,

$$\theta_1 = \cos^{-1}\{(L^2 + R^2 - P^2)/2RL\} \quad \cdots\cdots\cdots\cdots \quad (1)$$

Here $L = (R^2 + X^2)^{1/2}$

$$\theta_2 = \theta_1 - \tan^{-1}(X/R) \quad \cdots\cdots\cdots\cdots \quad (2)$$

$$\theta_3 = 2\sin^{-1}(P/2R) \quad \cdots\cdots\cdots\cdots \quad (3)$$

$$\theta_4 = \theta - \theta_2 - \theta_3 \quad \cdots\cdots\cdots\cdots \quad (4)$$

Hereupon $A = R(1 - \cos\theta_4)$

$$Y = (P^2 - A^2)^{1/2} - R\sin\theta_4 \quad \cdots\cdots\cdots\cdots \quad (5)$$

$$Z = X + Y \quad \cdots\cdots\cdots\cdots \quad (6)$$

The calculation of the total change quantity of Z when the value of X changes from $X = 0$ to $X = P$, results in the pulsating quantity $\triangle Z$, as follows.

$$\triangle Z = Z_{max.} - Z_{min.}$$

The relationship between radius of the curved track and the pulsating quantity is shown in Fig. 12. The pulsating quantity can be minimized by selecting the best radius for the curved track. Based on the foregoing calculation , when the step link pitch is 408mm, to minimize the pulsation, a curvature 1750mm, 2500mm or 3300mm should be selected. It is thus possible to reduce the pulsation to 1/18 or less than that experienced with a curvature 1300mm.

We applied this best curvature in all of the tracks at the horizontal mid-section, and the pulsation could not be measured.

6. SAFETY CONSIDERATIONS

For improvement of safety, the super high-rise escalator is provided with many safety features as shown in Fig.13 and described below :

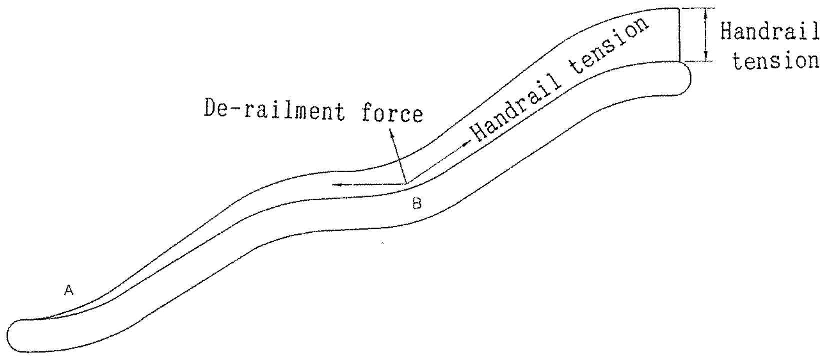


Fig.9 Distribution of handrail tension.

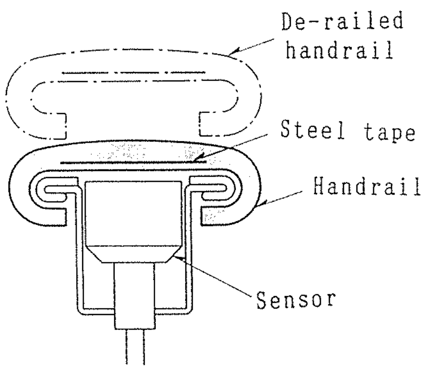


Fig.10 Handrail de-railment safety device.

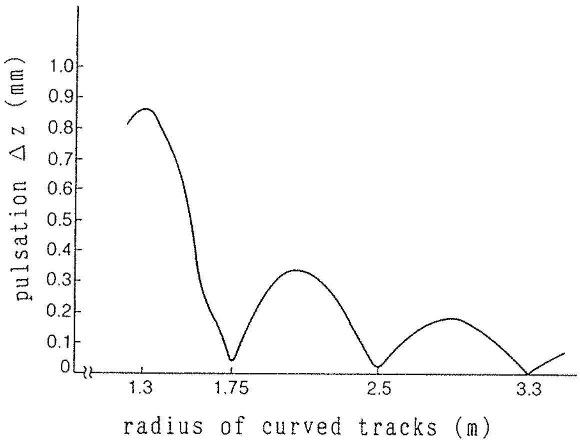


Fig.12 Relation between pulsation and radius of curved-tracks.

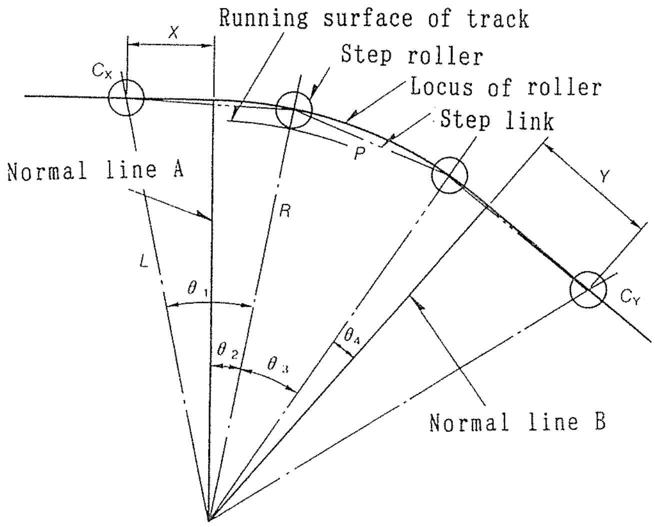


Fig.11 Relation between curved-track and step link.

(1) Improvement of braking characteristics
Brake capacity is improved and braking deceleration is also improved for smoother stop.

(2) Extension of top and bottom flat steps
It is effective for safety boarding and alighting.

(3) Handrail speed safety device
This device activates when the handrail speed decreases below design limits.

7. TEST RIDE RESULT

The psychological value of a horizontal mid-section in high-rise escalator greatly exceeded original expectations. Especially, it is effective for eliminating the passengers' anxiety from the downward view from the top (shown in Fig.14). According to the result of test ride of 100 passengers, 87% of the passengers replied that the horizontal mid-section is very effective for the elimination of anxiety, 92% of passengers preferred it to two low-rise escalators.

8. CONCLUSION

The super high-rise escalator with a horizontal mid-section as developed proved to be a solution to the psychological problem of passengers' anxiety. Moreover, horizontal mid-section is not only applicable to super high-rise escalators, but also will be effective on the area of standard rise escalators. And, this application on standard rise escalators is expected to offer new amenities by providing a unique design.

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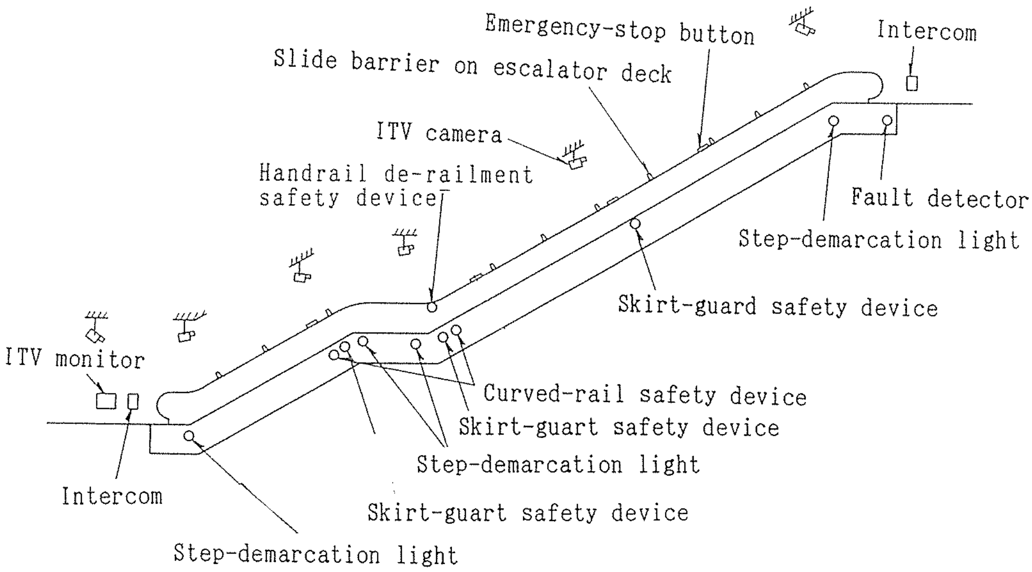

Fig.13 Safety teatures.

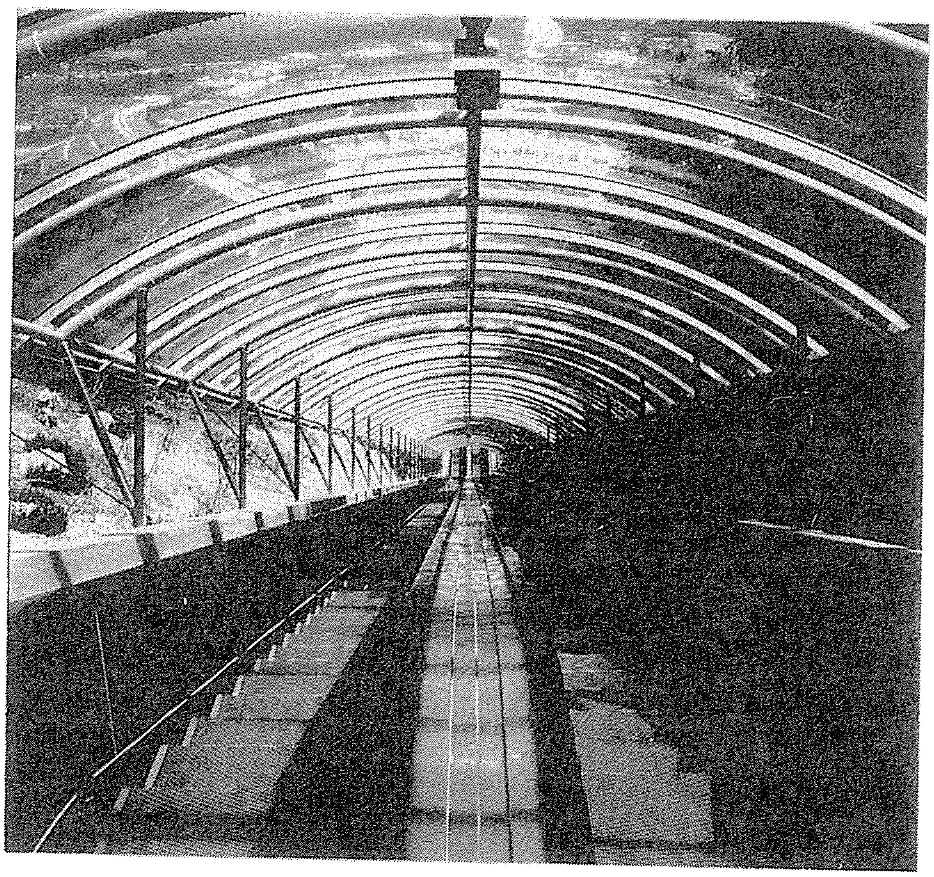

Fig.14 View from the top of escalator.