

Development of an Ideal Sleeper



Masaki Sue*



Yuki Okumura**



Yuichiro Hori*



Takayuki Onodera*

Prestressed concrete sleepers are currently designed under a concept formed about 50 years ago. As a result of our investigation of prestressed concrete sleepers that have been used on tracks for about 40 years, most of them are shown to retain their strength sufficiently. We have thus started research to make sleepers thin, reviewing their strength according to track conditions. On the other hand, the material of under sleeper pads (USP), which are recognized for their effectiveness for reducing track settlement, is rubber in Japan and urethane in Europe. We confirmed that the performance in reducing track settlement by urethane was superior to that of rubber by cyclic loading tests. Since we expect various effects by urethane, we have started research on using urethane as material for USPs. Into the future, we will develop a so-called "Ideal Sleeper", which has suitable thickness and is composed of effective resilient materials, in order to mitigate our maintenance work.

●Keywords: Sleeper, Resilient Sleeper, Under sleeper pad (USP), Ballast

1 Introduction

Sleepers have important roles of broadly distributing train loads transmitted from rails to ballast as well as of securing rails to maintain the gauge. At present, mainly prestressed concrete sleepers (PC sleepers) are used, except in sections with special conditions. Our surveys of the strength of sleepers that have been used for 30 to even 50 years after being laid revealed them for the most part to be sound. We thus decided to review the design strength of sleepers and undertake research on the development of thinner sleepers. At the same time, we also decided to start research on a urethane under sleeper pad (USP) with ideal physical properties and shape for resilient sleepers. USPs have proved effective in reducing track subsidence. Rubber USPs are the prevailing type in Japan, but USPs of urethane have been commercialized and deployed in Europe, and urethane USPs can be expected to have many other effects in addition reducing track subsidence. This article will introduce our efforts in making thinner sleepers and developing a so-called "Ideal Sleeper" using an effective USP.

2 Design Strength of PC Sleepers and Possibility of Making Them Thinner

JR East has, since the pre-privatization Japanese National Railways (JNR) era, developed and deployed many types of PC sleepers, including those for local lines. The design strength of sleepers applied up to now is based on theories established in the development of standard sleepers for main track in 1961, during the JNR era. However, the service life of PC sleepers is still unknown. In light of that, we decided to survey the deterioration level of the sleepers used for about 30 to 50 years after being laid (including some sleepers used for about 10 years) and re-examine design strength and other standards.

2.1 Strength of Sleepers Used for 30 to 50 Years

We collected from branch offices in fiscal 2013 a total of 103 defective sleepers that have been in use for 30 to 50 years. Those

were selected from defective PC sleepers with cracks on the surfaces or with damage to sleeper plugs in which bolts of the rail fastening system are put (Fig. 1). To observe their deterioration level, we conducted appearance checks, strength tests, and other tests.



Fig. 1 Defective Sleepers

The results of sleeper plug pullout strength tests (Fig. 2) are as shown in Fig. 3. About half of the sleepers fell below the standard value at which sleepers must break when applied with a load specified in Japanese Industrial Standards (JIS), and about 20% of the sleepers were below the proof load at which sleepers must not crack, showing a high rate of sleeper plug damage or deterioration. In terms of sleeper plug fracture resistance, we found some variation, but no significant difference.

In concrete compressive strength tests using core-drilled samples shown in Fig. 4, we confirmed that about 20% fell below the standard value, while the rest were for the most part sound. No aging deterioration was found (Fig. 5).

In bending strength tests and checks of the amount of prestress of PC steel rebar, corrosion, and the like (Fig. 6), we found that the sleepers were for the most part sound, indicating that there was no drop in the functionality of the body of sleepers used for 30 to 50 years.

From those results, we can conclude that the major reason for sleepers to be defective is insufficient strength of the sleeper plug. However, the strength of the sleeper body is maintained with the majority of the sleepers, excluding the problem of defective sleeper plugs.



Fig. 2 Sleeper Plug Pullout Strength Test

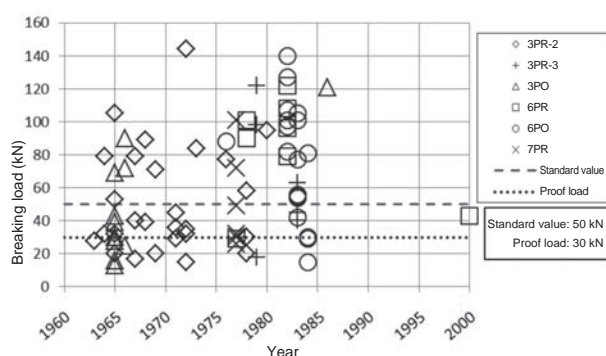


Fig. 3 Results of Sleeper Plug Pullout Strength Tests



Fig. 4 Core Sampling in Compressive Strength Test

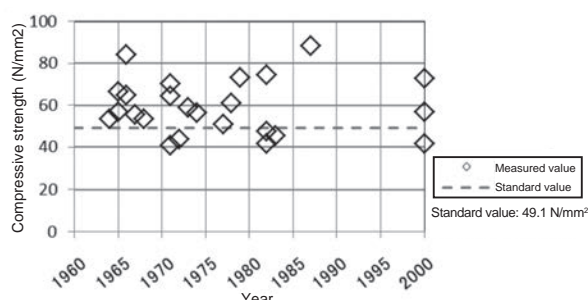


Fig. 5 Results of Compressive Strength Tests



Fig. 6 Condition of PC Rebar

2.2 Current Design Strength

Design strength of sleepers can be obtained by multiplying the wheel load (the load of the wheel applied perpendicularly to the rail surface) by the dispersive power and the wheel load fluctuation rate. The actual situation of dispersive power is not exactly known in the current track condition. Moreover, the wheel load fluctuation rate takes account of the impact rate at the rail joint, and there is a possibility as well that the wheel load fluctuation rate includes overestimation of the impact rate on relatively stable tracks other than at rail joints. As the aged sleepers we checked maintain for the most part soundness as described in the previous section, the current design strength for PC sleepers other than those used at rail joints is likely to be unnecessarily high.

2.3 Possibility of Making PC Sleepers Thinner

For the design load with which the design strength of sleepers is calculated, we have to take account of the conditions of sections and sites where the sleepers are to be laid (rail joints and ordinary tracks) and precisely identify the behavior of the sleepers when a train runs on them, such as the dispersive power and the wheel load fluctuation rate. If we achieve those, we will be able to review the current design strength to design a thinner PC sleeper.

2.4 Effects of Thinner PC Sleepers

If we can put thinner PC sleepers into use, we can secure sufficient ballast thickness in sleeper replacement work without large-scale track improvement work such as raising the track or lowering the ballast at sections with structural restrictions. When thinner sleepers can be used for track with relatively unfavorable conditions such as where the ballast is degraded, new ballast to serve as an adjustment layer is inserted to the space created by making the sleepers thinner as shown in Fig. 7. That could improve drainage in the ballast as well.

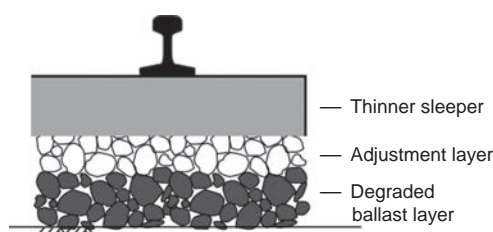


Fig. 7 Image of Ballast with Thinner Sleepers

2.5 Effects of PC Sleepers in Special Sections

A turnout using PC sleepers has been laid at the yard of the Otsuki Station on the Chuo Line (inbound line) with an aim of reducing maintenance work (Fig. 8). Even 20 years after being laid, the repair history for the latest five years showed that maintenance work needed there was just tamping on the whole turnout once to repair track irregularity of levelness and regular replacement of material at the turnout, proving great labor-saving effects were gained when compared with other turnouts nearby. If thinner and lighter PC sleepers can be used, material cost could probably be reduced and workability in sleeper replacement radically improved.



Fig. 8 Turnout Using PC Sleepers in Yard of Otsuki Station on Chuo Line

PC bridge sleepers are laid on some bridges on the Senzan Line (Fig. 9). Those have also been used for about 20 years since being laid, and the recent repair history indicates that they remain in good condition even with no history of material replacement. If ideal PC bridge sleepers with smaller thickness and other improved functionality are successfully developed, considerable reduction of material cost will be achieved when compared with the cost of current synthetic sleepers.



Fig. 9 PC Bridge Sleepers on Senzan Line

3 Planned Check of Dynamic Behavior and Review of Design Strength

We are planning to collect data on which we will base review of the design strength of PC sleepers according to the conditions in which they are used. Here we introduce the details and methods of measurement for the data collection.

3.1 Identifying Dynamic Behavior Using Cutting-edge ICT

To identify dynamic behavior of PC sleepers when a train runs on them, we will make use of motion capture technology where cameras capture and analyze movement of markers attached to the subject to enable measuring of aspects of the subject such as speed, angle, and acceleration. For example, as seen in Fig. 10, when a person to which markers are attached at body joints makes a throwing motion, movement of the whole body, the speed of the wrist, and other data can be measured. This technology is used in many different fields such as measurement and analysis of the human body.

In past checks, we measured with markers attached to sleepers as shown in Fig. 11. As a result, we were able to determine that the technology can be used to observe behavior of sleepers when a three-car train runs on them as shown in Fig. 12, capturing sleepers dynamic behavior such as track subsidence per axle and uplift of sleepers as wheels passed (a phenomena whereby load

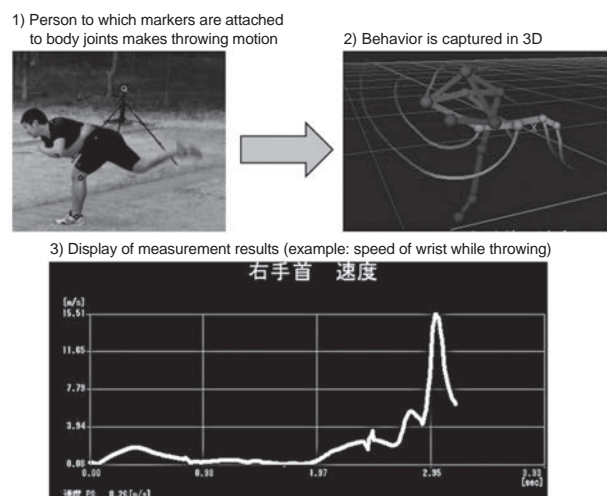


Fig. 10 Example of Motion Capturing



Fig. 11 Markers

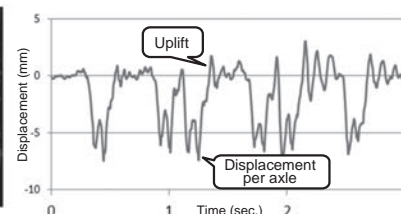


Fig. 12 Behavior While a Train Is Passing

of a wheel on a sleeper raises the next and previous sleepers). With traditional measurement methods, many devices needed to be implemented to use displacement gauges, and displacement gauge setup work required much time and labor. With motion capture technology, we can improve measurement work efficiency as well as worker safety since the cameras can be set up outside of the track (Fig. 13). We are now planning to confirm the dynamic behavior characteristics of sleepers on commercial lines using that technology.



Fig. 13 Camera Setting

3.2 Review of Design Strength of Sleepers Based on Measurement on Commercial Track

We are planning to take measurements of the pressure on the lower surface of rails when a train passes on the track of commercial lines with different section conditions such as sections where express trains run and sections where freight trains run. In the measurement, we will use track pads with pressure sensors, employing piezoelectric elements as shown in Fig. 14. Such track pads with pressure sensors can significantly cut material costs when compared with traditional track pads having strain

gauges and accelerometers embedded, thus providing advantages such as ability to measure over longer distances. Based on the results of the measurement of rail pressure, we will make detailed investigations on dispersive power of load, which tells how much the dynamic load applied on the sleepers is distributed to the next and previous track sections as shown in Fig. 15. We are planning to review design strength of sleepers according to the situation under various line conditions sections.



Fig. 14 Track Pad with Sensors Using Piezoelectric Elements

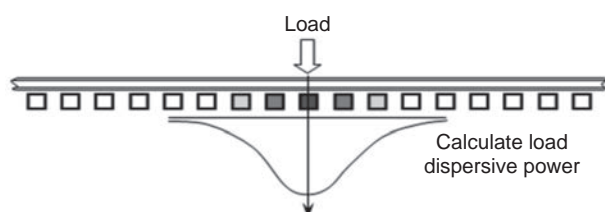


Fig. 15 Load Distribution

4 Possibilities for Under Sleeper Pads Used for Resilient Sleepers

USPs have been developed for purposes such as controlling subsidence of track, with rubber being the main material used in Japan, and the effects of those have been confirmed. However, in Europe, many types of USPs using urethane have been commercialized and introduced. With understanding of the characteristics of urethane USPs, we decided to start development of a urethane USP that will suit conditions in Japan.

4.1 Effects of Current Resilient Sleepers

Aiming to achieve goals such as reduced maintenance work and vibration, research on resilient sleepers as shown in Fig. 16 has been underway in Japan for about 30 years. USPs for resilient sleepers are mainly made of rubber (styrene-butadiene rubber, SBR) or urethane. Many tests of USPs of those materials have been carried out in Japan too, and rubber USPs have become mainstream for reasons such as material costs. Rubber USPs in Japan have gained a certain level of appreciation in terms of their ability to control subsidence of track as shown in Fig. 17. However, they have yet not come into wide use. Furthermore, we have no concrete information on the spring constant and thickness of resilient sleepers needed to effectively control subsidence of track. We thus decided to take measurements using a full-scale track tester.



Fig. 16 Resilient Sleeper

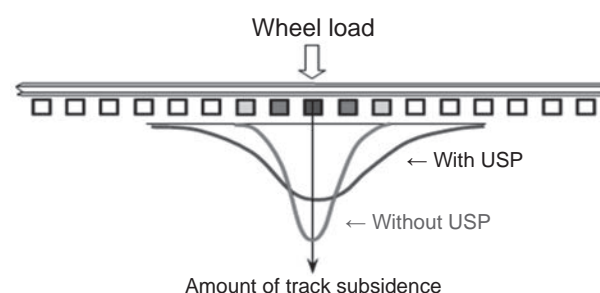


Fig. 17 Track Subsidence Control Effect of USPs

4.2 Evaluation of Effects of Resilient Sleepers Using a Full-Scale Track Tester

In fiscal 2013, we conducted tests in areas such as subsidence characteristics of resilient sleepers with USPs (rubber or urethane) used in Japan and other countries. The tests were done using a full-scale track tester shown in Fig. 18.



Fig. 18 Full-Scale Track Tester

As shown in Table 1, six types of USPs were tested: three rubber USPs and three urethane USPs. The thickness of the USPs is 10 to 20 mm. Bedding modulus (BM) values here are units used in European Norm standards to represent physical properties such as elastic modulus. We used those values as reference for physical properties of those materials.

Table 1 Types and Physical Properties of USPs

	Test sample 200 mm × 200 mm					
	Urethane A	Rubber A	Rubber B	Rubber C	Urethane B	Urethane C
BM value measured (kN/m ²)	7	8	8	9	11	21
Thickness (mm)	10	20	15	15	10	10

As the load conditions, we set a wheel load of 51 kN (taking into consideration wheel load equivalent to that of an EF66 electric locomotive with load dispersive power) and a frequency of 7 Hz (equivalent to velocity of 60 km/h), and we repeatedly applied that load up to 600,000 tons at which we see progress in subsidence of the track after initial subsidence (Fig. 19). The results are as shown in Fig. 20. We found no significant difference between the results with no USPs and with rubber USPs or urethane USPs. On the other hand, the amount of progress of track subsidence between 200,000 to 600,000 tons after initial subsidence is shown in Fig. 21. The results indicate that resilient sleepers have an effect of controlling subsidence of track when compared with sleepers without USPs. When comparing the USPs of different materials, the amount of subsidence of track tends to be smaller with urethane USPs than with rubber USPs. In measurement of lateral resistance of ballast shown in Fig. 22, the three types of urethane USPs showed higher resistance than



Fig. 19 Cyclic Loading Test

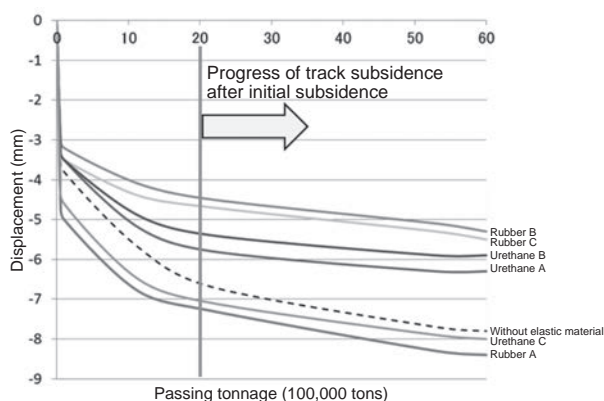


Fig. 20 Comparison of Track Subsidence of Resilient Sleepers

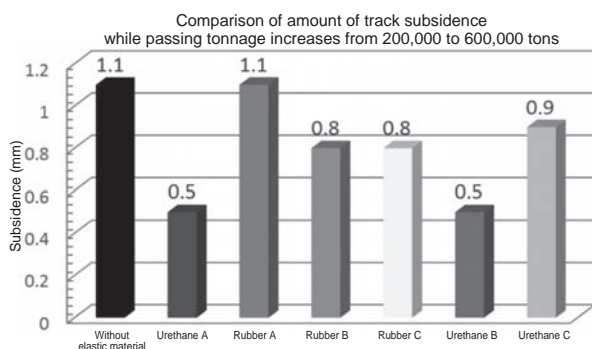


Fig. 21 Comparison of Progress of Track Subsidence of Resilient Sleepers After Initial Subsidence

the three types of rubber USPs (Fig. 23). The reason could be due to much gravel being biting into USPs and increasing contact area, thus increasing lateral resistance borne on the bottom surface of resilient sleepers.

In terms of factors such as the shape and spring constant of USPs effective in controlling subsidence of track and the vibration under the USPs, we observed no quantitative characteristics or tendencies, so we could not identify the optimal material for USPs.

4.3 Expectations for Urethane USPs

As explained above, rubber USPs for resilient sleepers are the mainstream in Japan. In contrast, urethane USPs have recently become the prevailing type in Europe, with many products being commercialized and introduced according to linearity conditions and purposes. Urethane is excellent in terms of flexibility and shock-absorbing properties, and the material itself has elasto-plastic deformation characteristics. Having those characteristics, urethane USPs increase the contact area between the bottom surface of a resilient sleeper and the gravel as shown in Fig. 24, preventing the gravel from being worn or rolling away. They also alleviate the load transmitted from the sleeper to the ballast, so further effects in controlling subsidence of track can be expected. Moreover, by making the spring constant of USPs equal to the spring constant of ballast of ordinary ballasted track (load required to cause a unit amount of perpendicular subsidence of

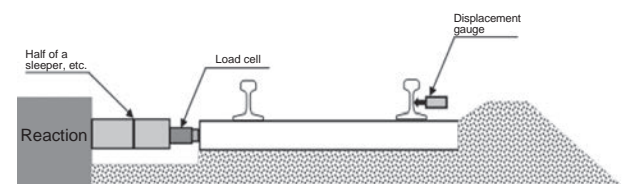


Fig. 22 Measurement of Ballast Lateral Resistance

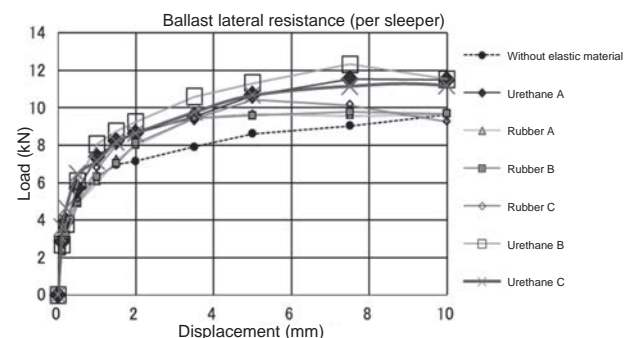


Fig. 23 Results of Measurement of Ballast Lateral Resistance

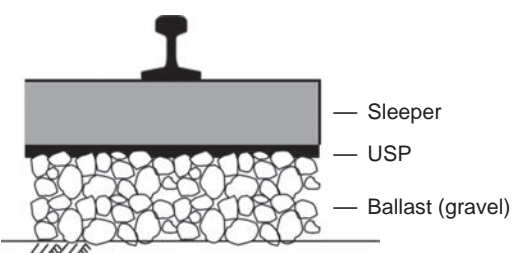


Fig. 24 Image of Contact between an USP and gravel

the surface of the ballast under resilient sleepers), urethane USPs might possibly serve as a substitute for gravel. We plan to start development with a focus on urethane material with which we can expect those effects.

4.4 Future USP Development

4.4.1 Study on Effective Spring Constant and Shape

Taking into consideration conditions such as train speed and load, we will study the effective spring constant and shape including thickness of USPs by applying perpendicular load and vibration to samples that simulate contact with ballast, as shown in Fig. 25. We will also check the effect of the performance of elasto-plastic material, such as initial subsidence immediately after a train passes, vertical amplitude while a train is passing, and recovery after a train passes. Furthermore, applying lateral load to the same samples, we will measure direct shearing force to evaluate binding force and resistance against deterioration of gravel. Based on the results of those tests and evaluations, we will determine the optimal shape and performance for USPs.

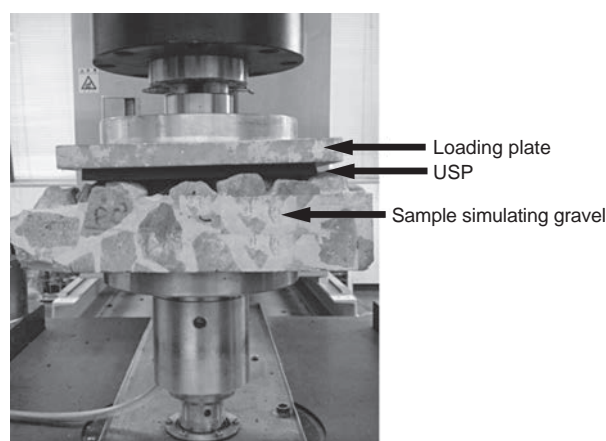


Fig. 25 USP Evaluation Test

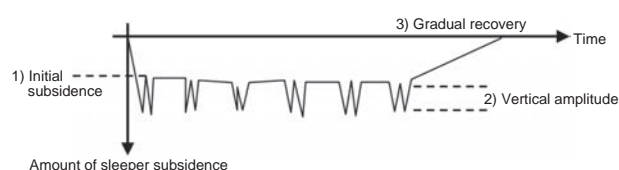


Fig. 26 Image of Elasto-Plastic Material

4.4.2 Verification Using a Full-Scale Track Tester

Based on the USPs studied in 4.4.1, we will carry out tests using a full-scale track tester to measure items such as track subsidence characteristics, track spring constant, vibration characteristics, and ballast lateral resistance. That will be done with different patterns of load, velocity, etc. to comprehensively evaluate and verify the effects and durability of resilient sleepers when laid on actual track. In this way, we will make performance evaluation of USPs and select the optimum USP.

4.5 Possibilities for USPs

With development of USPs that make full use of urethane material, it will be possible to control subsidence of track by reducing vibration as well as to make the thickness of sleepers

smaller than current ones by reducing the load transmitted to the ballast.

Moreover, by giving USPs, which are elastic bodies, the spring constant of ballast, resilient sleepers can be made to be elastic too. Securing such elasticity could possibly eliminate the need of ballast replacement work of sites with defective ballast. Moreover, the elasto-plastic characteristics of urethane could also reduce vibration transmitted to the ballast, thus preventing phenomena such as mud pumping and reducing ground vibration.

5 Conclusion

In this paper, we have given an overview of and covered possibilities for development of a thinner PC sleeper and “Ideal Sleeper” with the optimal USP. Achieving that development will allow selection of materials suiting the conditions for individual sections, significantly reducing costs of material and maintenance work. We also believe that we can expect such sleepers to be adopted taking into account life cycle cost of materials and the like and innovation to maintenance management concepts. We will thus go forward with research and development of those with an aim of their actual introduction.

Reference:

- 1) Shigeru Miura, Fujio Oishi, Atsushi Yokota, Takahiro Horiike, “Development of Resilient Tie for Practical Use”, *RTRI Report*, Vol. 4, No. 5 (May 1990)
- 2) Takahiro Horiike, Masanori Hansaka, Hideaki Yanagawa, Katsutoshi Ando, Kazuhiro Date, “Development of Low Cost Resilient Sleeper for Ballasted Track”, *RTRI Report*, Vol. 12, No. 3 (March 1998)
- 3) Railway Technical Research Institute, Draft of *Tetsudo Kozobutsu-to Sekkei Hyojun, Do Kaisetsu, Kido Kozo [Yu-dosho Kido]* [in Japanese], (March 1997)
- 4) Railway Technical Research Institute, *Tetsudo Kozobutsu-to Sekkei Hyojun, Do Kaisetsu, Kido Kozo* [in Japanese], (Maruzen Publishing, January 2012)
- 5) Toshimitsu Miyamoto, Kainen Watanabe, *Senro: Kido no Sekkei Kanri* [in Japanese], (Sankaido Publishing, June 1980)