Recent Tendencies in Ballasted Track Maintenance

Atsushi FURUKAWA
JR Affairs, Research & Development Promotion Division (The former Director of Track Technology Division)

Ballasted track is widely as a main track structure and requires regular maintenance because track geometry deteriorates under the influence of dynamic loads. Therefore, several pieces of research into prediction and prevention of ballasted track deterioration, and maintenance of deteriorated ballasted track have been conducted by RTRI or other organizations around the world. This paper introduces some of the results obtained from the recent research into ballasted track carried out by RTRI and suggests possible future developments in this field.

Keywords: ballasted track, ballast settlement, maintenance work, maintenance scheduling, tamping work

1. Introduction

Ballasted track, which is widely used as a major track structure, requires regular maintenance because of gradual settlement and deformation. A range of studies and developments are underway in Japan and abroad to reduce the need for regular maintenance of ballasted track. This report outlines the results of some of the latest R&D activities at RTRI and future trends in ballasted track maintenance.

2. Overview of recent studies on ballasted track

Studies about ballasted track can be classified into the following fields:
(1) Mechanisms behind settlement of ballast layer
(2) Ballast settlement law
(3) Measuring and assessment of condition of ballasted track
(4) Maintenance schedule for ballasted track
(5) Ballasted track maintenance operations
(6) Life cycle cost evaluation for ballasted track
(7) Measuring and assessment of condition of ballasted track
(8) Anti-seismic facilities

Field 1 - Mechanisms behind settlement of ballast layer: This area is one of the most basic themes related to ballasted track and has long been studied extensively in Japan and abroad. Studies in this area began before WW II. The first systematic analysis was made in “the theory of track deterioration,” released in the 1950s [1]. Recently, large-scale simulation is revealing the behavior of sleepers and ballast stones subject to train loads.

Field 2 - Ballast settlement law: A number of empirical formulas have been proposed based on track loading tests that were conducted using full-scale models [2]. More recently, prediction models for tracks settlement using FEM and DEM analytic techniques were developed. However, no analytic models exist today that are practical enough to be used for designing ballasted track. Instead, the empirical formula mentioned above is often used in design processes.

Besides settlement of the ballast layer, theories for predicting growth with time in track irregularity have been proposed. In Japan, the S-formula [3], proposed in 1978, is well known. The optimum maintenance scheduling model developed by RTRI uses exponential smoothing to predict track irregularity based on track measurement records [4].

Field 3 - Measuring and assessment of condition of ballasted track: A method has been proposed for evaluating ballast condition based on data obtained from track recording cars. Data typically used are processed track irregularity data (5m-chord versine or subtraction in longitudinal level measurement) and axlebox acceleration [5].

Field 4 - Maintenance schedule for ballasted track: An optimum tamping-machine operation scheduling system using mathematical programming has been developed for practical application. This will be discussed in Section 4 of this report.

Field 5 - Ballasted track maintenance operations: This area has been discussed primarily by tamping machine manufacturers including optimum excited vibration frequencies. In addition, maintenance procedures that take into account spots lacking the required ballast layer’s thickness and spots with deteriorated ballast as well as a method for evaluating sleeper supporting stiffness after tamping, have been developed by RTRI. These items will be discussed in Section 3 of this report.

Field 6 - Life cycle cost evaluation for ballasted track: Ballast settlement can be reduced through structural reinforcement techniques, such as use of heavy rails and prestressed concrete sleepers and increasing the number of sleepers. Although these measures will increase construction cost, they can lower maintenance costs. The most economical option is to adopt the track structure with lowest life cycle cost (LCC), which in this case is the sum of construction and maintenance costs. In Japan, the optimum track structure based on the theory of track deterioration mentioned above is well known. This optimum track structure evaluation is what the Japanese National Railways used to decide on ballasted track as the main track structure. At RTRI, a long-term optimum track structure maintenance scheduling system using mathematical programming is being developed [6].

Field 7 - Ballasted track-specific sections: It is well known that ballast settles faster in sections where track...
stiffness changes rapidly, such as abutments or at the edge of road crossings, and several measures to remedy this problem are being studied in Japan and abroad. At RTRI, a method using automatic irregularity correcting sleepers was developed [7].

Area 8 - Anti-seismic facilities: It has been known that the stability of ballast layer is reduced by seismic vibration during earthquakes. A review is underway on the evaluation of ballast’s lateral resistance during earthquakes. A related report has been released in RTRI REPORT Vol. 29, No. 8, Aug. 2015.

Lastly, the resistance force of the ballast layer is an important parameter for ballasted track performance. In Japan, this parameter has been a component in research and development on continuous welded rails.

3. Study on ballasted track maintenance operations

3.1 Evaluation of sleeper supporting stiffness after tamping using FWD

The condition of the under-sleeper ballast layer can change after tamping. The ability to detect any change immediately after tamping is useful for controlling tamping work. At RTRI, a kinematic tamping controlling method using a FWD (Falling Weight Deflectometer) for taking measurements on the edges of sleepers or rails is being developed to improve the quality of tamping work [8].

The kinematic method uses the sleeper support spring constant \( K_S \) (Fig. 1 (a)) to indicate sleeper supporting stiffness and response displacement delay \( T_D \) (Fig. 1 (b)) to obtain the sleeper supporting condition, both based on FWD measurements. Verification trials on test and commercial lines found that the method was useful for quantitative evaluation of the effect of tamping work, by comparing measurements from before and after tamping (Fig. 2) and to ascertain the supporting stiffness of hanging sleepers.

3.2 Maintenance of thin ballasted layer

In normal tamping operations, a manual tamping tool (TT) is inserted around 100 mm below the bottom of the sleepers to tamp and pack ballast under the sleepers. When the ballast layer thickness is less than 100 mm due to structural and other reasons, insertion of the tool becomes difficult, substantially hampering tamping operation. In addition, due to the larger ballast stones relative to ballast layer thickness, tamping can become uneven across the ballast, possibly leading to premature track irregularity. As such, a track tamping method, that can effectively handle areas with a thinner ballast layer, was developed [9].

The tamping method uses single-sized crushed stones smaller than the ballast and a special TT. The special TT is equipped with tools that are bent steeper (Fig. 3) than the normal tool so that they can reach under the sleepers even where the ballast layer is thin. The special tool is twice as wide at the tip as the normal tool to enable it to efficiently tamp small crushed stones and has a forked end to ensure sufficient insert.

Experiments using a full-scale track model verified the effectiveness of the tamping method. It was also found that the diameter of the crushed stones being used must be less than half the ballast layer thickness. A trial operation with the special TT on a commercial line revealed that the track was still in good condition 10 months after the operation.

3.3 Maintenance of ballasted track mixed with fine-grained soil

Hanging sleepers, often seen on ballasted track, can lower ride quality, turn ballast stones into smaller grains and cause mud pumping. A possible result from this is in-

![Fig. 1 Evaluation parameters based on FWD measurements](image)

![Fig. 2 Change in \( K_S \) after tamping](image)
creased ingress of fine-grained soil into the ballast, weakening the effect of tamping. Replacement of ballast is an effective solution but costly.

To eliminate the need for ballast replacement, a polymer mixing method was developed whereby a two-mixed-liquid type biodegradable polymer is packed under the sleepers together with ballast by a TT [10]. This method does not require any special tools as the polymer is injected under the sleepers using a TT, as shown in Fig. 4.

The method was tested using a full-scale model and, after its effect was verified, was then tried on a commercial line. It was found that 10 months after the trial, the track was still in good condition.

4. Study on ballasted track maintenance scheduling

4.1 Tamping-machine operation scheduling support system

Tamping machines are used for continuous maintenance (continuous tamping and track realignment) of ballasted track. Currently, tamping machine operations are scheduled taking into account track and other working conditions (maintenance depot layout, restriction in operation hours, compatibility with other maintenance operations, etc.), which is time and resource consuming. RTRI therefore developed a tamping-machine operation scheduling system. Using numerical formulas to take into account various constraints, the system proposes optimum scheduling according to the following optimization tasks:
1) minimize the track irregularities (the sum of the standard deviations of all lots) or
2) minimize the total work volume (or the total track length worked) of the tamping machine in the given track conditions [11]. The outline of the system is

![Fig. 3 Tamping method for thin ballast layer](image)

![Fig. 4 Outline of polymer mixing method](image)

![Fig. 5 Tamping-machine operation scheduling support system](image)
4.2 Maintenance planning based on replacement of track components

As track components deteriorate, such as roughening of the rail surface, or deterioration of ballasts, the effect of tamping work will decrease, leading to a need for more frequent maintenance. On the other hand, maintenance such as rail grinding or ballast replacement, may be more onerous in the short term but can create savings on long-term maintenance costs (Fig. 6). RTRI developed a long-term track maintenance scheduling system that covers track component replacement by upgrading the tamping machine operation scheduling support system mentioned above [5]. The long-term track maintenance scheduling system evaluates the condition of components based on track irregularity and axlebox acceleration data and, based on these results, creates track maintenance schedules that realize minimum LCCs.

Currently, the application range and accuracy of the system are being determined by comparing its data against corresponding actual data.

5. Future prospects

As discussed above, ballasted track requires a range of maintenance operations. This has led to the development of non-ballasted track solutions in Japan and abroad. It is therefore considered unlikely that ballasted track will be adopted for new lines or sections of large-scale improvement such as the construction of new viaducts.

Nevertheless, tracks are a continuous structure, and since they must be continuous, the combination of sleeper and ballast has high maintainability appeal. Japan is frequently hit by earthquakes, heavy rain and other large-scale natural disasters. Ballasted track can be restored relatively quickly by refilling the ballast and tamping. That is why ballasted track is likely to continue to be used as a primary track structure, but only when the following major technical challenges are overcome.

1) Ballast settlement law

As discussed in Section 2, a number of empirical formulas have been developed. While these formulas were derived from repetitive loading tests at fixed points, it is important in the future that empirical formulas which faithfully represent running trains be developed from loading tests that simulate a moving load. It is also important going forward for practical analysis models to be developed which can accurately estimate ballast settlement by accommodating a range of factors such as changes in sleeper shapes, the introduction of under-sleeper pads and changes in ballast layer thickness.

In addition, the degree of settlement and degradation of ballasted track are likely to be very different from one to the next, even with the same structure. It is therefore necessary to develop statistical settlement prediction methods that take variation into account based on high volumes of track measurement data.

2) Optimization of maintenance procedures

While some of the methods developed by RTRI are presented in Chapter 3, ideal maintenance of ballasted track will require consolidated procedures of the following elements:

① Evaluation of the condition of ballasted track

② Selection of optimum maintenance methods based on the results of the above noted evaluation

③ Evaluation of track condition immediately after maintenance, to enable a decision to be made on whether follow-up maintenance is required

Optimum maintenance methods mentioned in ② above include the selection of techniques such as tamping and ballast replacement, and the selection of parameters such as...
as the tool insert depth of the tamping machine, the duration of squeezing and squeeze force. Element ③ above applies to FWD which was discussed in Section 3. RTRI has been working on systematic methods with tamping machines.

3) Track maintenance with combined methods

While Section 4 covers the scheduling of multiple maintenance machines and a track components maintenance scheduling system, maintenance cost can be reduced further by carrying out multiple maintenance operations at the same site simultaneously. For example, LCCs can be reduced by operating a tamping machine and a rail grinding machine, currently operated separately, at the same time. That is because rail grinding reduces wheel load variation and, in turn, ballast settlement. Optimum maintenance scheduling systems that combine multiple maintenance types such as the one just mentioned above are currently being studied.

4) Review on maintenance procedures

The style of maintenance discussed above could best be performed at a minimum cost if conducted during the daytime with sufficient track possession periods secured. In Europe, either one line of a double track is possessed during the daytime for maintenance while the other line is used for two way operations. While this raises a number of challenges, such as a major changes to the signaling system and insertion of a crossover between stations, this model should be realized here as well so that ballasted track can be maintained properly.

6. Conclusion

Ballasted track has been used since railway services were originally launched and are expected to be in place into the foreseeable future without major changes. Today, with an aging population and low birth rates, railway operators are and will be struggling to increase revenues from rail transport while trying to secure a sufficient labor force. In this social environment, sustainable use of ballasted track will require continued development of a range of technologies such as those presented in Section 5. RTRI will continue to strive to work on improving the maintenance of ballasted track through cooperation with related partners.

Part of RTRI’s study on the FWD and long-term track structure optimization scheduling system was subsidized by the Ministry of Land, Infrastructure, Transport and Tourism.

References


Author

Atsushi FURUKAWA
Director, JR Affairs, Research & Development Promotion Division
(The former Director of Track Technology Division)