STUDY ON THE MEASURES TO IMPROVE THE DURABILITY OF CHINESE CRTS

I SLAB TRACK

Hongsong Lin
Senior Engineer, Ph.D.
China Railway Eryuan Engineering Group Co., Ltd.
No. 3 Tongjin Road, Chengdu, China
Tel: 8613880993080 Fax: 86-28-86445035; Email: hongsonglin@163.com

Hua Yan
Professorate Senior Engineer
China Railway Eryuan Engineering Group Co., Ltd.
No. 3 Tongjin Road, Chengdu, China
Tel: 86-28-86445959 Fax: 86-28-86445035; Email: tevvh@sina.com

Word count: 3,659 words text + 10 tables/figures x 250 words (each) = 6,159 words

Submission Date: July 31, 2014
Revision Date: Nov. 15, 2014
**ABSTRACT**

China has built the world’s largest high-speed railway network with the ballastless track. CRTS I slab track runs well and the expected purposes of high ride comfort, high stability, low maintenance were achieved. However, worldwide experience of ballastless track shows that defects and deterioration were inevitable. At present, there is a lack of the systematic research for the durability of ballastless track in China. In this paper, on the basis of summarizing the structural characteristics of CRTS (Chinese Railway Track System) I slab track, combined with the field application of slab track, the typical damages and its influencing factors were discussed. Damages include: (a) anchor point cracks and bars fracture of prestressed slab, (b) convex block cracks of slab track at the large-span bridge end, (c) cracks between cement asphalt mortar layer and slab, (d) mud pumping of surface layer of subgrade bed, and (e) poor drainage of prestressed concrete frame slab track. Additionally, for enhancing the durability of CRTS I slab track, measures based on material, design, construction and operational maintenance were proposed. Enhancing measures include: (a) improving the requirements of material performance for prestressed steel bars, (b) drawing up water resistance indicator of cement asphalt mortar, and adopting sealant material with high flexibility and anti-aging performance, (c) using pretensioned prestressed slab, optimizing drainage system, setting rail expansion joint reasonably on large span bridge, (d) optimizing pouring technology of cement asphalt mortar, (e) improving the construction accuracy of drainage slope of concrete base bed, and (f) filling in cracks timely.

**Keywords:** High-speed railway, Ballastless track, Durability
INTRODUCTION
With the rapid development of railway in recent years, China currently has built the largest high-speed railway network with the maximum operation speed in the world. Ballastless track is the main type of Chinese high-speed railway track (1-2). Since ballastless track is a layered reinforced concrete structure composed of a variety of materials, track and its components are in a continuous deteriorated state under the influence of repeated vibration loads and climatic environmental changes (3-6). Thus, under a proper maintenance condition in track’s life cycle, how to ensure the capacity of ballastless track structure to resist deterioration is the key to achieving the ballastless track’s durability. With the operation of ballastless track on high-speed railway, part of it has a few different forms of damages, which will affect the durability of track structure. However, for the durability of ballastless track structure there is a lack of systematic research because of its short operation time. This paper focuses on Chinese CRTS I slab track, summarizing track typical damages’ characteristics and discussing its influencing factors, and proposing some measures to improve its durability in terms of material, design, construction as well as operational maintenance.

CHARACTERISTICS OF CRTS I SLAB TRACK
CRTS I slab track is one type of Chinese ballastless track. It has many advantages including a simple transfer mechanism, fast speed of construction, mature construction process as well as better repairability, and has been applied widely in Chinese high-speed railway including Wuhan-Guangzhou Passenger Dedicated Line (PDL), Shanghai-Nanjing intercity rail, Guangzhou-Zhuhai intercity rail transit, Harbin-Dalian high-speed railway transit, and Mianyang-Chengdu-Leshan PDL. Figure 1 shows the CRTS I slab track on a bridge.

FIGURE 1  CRTS I slab track on bridge
CRTS I slab track structure consists of rail, elastic fastenings, track slab, cement asphalt mortar fillings, concrete base bed, convex block with the resin fillings surrounded, etc. (7). The track slab is classified as two types. One type is the plain slab, a bidirectional post-tensioned concrete structure. The other type is the frame slab, a longitudinal post-tensioned concrete structure or reinforced concrete structure. Cement asphalt mortar fillings underneath track slab, could adjust the track construction error and distribute train load from track slab to concrete base bed. Convex block on the concrete base bed can prevent the lateral and longitudinal movement of the track slab. The concrete base bed is a reinforced concrete structure with the length of 5.0 m on bridge and in tunnel, or 10-20 m on subgrade. In addition, the anti-vibration slab track supported by elastomeric mats on concrete base bed could reduce the vertical vibrations of the track compared to conventional track.

**TYPICAL DAMAGES OF SLAB TRACK IN JAPAN**

CRTS I slab track has the similar structural components as Shinkansen slab track in Japan, of which damages were also found. Typical damages of Shinkansen slab track include (a) cracks of cement asphalt mortar, and (b) fragmentation of cement asphalt mortar, as shown in Figure 2. (8)

**FIGURE 2** Cracks (left) and fragmentation (right) of cement asphalt mortar

**TYPICAL DAMAGES AND ITS INFLUENCING FACTORS IN CHINA**

Field application shows that, CRTS I slab track runs well and achieves its expected purpose of high ride comfort, high stability and low maintenance. Inevitably, a few of track damages were found, which include (a) anchor point cracks and bars fracture of prestressed slab, (b) convex block cracks of slab track at large span bridge end, (c) cracks between cement asphalt mortar layer and slab, (d) mud pumping of surface layer of subgrade bed, and (e) poor drainage of prestressed concrete frame slab track etc. It should be noted that most of these damages were found in freight line.

**Anchor point cracks and bars fracture of prestressed slab**

The field investigation of CRTS I slab track shows that anchor point cracks and bars fracture of prestressed slab were found, as shown in Figure 3 and Figure 4, respectively, which will affect track’s durability.
According to the characteristics of bars fracture, related influencing factors include:

(a) Defects of bar steel. Steel wire mixed with iron oxide in rolling process.

(b) Defects of bar manufacturing process. Quenching and tempering, the two key processes of steel bar manufacturing, did not meet the quality control requirements, which resulted in temper brittleness.

(c) A small portion of steel bars were not assembled with non-bonding process as required but oiled coating process. Rainwater flowed into the gap between the bars and the sleeve, which caused tensioned steel bar corrosion and even fracture under fatigue load.
Convex block cracks of slab track at large span bridge end

Convex block cracks of slab track occurred at the end of the continuous beam with large temperature range. Maximum width of convex block crack is up to 5mm and angle of inclination is about 45°, as shown in Figure 5.

FIGURE 5 Convex block crack

According to the characteristics of cracks and analysis of track structure design, related reasons may include:

(a) Strong interaction between rail and bridge. Long span continuous beam usually has a large temperature range, and consequently has a long expansion displacement under temperature load. Also, strong interaction between rail and bridge will lead to large shear force and bending moment of convex block, as shown in Figure 6. In this case, rail expansion joint is proposed.
FIGURE 6 Interaction between track and bridge

(b) Bolt torque of low resistance fastening is larger than its requirement, and composite pad has corrosion, which leads to larger longitudinal fastening resistance and a larger force of convex block.
(c) Inadequate strength of convex block. Strength calculation of convex block at the end of long span continuous beam is necessary.

Cracks between cement asphalt mortar layer and slab
Cement asphalt mortar layer is a filling and adjusting layer of CRTS I slab track, and the weak part prone to diseases. There are two construction methods for cement asphalt mortar layer, formworking and bag filling. For formworking cement asphalt mortar, interface between cement asphalt mortar layer and track slab usually develops as the interface cracks, especially at the edge of track slab. Under the train load and water erosion, the interface crack will develop as crushed particles. For bag filling cement asphalt mortar, initial interface crack always exists because of empty interface. The typical defect of cement asphalt mortar is shown as in Figure 7.

FIGURE 7 Cracks between cement asphalt mortar layer and slab

Related reasons for cracks between cement asphalt mortar layer and slab may include:
(a) Bonding between track slab and cement asphalt mortar layer was not strong enough to resist the warping of track slab under temperature gradient load.
(b) Under train load and rainwater erosion, cement asphalt mortar frost boiling emerged, and even gradually developed to void under track slab.
Studies show that the deterioration of cement asphalt mortar, the key structural material of slab track, has a significant influence on the slab track. The Cracks between cement asphalt mortar layer and slab could accelerate slab track’s vibration, and even lead to damages of track
components, which would have an impact on slab track’s durability (4, 9). Therefore, it is necessary to pay more attention to cracks between cement asphalt mortar layer and slab.

**Mud pumping of surface layer of subgrade bed**

The site investigation shows that the surface layer of subgrade bed of part of slab track have the diseases of cracks, water erosion, and mud pumping, as shown in figure 8. These diseases are gradually worsened under the repeated train load.

![Mud pumping of surface layer of subgrade bed](image_url)

**FIGURE 8 Mud pumping of surface layer of subgrade bed**

Preliminary analysis shows that the main reasons include:

(a) Hot asphalt is usually used as the sealing material, and its sealing effect is not enough to prevent water from entering.

(b) Water permeability of surface layer of subgrade bed is poor and rain water could not be permeated in time, which leads to the pumping effect of base bed.

(c) Part section of subgrade has a settlement deformation.

**Poor drainage of prestressed concrete frame slab track**

Poor drainage of prestressed concrete frame slab track was found in the site investigation, as shown in Figure 9. Rain water has a significant effect on the performance of slab track especially cement asphalt mortar. If cement asphalt mortar is flooded in a long time, cement asphalt could be loose and the performance of the mortar could be changed. Additionally, water could lead to bar corrosion if the track slab or base bed had cracks.
FIGURE 9 Poor drainage of prestressed concrete frame slab track

Reasons of poor drainage include:
(a) Drainage channel capacity is inadequate. Rain water is discharged through the channel of the two sides of convex block, whose width is only 80mm, as shown in Figure 10. Rain water cannot be discharged in time.
(b) Drainage channel is easily blocked and difficult to clear. Even long time after rain, there is still some water in the framework.

(a) Water flow direction in plane view
MEASURES TO IMPROVE DURABILITY OF CRTS I BALLASTLESS TRACK

Based on the causes and influencing factors, combined with the site situations from the aspects of material, structure design, construction, maintenance and so on, the measures of improving track durability have been studied and proposed.

Material

Prestressing steel bar (4)

Unbonded crafts must be under a rigorous control. Based on the requirements of relevant standard, examinations of manufacturing equipments and crafts should be strengthened. Simultaneously, the internal groove of anchor hole should be disposed strictly according to design requirements. The requirements of material and technology for heating processing should be explicit further. Harmful elements like H, N, P and S must be under control rigorously in order to improve wire rolling quality.

Cement asphalt mortar

The basic working environment of cement asphalt mortar is soaking in water and in a dry-damp loop. The current cement asphalt mixture mainly uses acidic aggregates (sands or quartz sands), which weakens the binding force between aggregates and asphalt, and lead to poor water resistance even spalling. In addition, elements like carboxylic acid, fatty amine, acid amide and ester in asphalt are easily combined with water, and lead to swelling and softening. Test results show that strength and elasticity modulus decreased to 40%, which mean that cement asphalt mortar has a low water resistance (4). The measures to improve water resistance of cement asphalt mortar are listed as follows:

(a) Using alkaline aggregates or aggregates with alkalization treatment. Machine-made sands of limestone and diorite crushed for classification are recommended to enhance the bonding force between aggregates and asphalts.

(b) Anti-stripping agents like amine and amide are recommended to mix in cement asphalt mortar, which could enhance the bonding force between aggregates and asphalts and improve the resistance to water damage.

(c) Hydrophobic polymer emulsion or hydrophobic groups such as polyurethane, poly urea, silicone -acrylic can be mixed to improve the water resistance.

(d) Drawing up water resistance indicator of cement asphalt mortar. The softening coefficient is recommended to be greater than 50%.

Sealing materials

There are many different structural joints in the ballastless slab track, such as the joint between concrete base bed and protective layer of bridge, the joint between base bed and surface layer of subgrade bed, the expansion joints of concrete base bed, the interlayer between track slab and cement asphalt mortar layer. If sealing material performance is not as good as its requirements or even becomes invalid, rain water may easily infiltrate and accumulate in structure joints. Hydrodynamic pressure under train load can lead to the disease of mud pumping, or frost heave of subgrade in cold areas, and security risks of may appear.
Common sealing materials of architectural structure include: (a) Asphalt factice. It is a kind of waterproof material with good cohesive performance, cheap price but poor heat and freeze resistance. It is commonly used in block seams of rigid waterproof roof. (b) Asphalt-rubber factice. It was boiled by reclaimed rubber powder and asphalt. (c) PVC cement. It is synthetized with coal tar and a small amount of PVC resin, and has a good performance of plasticity, low temperature flexibility and heat resistance. It is commonly used in construction joints and structural component seams. (d) Water-stop belt. It is a strip material made of rubber or PVC resin with a special craft. It can adapt to the joint deformation and usually is buried on both sides of the concrete seam in cast-in-situ construction.

Sealing materials on cement concrete pavement of express way include two categories (10). One is the general category which contains polyurethane, poly-sulfide, neoprene, emulsified asphalt rubber, etc. The other one is the silicone category which is superior to the general category from the aspect of durability and the ability to resist displacement.

Both ballastless track and cement concrete pavement are layered structure systems bearing repeated load of trains or cars. So, sealing material of cement concrete pavement has a strong referential significance to the ballastless tracks. At present, combined with the characteristics of ballastless tracks, the polyurethane sealing materials is gradually adopted instead of asphalt. The further research of sealing materials is suggested to focus on the material with high deformation flexibility, water resistance performance and ageing resistance.

Structure Design

Pre-tensioned track slab

Pre-stressed concrete members are divided into the pre-tensioned and the post-tensioned. Based on the design principles and methods of concrete structures, both of the two kinds are possible for the concrete track slabs. According to the existing damages of unbonded prestressed steel rebar system of post-tensioned track slab, the pre-tensioned track slab system technology is being researched, by which the steel rebar problems can be completely avoided. Several remarkable periodic results have been achieved in pre-stressed system design technology, the track slab manufacturing process, static load test, etc. (11)

Optimization of drainage design

Suggests for drainage design are listed as follows:
(a) CRTS I frame slab track is recommended to lay in tunnels.
(b) Slab joints of frame slabs should be further optimized to improve its drainage ability.
(c) Longitudinal and lateral drainage slope of base bed should be optimized. A L-shaped transverse drain-pipe on the base bed is proposed to increase the drainage ability of frame slab track.

Setting rail expansion joint reasonably on the Long-span Bridges

For cracks of convex block on the long-span bridge end, there are several suggests as follows.
(a) Continuous welded rail design should be further optimized on the long-span bridges. According to the technical requirements, low resistance fastenings and rail expansion joints should be installed reasonably.
(b) Structure design of semicircular convex block should be further optimized. The reinforcement between convex block and base bed should be enhanced as well as the reinforcement between the base bed and the bridge.
(c) Pay much attention to the maintenance and management of bolt torque of low-resistance fastenings on the long-span bridges, and ensure that the bolt actual torque is in the design scope. On the other hand, severe corrosion fastening composite pad should be replaced in time.

Construction and operational maintenance

Optimizing infusion process of cement asphalt mortar

The size of the four corners of cement asphalt mortar bags should be appropriately increased, and track slab corners should be supported by special counterforce supports. After infusion and sealing, redundant cement asphalt mortar at comers should be pressed back for a full contact between cement asphalt mortar bags and track slab as well as the base. This process can also improve uniformity to reduce seams and slab void.

Improving the construction precision of base bed drainage slope

Field application shows that whether drainage is obstructed or not has a significant influence on the failure modes emergence and development. Many diseases are related to drainage such as mud pumping between cement asphalt mortar layer and track slab, frost boiling between the concrete base bed and surface of subgrade bed, poor drainage system of the frame track slabs, etc. As a result, it is necessary to pay more attention to drainage system design of ballastless track. Due to the base bed construction precision, the drainage slope is insufficient, and it cannot realize drainage function. It is suggested to increase the drainage slope of the base bed and surface of subgrade bed as much as possible without affecting the mechanical properties of main structures. On the other hand, drainage slope construction precision should be improved. In addition, the construction technology of sealing materials should be met with its requirements.

Sealing seam in time

If seams emerged, it is suggested to seal seams in time to avoid damage deteriorating after the rain was infiltrated. In sealing process, the seam should be cleaned. Expansion joints should be cut out to meet the requirements if necessary. After cleaning, materials such as polyurethane or organic silicone can be used to seal the seams.

CONCLUSIONS

On the basis of summarizing structural characteristics of CRTS I slab track, and analyzing influencing factors of typical damages, the measures to enhance the durability of track are proposed as follows:

Construction material. (a) Improving the material performance requirements of prestressing steel bars, (b) drawing up water resistance indicator of cement asphalt mortar, and (c) adopting sealant material with high flexibility and anti-aging performance.

Structure design. (a) Using pretensioned prestressed slab, (b) optimizing drainage system, and (c) setting rail expansion joint reasonably on large span bridge

Construction and operational maintenance. (a) Optimizing pouring technology process of cement asphalt mortar, (b) improving the construction accuracy of drainage slope of concrete base bed, and (c) filling in cracks timely.
REFERENCES


5. LIN Hongsong, LI Peigang, YAN Hua and LIU Xueyi. Mechanical Analysis of Ballastless Track with Damaged Cracks under Train Load, *Journal of Southwest Jiaotong University*, Chengdu, China, Dec., 2010, pp. 904–908.


