8th WCTR

DEVELOPMENT AND PRACTICAL USE OF CONCRETE ROADBED FOR SLAB TRACK ON EARTHWORKS

KATSUTOSHI ANDO & SHIGERU MIURA
Railway Technical Research Institute
Track Technology Development Division
2-8-38 Hikari-cho, Kokubunji-shi,Tokyo, JAPAN

JUN OKAZAKI
Japan Railway Construction Public Corp.
Shinkansen Department
Sanou Building, 2-14-2 Nagata-cho, Chiyoda-ku, Tokyo, Japan

MAKOTO SUNAGA
Railway Technical Research Institute
Structure Technology Development Division
2-8-38 Hikari-cho, Kokubunji-shi,Tokyo, JAPAN

HIFUMI AOKI & OSAMU MARUYAMA
Japan Railway Construction Public Corp.
Design Divisiont
Sanou Building, 2-14-2 Nagata-cho, Chiyoda-ku, Tokyo, Japan

Abstract

In recent years the destructive force to the track has increased with the rise of train speed and the increase in the number of trains, therefore more labor and expenditure are needed to maintain the track in good condition. The purpose of this study is to develop an economical and reliable low-maintenance track structure. The authors proposed a concrete roadbed system for slab track which could be laid on embankments and cuttings. This paper describes the history and present status of slab track, proposal of the new track structure, test-laying and its performance tests of full-sized track, the test under train running at Hokuriku Shinkansen line.

INTRODUCTION

Ballasted tracks have some advantageous features. For example; thier construction costs are low, it is easy to repair track irregularities and so on. However, track ballast is gradually destroyed by repeated train load and it needs periodical track maintenance work. In recent years the destructive force to the track has increased with the rise of train speed and the increase in the number of trains, therefore more labor and expenditure are needed to maintain the track in good condition. The purpose of this study is to develop and put into practical use an economical and reliable low-maintenance track structure, which can be laid on earthworks instead of ballasted track. The authors proposed a concrete roadbed for slab track which could be laid on embankments and cuttings. This paper describes the history and present status of slab track, proposal of the new track structure, test-laying and its performance tests of full-sized track,the test under train running at Hokuriku Shinkansen line(Ando et al.1996; Nakahara 1996).

SIGNIFICANCE OF SLAB TRACK INTRODUCTION AND MAINTENANCE

Generally speaking the railway track needs huge maintenance costs because it has facilities long stretched along railway lines. Maintenance works of the conventional track still remain in much of labor-intensive form. The work features not only manual labor but also dangerous and hard job in many cases. The future prospects of manpower supply for track maintenance are gloomy, because Japan is rapidly shifting to a society of elders. Against this background, transition to a system that can keep the required quality of track at minimum cost with limited workforce is now an urgent demand facing Japanese Railway Companies.

Fig.1 illustrates the change of track irregularities in Tohoku Shinkansen. This means the number

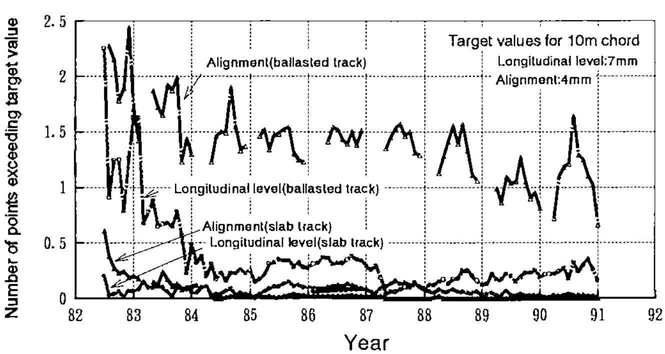

Fig.1 Change of track irregularities in Tohoku Shinkansen

of irregular points per km length which exceeds the target value for riding comfort of Shinkansen. Thus slab track keeps the track in better condition than ballasted track does. Fig.2 shows maintenance costs of slab track in comparison with ballasted track of Sanyo Shinkansen. The ratio of maintenance costs, slab track versus ballasted track, is one fifth to one third on Shinkansen lines. Thus slab track has made a greater contribution to reducing maintenance costs and manpower. In planning new railway lines, the important factors for decision-making are economics, durability, environment and workability. For example the construction costs of slab track laid on Sanyo Shinkansen are 1.3 to 1.5 times those of ballasted track. It had been estimated that extra investment would be redeemed in about two to six years of commercial operation. And it had been expected that manpower for maintenance of slab track would be reduced by about 30 percent compared with ballasted track.

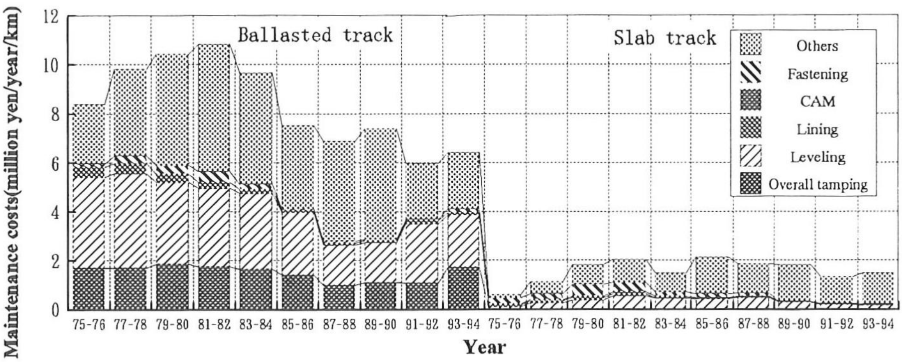

Fig.2 Maintenance costs of slab track and ballasted track of Sanyo Shinkansen

Thus slab track for new railway lines is a good investment for Japanese Railway Companies and it is expected to be able to keep the track in good conditions with less manpower. Consequently, slab track is believed to be superior to ballasted track from a viewpoint of the maintenance planning. As for slab track on earthworks, the effects are the same as would be expected on viaduct or in tunnel provided geological and ground conditions are good.

PAST STUDIES OF SLAB TRACK ON EARTHWORKS

History of development

The former Japanese National Railways (JNR) organized a committee on the new track structure in 1965 and started an earnest study of this subject. Slab track type RA to be laid on earthworks (RA) was proposed in 1968 and its performance test was carried out at Railway Technical Research Institute (RTRI). RA is consisted of rails, fastenings, short track slabs, cement mortar and asphalt pavement as shown in Fig.3. On the basis of the test result, RA was first laid on 100 m section of Tokaido narrow gauge line on trial. Then it was laid on an arrival and departure track of Toyohashi station of Tokaido Shinkansen in 1971 and a through line of it in 1973. Thus it was experimentally installed at twelve sites in total for about 1.8 km extension including the above lines as of 1974.

According to the investigation at these sites after commercial operations, some sites remained in good condition and some ones did not. The site on the Kosei narrow gauge line between Nagahara and Ohmi-shiozu was a successful example. This RA was laid on a high embankment of 16m height. Nevertheless, final cumulative settlement was less than 10 mm as shown in Fig.4.

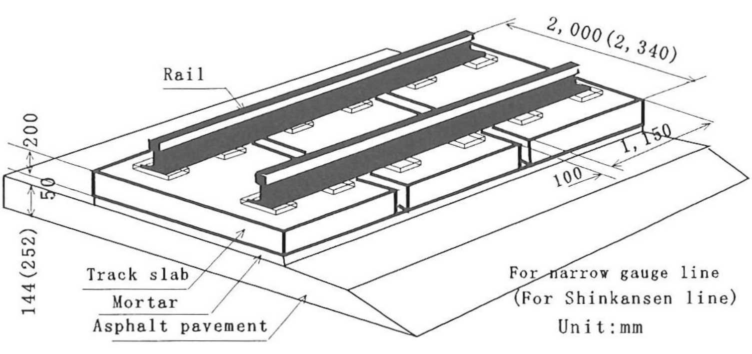

Fig.3 Slab track structure of type RA

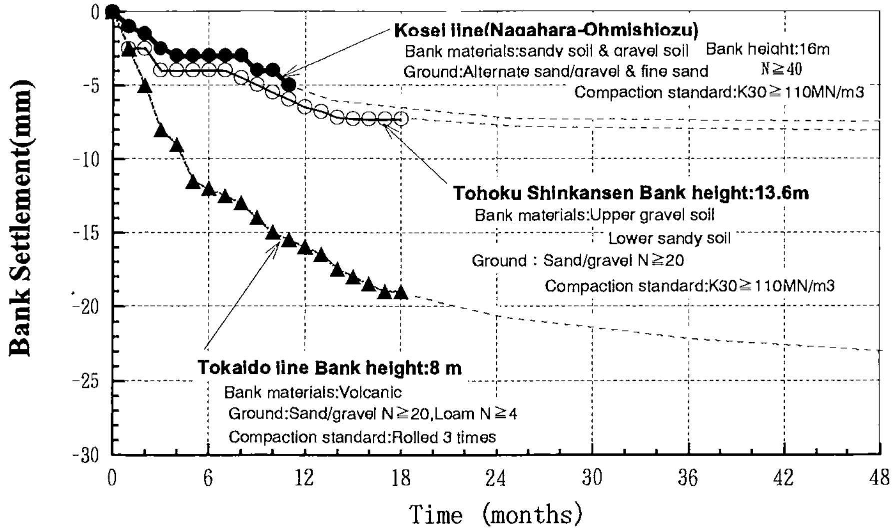

Fig.4 Change of settlements of some embankment

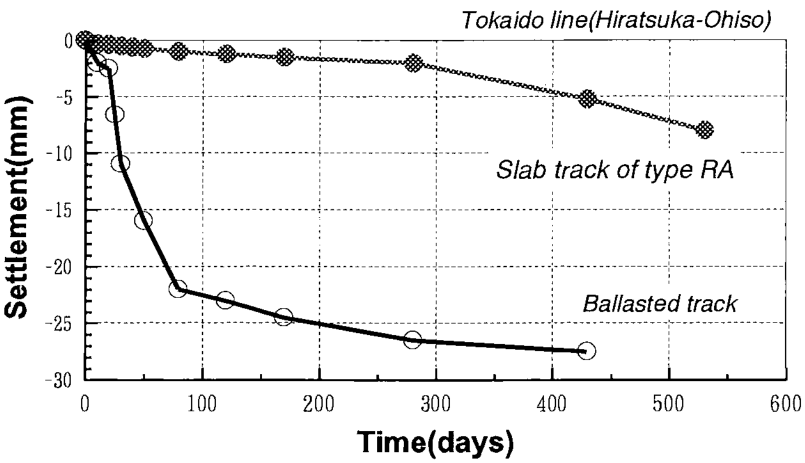

Fig.5 Settlement of slab track RA in comparison with ballasted track at Tokaido line

Fig.5 shows a bad example which was laid at Tokaido narrow gauge line. At first the settlement of RA had been smaller than that of ballasted track. However it seemed to increase after one year after in commercial operation. Later JNR was obliged to go to maintenance because of cracking in pavement and the adjustable tolerance limit of fastening being reached.

In order to meet the severe maintenance standards required for Shinkansen, further study on the settlement and durability of pavement was demanded. Therefore JNR decided to forgo installing RA to on Sanyo and Tohoku Shinkansen.

Standard for laying of slab track on earthworks

The settlement of roadbed has direct influence on success of the low-maintenance track.So

Table 1 Standard for laying slab track on earthworks

Items	Standard
Final settlement (estimated)	≦ 30 mm
Deflection	≦ 1/1800
Angular bending	≦ 3/1000
Bearing capacity of bank and cutting bed	K_{30} ≧ 110 MN/m^3

standard for slab track on earthworks was established as shown in Table 1.
The item (1) is decided from the vertical adjustable tolerance limit of fastening (30 mm). (2) and (3) are decided mainly from riding comfort. (4) is from a viewpoint of suppressing the settlement and structural designing of slab track.

PROPOSAL OF NEW STRUCTURE AND ITS BASIC STUDIES

Proposal of new slab track structure on earthworks

The most important thing for a low-maintenance track is to spread imposed loads effectively over earthworks and restrain the cumulative settlement. So authors proposed a reinforced concrete roadbed system for slab track (RCRS) as shown in Fig.6. It consists of very rigid reinforced concrete slab. RCRS is expected to be superior to RA consisting of asphalt pavement in terms of settlement, durability and economy. Its structure is simpler, and the same type of track slab for viaducts and tunnels can be used for earthworks.

Basic studies on RCRS

In order to confirm the performance of RCRS, the test track was laid at the Civil Engineering Test Site of RTRI. The subgrade soil layer of test track was build up 1.2m in thickness by replacing the original soil with sand (including silt ≦ 15%). The average of K_{30}-values by the method of plate load test for road (plate diameter:30cm) was 114 MN/m^3 at the surface of original soil (supporting bed) which consists mostly of conglomerate. The special sand was compacted four

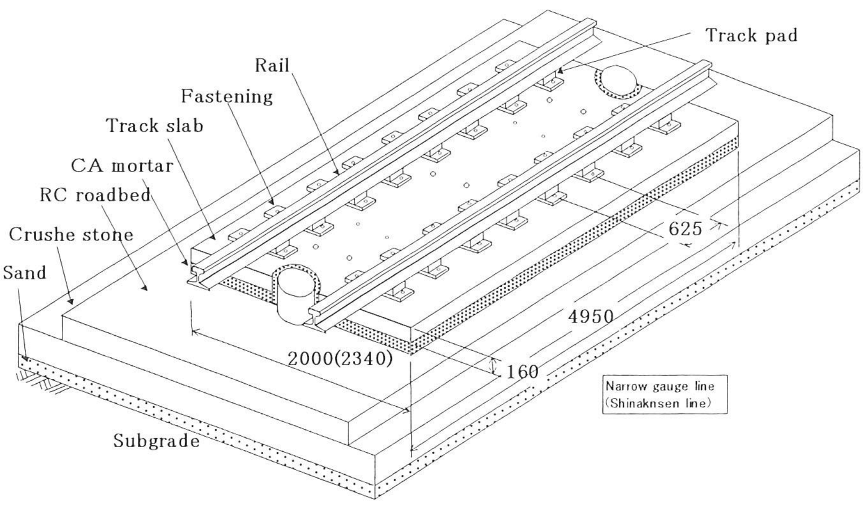

Fig.6 Reinforced concrete roadbed system for slab track type

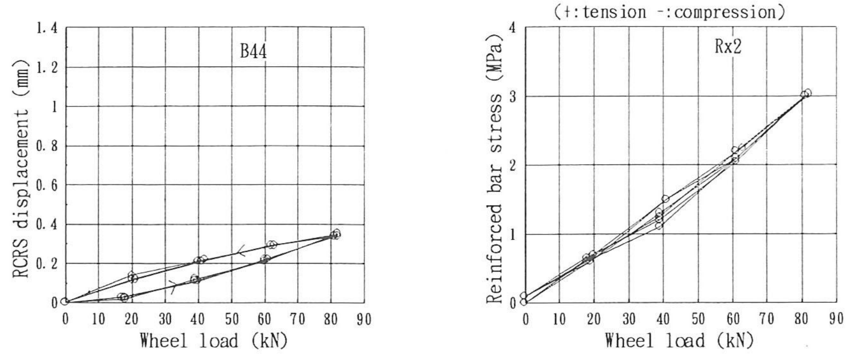

Fig.7 Results of static loading test at RTRI

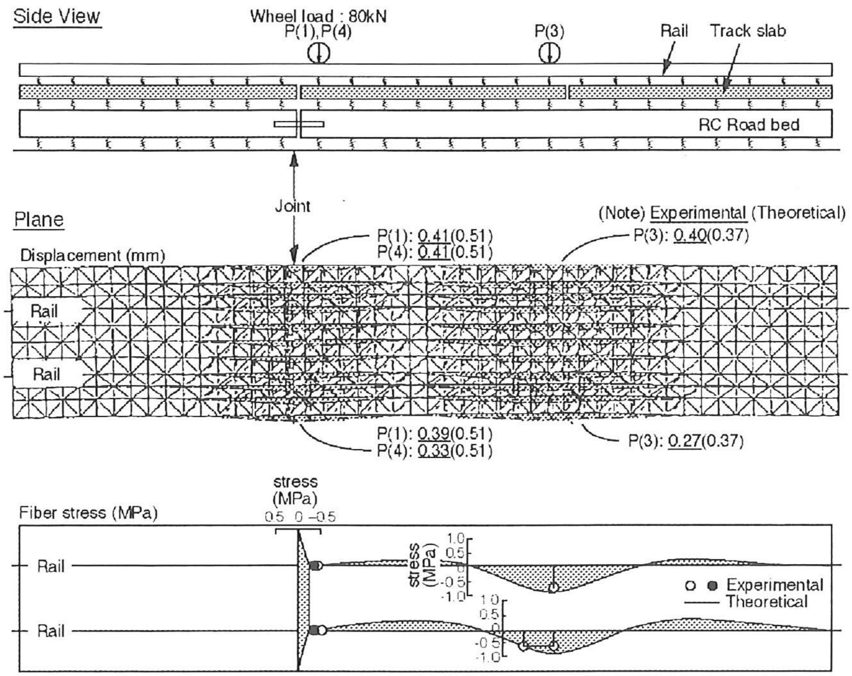

Fig.8 Theoretical deflection and stresses of RCRS compared with experimental ones

times in layers by rolling with a vibration roller. The plate loading test confirmed that K_{30}-values averaged 114 MN/m^3 and the degree of compacting was 94.8% at the upper layer.

First of all, a static loading test had been done to confirm the behavior against static wheel load and lateral force. Fig.7 shows the relations between measured values(displacement and stresses) and wheel loads. It shows an almost elastic behavior under 80kN static wheel loads. When the wheel loads of 80kN were imposed on the rails, the maximum displacement of RCRS was about 0.4 mm,fiber stress of the RCRS-surface about -0.5 MPa and reinforced bar about 3 MPa. According to the Japanese concrete criteria, bending strength was expected to be 3.1 MPa for this concrete roadbed. There would be low possibility of cracking on RCRS. The average track spring constant K (wheel load/rail displacement) was 72.6 MN/m. It was proximately one half of slab track on viaduct. Fig.8 shows theoretical deflection and stresses of RCRS compared with

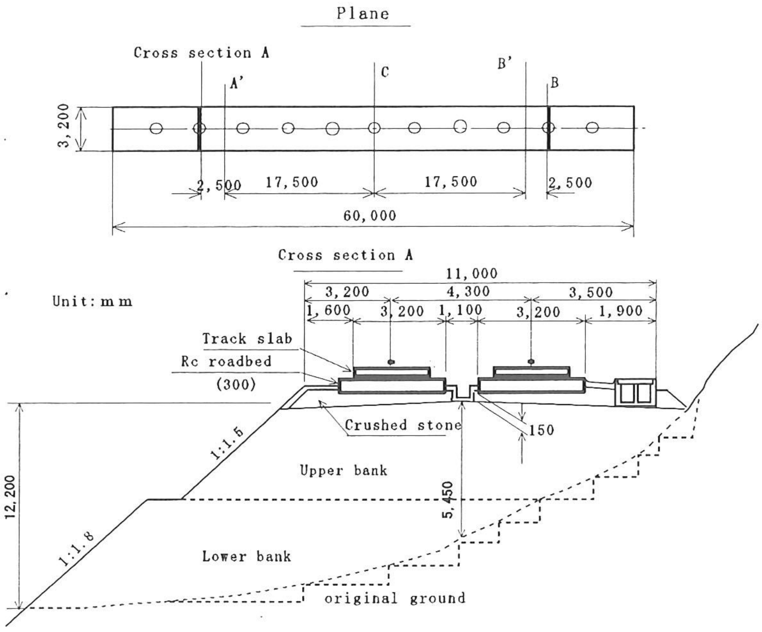

Fig.9 Test track structure at Kashiyama section of Hokuriku Shinkansen

experimental ones. Theoretical results agree pretty well with experimental ones in consideration of unequal thickness and bearing properties.

FULL-SIZED TESTS AT HOKURIKU SHINKANSEN

Test track of Kashiyama section

In order to see whether RCRS is appropriate or not as a low-maintenance track of Hokuriku Shinkansen, the full-sized test track was laid on the site (Kashiyama section). A 60m section composed of embankment (6.5m in height) and cutting was selected as the test site. Fig.9 shows the test track structure which consisted of embankment, reinforced concrete roadbed, cement asphalt mortar, slab tracks, fastenings and rails. The construction of embankment was completed in December 1991 and left it as it was for three months. Next the reinforced roadbed was constructed in March 1992. After laying of track slabs, the static and dynamic loading tests were carried out in April to May. The A-group (sand & gravel) materials composed of sand and gravel were used for banking. They were compacted two times in layers by rolling with a 10-ton vibration roller followed by four times of rolling with a 15.5-ton tired roller. To ensure that the rolling came up to the standard, the plate loading test was done to confirm that K_{30}-value of embankment was 143 MN/m^3 at lower layer and 186 MN/m^3 at upper layer. The degrees of compacting were 95.0-99.0%. Thus all the test results satisfied the standard for embankments shown in Table 2.

Static loading test

A static loading test was done for the first time. When wheel loads of 80 kN were imposed on the rails, the maximum displacement of RCRS was 0.43 mm, lower fiber stress of RCRS 0.5 MPa,

Table 2 Standard of materials and geological condition for RCRS

Items	Embankments	Cuttings
Bank materials	Upper layer: Group-A (sand & gravel) Lower layer: Group-A or B (sand & gravel including fine sand less than 30%)	-
K_{30}-value	Upper layer:$K_{30} \geqq 110$ MN/m^3 Lower layer:$K_{30} \geqq 110$ MN/m^3	On subgrade:$K_{30} \geqq 110$ MN/m^3
Degree of compacting	D ≧ 90%	
Supporting bed	Sandy: N-value ≧ 20 Loam: N-value ≧ 4	Not include a soft & fine alluvium deposit within 3m beneath formation

reinforced bar 1.7 MPa and earth pressure 0.24 kPa. There would be low possibility of cracking on RCRS because bending strength could be expected to be 3.1 MPa for this concrete roadbed. The earth pressure of RCRS is smaller than ballasted track. The average track spring constant K was 93.5 MN/m. It was pretty larger than that (72.6 MN/m) of RTRI test site.

Dynamic loading test

Next a dynamic loading test was done the same as the RTRI test site. The dynamic load the same as the RTRI test site was repeated at frequency of 28 Hz about two million times (corresponding to about 50 million gross tonnage) to check the durability of track and roadbed, and to measure the settlement. Fig.10 illustrates the change of lower fiber stress of RCRS and earth pressure during dynamic test. Results show that there was little change in them. And stresses and pressures at frequency of 28 Hz are on a low level under the condition corresponding to fatigue wheel load. Fig.11 relates cumulative settlements of roadbed to the number of applied loads. Assuming an annual load of 10 million gross tonnes for Shinkansen track, cumulative settlement of the roadbed would be estimated to be less than 1 mm in 10 years of commercial operation.The growth of roadbed settlement was 0.089 mm/year/10 MGT at embankment section. Fig.12 shows the relation between the embankment height and its settlements at the test section. What is evident from it are as follows.

(1) The settlement at point S2 measured by surveying had increased rapidly under construction of embankment and reached about 22 mm in 200 days. However it seems to have decreased little

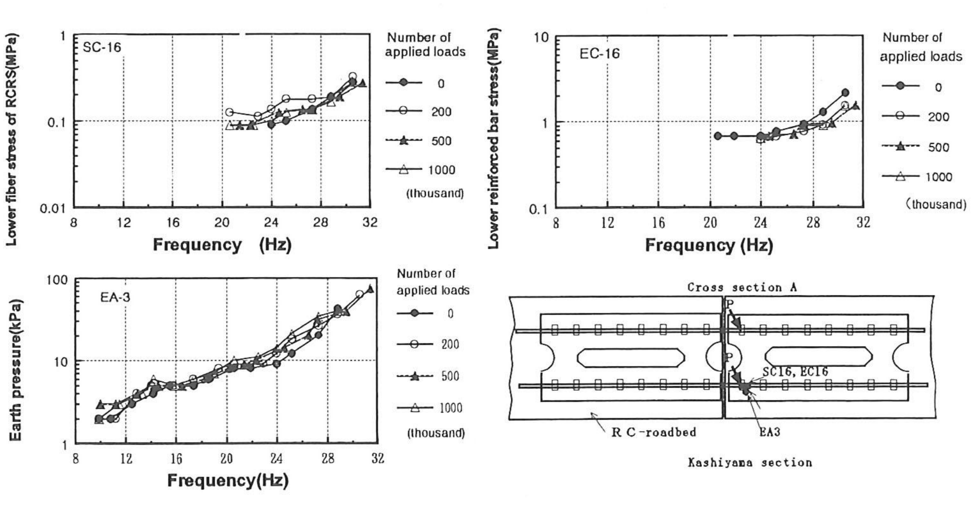

Fig.10 Change of lower fiber stress of RCRS and earth pressure during dynamic test

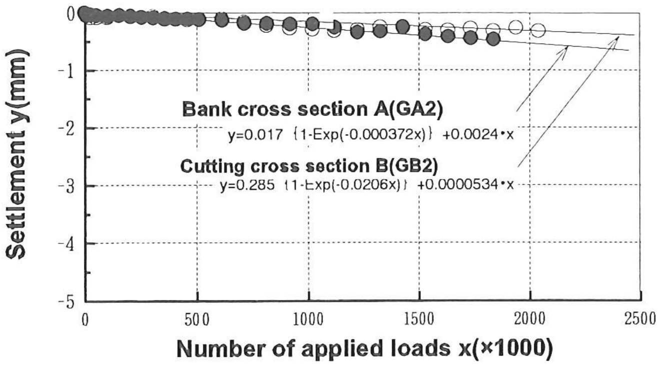

Fig.11 Settlement of roadbed due to dynamic loads

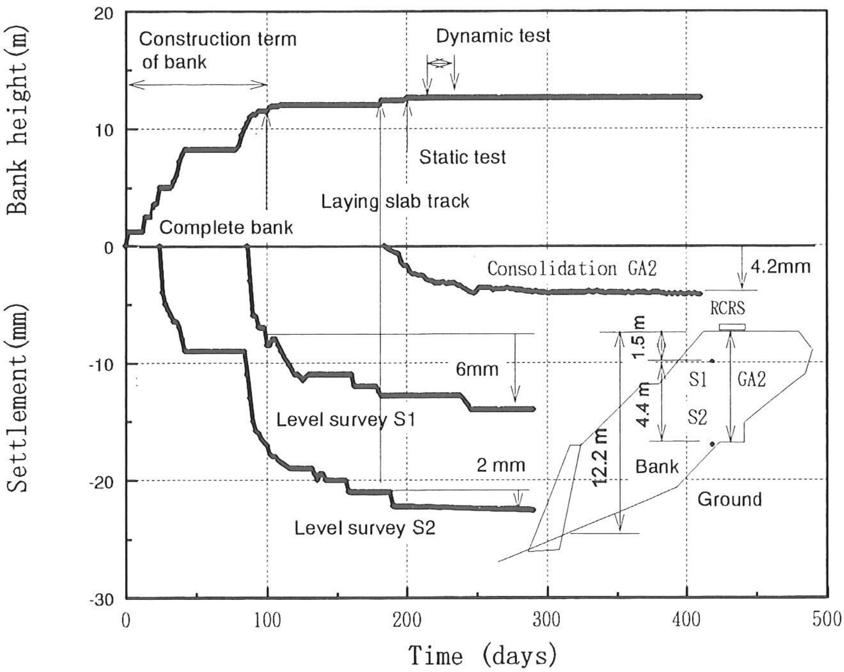

Fig.12 Settlements of embankment at Kashiyama section

by little after 200 days passed.

(2) The settlement at point S1 measured by surveying consists of those of original ground and consolidation of embankment materials. The difference between S2 and S1was small after 100 days passed. It means that settlement at S1 was mostly that of original ground.

(3) The consolidation settlement (GA2) measured by meters was about 4.2 mm after laying slab track. Sum of S2 and GA2 was 6.2 mm. It tends to virtually cease.

Thus as for embankment settlement, it is likely that it can be suppressed to 10 mm against the target 30 mm in case of vertical adjustment magnitude of fastener.

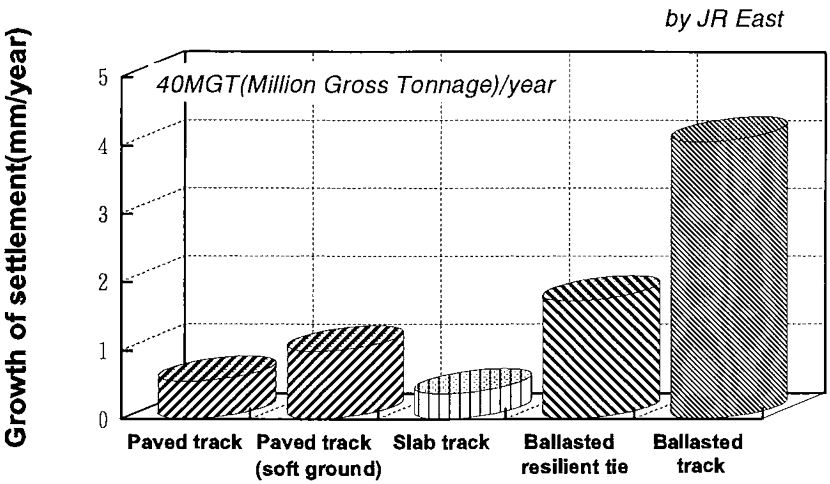

Fig.13 Growth of settlement on some low maintenance tracks at Yamanote line

Estimation on tests

Maintenance reducing effect

The growth of RCRS settlement due to the dynamic loads was 0.089 mm/year/10 MGT as before.

On the other hand, the settlement properties on low-maintenance tracks which were laid on Yamanote line were measured by East Japan Railway Company (JREC). Fig.13 shows that the slab track seems to have the best performance maintaining good track geometry with its growth of settlement 0.091 mm/year/10 MGT (Konishi et al.1995). The paved track has also good performance with its maintenance cost at one fifth of ballasted track. The RCRS system is more rigid than these track structures. Therefore the maintenance reducing effect is expected to be pretty equal to that of the conventional slab track.

Variation of settlement

It is difficult to discuss about differential settlement of RCRS. Fig.14 shows the variations of settlement between slab track and ballasted track with resilient ties in fourteen months on Yamanote line (Konishi et al.1995). It seems that the settlement variation on slab track is smaller than ballasted track. That of RCRS would be smaller than in above cases, because it consists of the continuous slab.

PRACTICAL USE OF RCRS AT HOKURIKU SHINKANSEN

Laying and structure

Japan Railway Construction Public Corporation (JRCC) is currently constructing five sections of Shinkansen on three routes. Hokuriku line from Takasaki to Nagano was laid with 1435 mm gauge track, and opened to traffic on October 1st in 1997. From the above test results JRCC decided to apply RCRS in 1993 and it was laid for about 10km on Hokuriku Shinkansen line, which was equivalent to 4% of this line as shown in Fig.15. It corresponds to one fourth of all earthwork sections. Fig.16 shows RCRS supporting canted slab tracks in cuttings and embankments. A crushed stone layer for mechanical stabilization is introduced below RCRS to facilitate drainage through the roadbed, and to distribute the train load evenly.

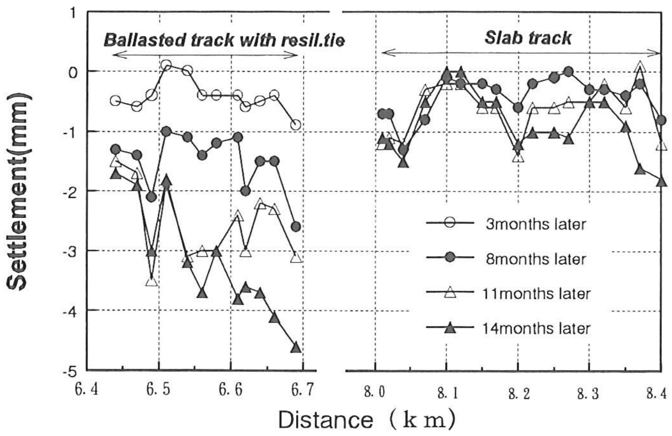

Fig.14 Change of settlement on slab track and ballasted track at Yamanote line(by JR East)

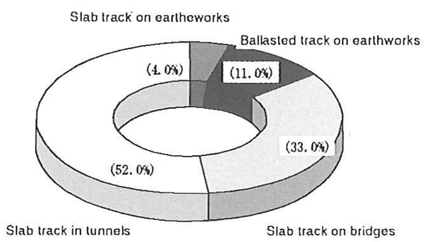

Fig.15 Applied rate of RCRS at Hokuriku Shinkansen line

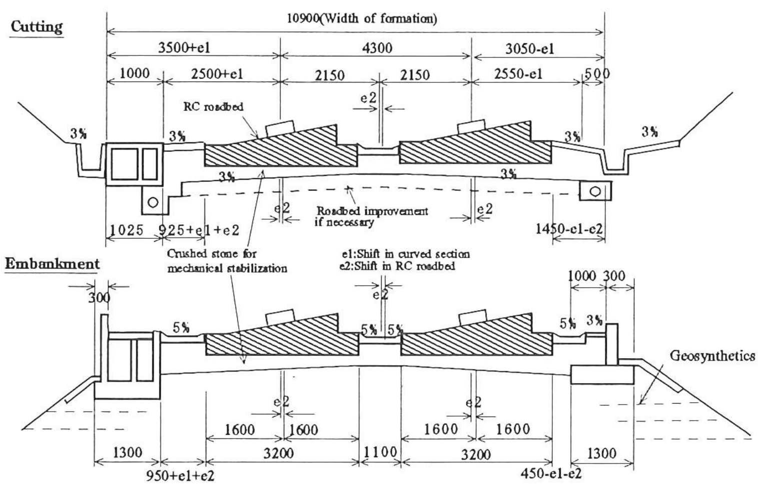

Fig.16 RCRS structure in cuttings and embankments at Hokuriku Shinkansen

Transition to bridges

The embankments approaching to bridge abutments or culverts supporting tracks are one of the weak points of track, because settlements of these parts tend to make progress faster compared with ordinary ones, and track supporting conditions tend to change before and behind. The approach blocks shown in Fig.17 were contrived to deal with such problems.They are made of crushed stone bound with cement. Minimum strength is set at uni-axial compression strength of 2 MPa. We also demand compacting of each 150 mm thick layer, to the K_{30}-value of 150 MN/m^3 or more, and the degree of compacting to 95% or more. In addition, the end part of RCRS is placed on the crown to prevent excessive deflection at the transition between RCRS and a bridge.

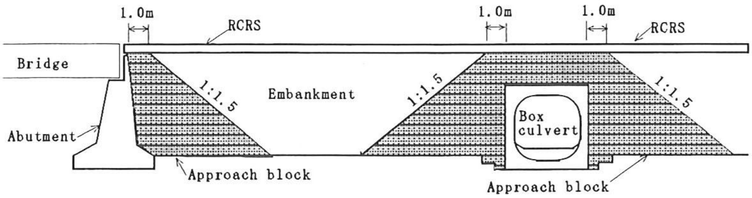

Fig. 17 The approach blocks structure

Noise

Generally speaking, noise level of slab track under train-running is 5dB(A) higher than that of ballasted track. The slab track on concrete roadbed on earthworks from Takasaki to Nagano was laid on mountainous sections where few people live. Special countermeasures for reducing noise were not adopted in these sections except sound protection walls.

Earthquake

Not only viaducts but also embankments were seriously damaged by the Hyogo-ken Nambu Earthquake in 1995. As for embankments of Hokuriku Shinkansen, geosynthetics (nets) were put into bank-layers to reinforce embankments against earthquake shocks. Banks are expected to avoid a fatal damage by this method.

Economic comparison

The initial construction cost of slab track is higher than that of ballasted track by 18% in cuttings and by 24% in embankments. Fig.18 shows the comparison example of total costs for both tracks. These prices include personal expenses, maintenance costs, municipal property tax and depreciation costs. In this case, the extra investment might be redeemed in about 12 years of commercial operation.

PERFORMANCE TESTS UNDER TRAIN RUNNING

Test at Kashiyama section

The performance tests under train running were carried out to confirm the running stability of slab track on embankment and cutting at Kashiyama section in December 1996. The alignment of test section was straight. Wheel loads, displacement, stresses had been measured under train running up to 250 km/h. Maximum values registered for each item are shown in Table 3.
Every stress was at low level from a viewpoint of durability. As the test results indicate, there was

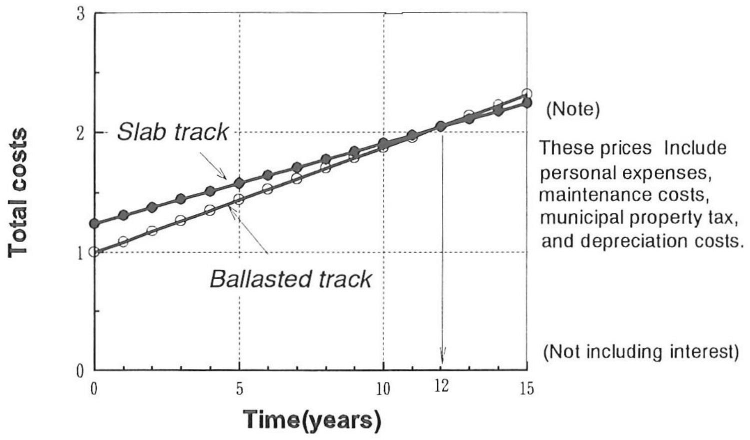

Fig.18 Comparison example of total costs between slab track and ballasted track

Table 3 Measured maximum values at embankment part

Items	Maximum values	Standard for high speed train running
wheel load	70.9 kN	≦ 200 kN
upper concrete stress	-0.24 MPa	-
lower concrete stress	0.17 MPa	-
upper reinforced bar stress	-1.5 MPa	≦ 80 MPa

no problem in terms of high speed train running.

Test at Saku section

The purpose of test at Saku section was to confirm the running stability at high speed on track around an approach block. Fig.19 shows the structure of Saku section. The height of the embankment is about 2 m. As for the alignment of test section, it was a curved track with curvature of 3500 m, cant of 200 mm, gradient of 30/1000. Wheel loads,displacement, stresses had been measured under train running up to 260 km/h in June in 1997. Maximum values measured for each item are shown in Table 4.
The wheel loads on approach block section were roughly equal in average and variationcompared with an ordinary section. As the test results indicate, there was no problem in terms of high speed running of trains.

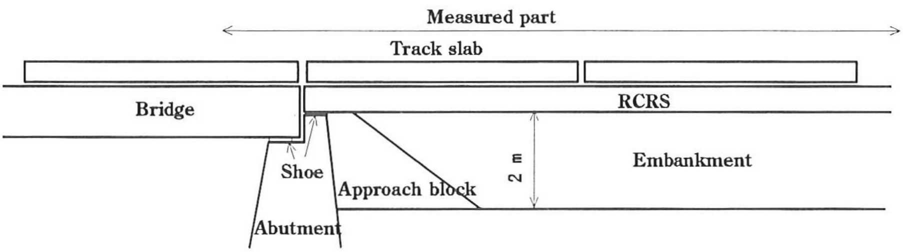

Fig.19 The structure of Saku section

Table 4 Measured maximum values at approach block part

Items	Maximum values	Standard for high speed train running
wheel load	97.8 kN	≦ 200 kN
rail displacement	0.64 mm	≦ 2.0 mm
RC roadbed disp.	0.11 mm	-
angular bending	0.09/1000	≦ 4/1000
rail stress	35 MPa	≦ 130 MPa
lower reinforced bar stress	1.4 MPa	≦ 80 MPa

CONCLUDING REMARKS

The Hokuriku Shinkansen line from Takasaki to Nagano opened for traffic in October 1997 just in time for the 1998 winter Olympics. A notable feature of this line is practically standard adoption of slab track not only for on viaduct and in tunnel but also on earthworks because of successful development of RCRS system.

Up to the construction of Tohoku Shinkansen, the use of slab track had been limited to viaduct and tunnel to satisfy the severe maintenance standards required for Shinkansen. The authors proposed the concrete roadbed structure for slab track which could be laid on embankments and cuttings. The test results confirmed that the fiber stresses and reinforced bar stresses of the roadbed were at low level from the viewpoint of durability, and that the settlement caused by dynamic repeating loads is extremely small. Therefore we had concluded that it had enough performance worthy the low-maintenance track. Now the application of slab track is being extended to embankments and cuttings.Our future subjects are to check the cumulative settlement in commercial operation and reduce construction costs.

REFERENCES

Ando Katsutoshi,T Sunaga,*et al.*(1996), Study on practical applications of concrete roadbed for on ground slab track, **Proceedings of JSCE, No.536/IV-31,** pp.87-98 (in Japanese).

Nakahara Akio(1996), Shinkansen slab track to be laid on earthworks, **Railway Gazette International, Volume 152,No.3**, pp.139-142.

Konishi Toshiyuki,*et al.*(1995), Investigation on settlements of low maintenance tracks on earthworks, **Annual Proceedings of JSCE,IV-292,** pp.584-585(in Japanese).