Summary

The Sanyo Shinkansen was opened between Shin-Osaka and Okayama in 1972, and was extended to Hakata in 1975. As a result of the through-service with the existing Tokaido Shinkansen, a large number of passengers came to be transported on this line which functions as the main artery between Tokyo and Hakata, thus contributing to the development of industry and the economy, and also the improvement of the lives of the Japanese people. Since the opening of the Sanyo Shinkansen, the Shinkansen trains have continued to maintain a high degree of safety with zero fatal accidents to passengers. Currently, Sanyo Shinkansen trains run at a maximum commercial speed of 300 km/h (was 210 km/h at the commencement of operation), thus putting them in the top world class for high-speed performance. Here, I will look back on the history of the Sanyo Shinkansen up to the present, and also give an outline of the Hokuriku Shinkansen which went into operation in March 2015.

1. Sanyo Shinkansen

(1) Outline of the section

With the opening of the Tokaido Shinkansen in 1964, the deficiency of transportation capacity was overcome. However, at that time there was remarkable development west of Osaka, and the transportation capacity of the Sanyo Main Line had reached its limit. For this reason, it was concluded that the best method of increasing the capacity of the Sanyo Main Line would be to lay a separate wide gauge track, and in 1965 construction work for the Sanyo Shinkansen was approved.

In particular, it was assumed that the capacity of the Sanyo Main Line would reach its limit around 1971, so it was decided to initially construct the part of the line between Shin-Osaka and Okayama, and later to extend it to Hakata.

The work was bogged down due to the purchase of land, and other matters, and was fraught with difficulties accompanying the construction of viaducts in three cities in the Hanshin area, the construction of the Rokko Tunnel, Shin-Kannon Tunnel and Aki Tunnel, and the construction of the double viaduct structure at Fukuyma Station. In addition, we were confronted with a labor shortage, as well as a shortage of materials and abrupt price increases brought about by the oil shock. Despite such a severe environment, the line was extended to Okayama in 4 years and 6 months, and to Hakata in a further 5 years and 1 month.

At least 5 years had passed from the enactment of the construction standards for the Tokaido Shinkansen, and new construction standards were enacted utilizing the technical advances made and experience gained from the Shinkansen during this period. Particularly, the maximum design speed for the time being was set to 210 km/h, which is the same as that of the Tokaido Shinkansen. However, with a view to enabling the maximum speed to be increased to 250 km/h in the future, provision was made during the construction work to ensure that parts of the construction such as the radius of curvature and the gradient which are difficult to modify in the future, and also parts such as power source facilities which involve a large amount of reworking, could cope with the transition to the higher maximum speed.

Also, as new technology, we employed a slab track aimed at simplifying maintenance of the track, utilized a 60 kg rail which has high vertical rigidity, and newly adopted the COMputer aided TRAffic Control (COMTRAC) consisting of CTC combined with a computer in order to carry out train operation control safely and quickly.

(2) Regional vitalization

The western Japan area through which the Sanyo Shinkansen passes has a relatively low population density, and in addition it has expressways and airports, resulting in severe competition with other modes of transportation. Particularly, the number of aircraft flying between Shin-Osaka and Hakata is such that this mode of transportation is convenient, and both Itami Airport and Fukuoka Airport are very conveniently located near urban areas, so from the viewpoint of overall traveling time as well, the Shinkansen was inferior. Accordingly, we carried out various measures such as increasing the frequency of service by adding more trains, improving riding comfort by adopting new type rolling stock, and increasing speed by improving the performance of the rolling stock, resulting in increased passenger volume.

(3) Efforts

I Improved safety

(a) Measures for concrete structures

In June 1999, a serious accident occurred in which approximately 200 kg of concrete separated from the bottom of a cold joint in the Fukuoka Tunnel and struck a moving train. Also, in October, approximately 220 kg of concrete from the joint between the upper and lower part of the concrete lining of the Kita-Kyushu Tunnel was found to have separated. In addition, around the same time, concrete fragments were found to have separated from a number of viaducts one after the other, thus greatly jeopardizing the reliability of safety of the Sanyo Shinkansen.

Over a period of about 50 days from October 25, 1999, a hammering test was carried out on the entire concrete lining of all 142 tunnels on the Sanyo Shinkansen. This test, which was called the “Sanyo Shinkansen Tunnel Safety Overhaul,” was carried out mainly by our employees who were involved with civil engineering, and extensive cooperation was provided by each Japan Railway Company, partner companies, former employees, and others. In total, some 69,000 persons were involved in this inspection work.

In the “Tunnel Safety Issue Investigative Committee” (Committee Chairman: Norihisa Adachi, professor at Kyoto University) which was established by the Ministry of Transport (at that time), it was concluded that the main cause of the concrete separation in all cases was the occurrence of cracks inside the concrete lining of the tunnel either while the concrete was being applied or immediately afterward. Consequently, in order to prevent these accidents from occurring, we adopted a soundness evaluation (a, β, γ) concerning separation of concrete in the railway tunnel inspections, and also a special general overhaul consisting of a careful visual inspection and a hammering test. In addition, since 2002 we have been using a tunnel lining image inspection car in Sanyo Shinkansen tunnels, aiming at efficiently and accurately obtaining a grasp of the deformation of the surface of the tunnel lining (Photo 1).

Concerning viaducts, a study was carried out by the “Sanyo Shinkansen Concrete Structure Investigative Commission” (Chairman: Shigeyoshi Nagataki, professor at Niigata University) which was established within the Railway Technical Research Institute. As a result, it was concluded that although there are no durability-related issues at present, it is necessary to establish a repair plan, and carry
out appropriate inspections and timely repair in order to maintain its soundness.

Accordingly, in order to collect basic data which is necessary for future maintenance, we conducted an overall diagnosis at some 12,000 points on viaducts and other structures, and drew up a repair plan based on the selection flow chart of the repair methods proposed by the Commission. Also, in order to improve the quality of the repair work, we established a "Concrete Repair Work Construction Managing Engineer" system whereby we certified engineers belonging to the construction company, and stationed them permanently at the site where repair work was to be carried out. In addition, based on guidance received from the "Investigation and Deliberation Committee Regarding Maintenance of Concrete Structures" (Chairman: Toyoaki Miyagawa, professor at Kyoto University) of the Society of Materials Science, Japan, we are making ongoing efforts regarding maintenance of concrete structures, such as validation of the durability of materials and also utilization of electrochemical repair methods.

(b) Hyogo-ken Nanbu Earthquake and anti-quake measures

The Hyogo-ken Nanbu Earthquake (January 17, 1995, Moment magnitude Mw 6.9) was an earthquake whose epicenter was directly below an urban area. It caused a great deal of damage to the various cities located mainly in the Hanshin Area. The Sanyo Shinkansen incurred damage between Shin-Osaka and Himeji. Particularly, major damage occurred over a distance of several kilometers eastward of the Himeji, was significant. Many instances of shear failure were seen, at an urban area. It caused a great deal of damage to the various cities located mainly in the Hanshin Area. The Sanyo Shinkansen incurred damage between Shin-Osaka and Himeji. Particularly, major damage occurred over a distance of several kilometers eastward of the

... and there were 8 instances of viaducts and bridges collapsing. Also, although the Mukogawa Bridge was not damaged to the extent that it collapsed, the cover concrete separated at the termination point of the main reinforcing bars in the axial direction, and also buckling of the reinforcing bars in the axial direction occurred (Photo 2).

Four tunnels in addition to the Rokko Tunnel sustained damage. In the case of the Rokko Tunnel, it was found that in the fracture zones which had been verified during construction, shear cracks in the arch crown, separation of the concrete at the end of the crown, and separation of concrete due to crushing of the concrete at working joints on the arches and side walls had occurred. In other places, only small pieces of concrete had separated. Regarding earth structures, some of the earth-retaining walls between the Nagasaka Tunnel and Nishi-Akashi had bulged out. Apart for some sections, almost the entire track is a ballast track. In the sections where bridges had collapsed, the track panel was curved like a ladder, and there were places where civil engineering structures incurred severe damage, and also places where the bridge girders had become misaligned.

Station facilities were also found to be damaged: The platform girders at Shin-Kobe and Nishi-Akashi were misaligned, the concourse tiles had risen up, and ticket vending machines had toppled over.

Regarding electrical facilities, at places where civil engineering structures had incurred major damage, overhead contact line supports had been damaged, overhead contact lines had been broken, and signal communication cables had become stretched or otherwise become damaged. Also, at the Rokko Substation, the transformers had become damaged due to subsidence of the ground.

For the restoration work, we formed a technical integrated team centered on JR West Japan Consultants (participated in by the Railway Technical Research Institute and the various Japan Railway companies). This team gave various kinds of technical guidance to enable us to judge the feasibility of reusing the bridges that had...
collapsed, and also guidance concerning reinforcement of the viaduct columns by wrapping steel sheets around them.

The work of restoring the Sanyo Shinkansen was completed on March 26, 1995, and in April 8 of the same year, that is, 81 days after the occurrence of the earthquake, the entire line was re-opened.

(i) Urgent Earthquake Detection and Alarm System

As a method of preventing access to damaged parts of the Sanyo Shinkansen, we installed the Urgent Earthquake Detection and Alarm System (UrEDAS) in November 1996. This system consists of 43 wayside seismometers installed at intervals of roughly 10 km along the track, and also 10 coastal seismometers installed closer to the epicenter of a plate type earthquake which is likely to occur at a location remote from the Sanyo Shinkansen. The initial microtremor (P wave) of the earthquake is detected by each seismometer, the scale of the earthquake and the location where it occurred are estimated immediately, and then an alarm is emitted to places that are considered to have been affected by the earthquake. Also, if the amplitude of the shaking along the track exceeds a certain value, the feed of electric power will stop, causing the moving train to stop or decelerate as quickly as possible.

In March 2006, the method of estimating the scale of an earthquake was changed to a type that was developed jointly by the Railway Technical Research Institute (name at that time) and the Meteorological Agency, enabling the time for estimating the scale of the earthquake to be reduced from the previous 3 seconds to 2 seconds. Also, in June 2012, we newly added a function to each coastal seismometer which detects the S wave and outputs an alarm, aiming at early detection of an earthquake that has a long period such as the Great East Japan Earthquake (March 11, 2011).

(ii) Anti-quake reinforcement

Since the occurrence of the Niigata Prefecture Chūetsu Earthquake (October 23, 2004), we have been engaged in devising anti-quake measures centered on "structure countermeasures (anti-quake reinforcement)," "prevention of access to damaged places," and "measures for reducing the possibility of a disaster after a derailment," based on guidance provided by the Ministry of Land, Infrastructure, Transport and Tourism.

From the lessons learned as a result of the Hyogo-ken Nanbu Earthquake (1995), we devised structural countermeasures based on the ministerial ordinances and transmittals of the Ministry of Land, Infrastructure, Transport and Tourism (former Ministry of Transport). The installation of 1,450 additional girders to prevent bridges from collapsing was completed at the end of fiscal 1997, the anti-quake measures employed in two tunnels that orthogonally intersect active faults were completed at the end of fiscal 2007, and the addition of 32,500 shear failure type columns was completed at the end of fiscal 2010. We are also successively carrying out the installation of steel-reinforced concrete piers, and as of the end of fiscal 2013 we had completed anti-quake reinforcement of 840 piers (out of a total of 1800 piers). Some of the viaduct columns were fortified using the "Aseismic reinforcements by Precastblocks and Additional Tendons (APAT method, Photo 3)" developed jointly between us and several companies. The APAT method involves installing divided PC blocks on pre-installed members, and then wrapping stranded wire around them. It realizes anti-quake performance that is at least as high as that of the steel sheet wrapping reinforcement method in general use, and also features the ability to enable damage such as cracks to be judged.

(iii) Derailment prevention guard

Based on the incident in which a Shinkansen car became derailed during the Niigata Prefecture Chūetsu Earthquake (2004), we are currently promoting the installation of derailment prevention guards (Photo 4). The target section for installation of the derailment prevention guards extends from Shin-Osaka to Himeji, a distance of approximately 110 km (track length), and the work is scheduled to be completed by the end of fiscal 2015. In March 2013, we adopted a separation prevention guard laying wagon (Photo 5), and carried out automated laying work, thus enabling the work to proceed at the rate of about 500 m/day, which is four times the rate when the work is performed manually.

(iv) Shinkansen Second General Control Center

Regarding the Tokaido and Sanyo Shinkansen, as a result of our experience with the Great Hanshin Earthquake we became aware that it was necessary to construct a general control center at a location remote from Tokyo as a backup in the event that the Shinkansen General Control Center located in Tokyo became damaged, and in February 1999 we newly constructed the Shinkansen Second General Control Center in the Osaka District which is currently operating as a backup facility in case of emergency.

The Shinkansen train operation control system used at the Second General Control Center is connected to the Tokyo General Control Center by a high-speed data communication circuit. Each day, the train timetable and other information necessary for starting the system used
at the Second General Control Center is transferred from Tokyo in case of emergency, and also it is used for training train control staff as well as for preventing accidents, during normal operation.

(v) Being prepared for the Tokai, Tonankai or Nankai earthquake

To ensure that the lessons learnt from the Great East Japan Earthquake and other past earthquakes are not forgotten, in August 2012 we established "Tsunami Evacuation Guidance Knowledge" which covers evacuation at the judgment of the crew, in the event that a major earthquake occurs and it is predicted that a tsunami will occur, and in addition communication has stopped or there is not much time.

This knowledge covers operation regulations which apply to the issuance of a tsunami warning, the operation regulation section for evacuation guidance and facilities inspection, and rules concerning the evacuation guidance routes. Also, in order to promptly provide relief to passengers in the event of a future earthquake, we carry out evacuation guidance drills in coordination with the police and the fire brigade, and keep a supply of water and foodstuff at major stations for passengers who cannot easily return home.

(c) ATC renewal

The ATC currently used on the Sanyo Shinkansen is the ATC-1W type which was adopted in 1993. It is primarily a wayside type which employs a multi-stage signal control method. Because it has reached its replacement time due to obsolescence along with the passage of time, we are currently carrying out work for replacing the ATC with the ATC-NS which has already been adopted on the Tokaido Shinkansen which carries out a mutual through-train service with the Sanyo Shinkansen, aiming at commencing operation in the spring of 2017.

The ATC-NS type is primarily an on-board type which employs a pattern signal control method. Train detection takes place using digital signals, making for greater security, and fine speed control corresponding to the performance of the rolling stock and single step brake control are employed for improved riding comfort.

II Improved service

(a) Improved timetable

The Sanyo Shinkansen has always been forced to compete against aircraft and other modes of transportation. On the other hand, the change of the environment has brought about new demands for the Shinkansen, and the needs of users with respect to the Shinkansen have tended to increase each year.

Based on such a situation, in order to properly meet new needs of passengers we have striven to achieve a level of comfort attainable only with the Shinkansen, such as by running express trains, increasing the number of trains, and increasing the number of stations that trains stop at. The history of the timetable is divided into six stages which are set out below.

(i) Immediately after the opening of the Shinkansen (1972 - )

Basically, when the line was opened as far as Okayama (March 15, 1972), trains running between Tokyo and Okayama were "Hikari" trains, and during early morning and late at night when there were no "Hikari" trains running, "Kodama" trains ran between Shin-Osaka and Okayama.

On March 10, 1975, the line between Okayama and Hakata was opened, and three kinds of "Hikari" ran directly from the Tokaido Shinkansen section (an express type "Hikari" running between Tokyo and Hakata, an all-stations type "Hikari" which stopped at all stations along certain sections of the entire route, and an all-stations type "Hikari" which ran between Tokyo and Hakata and stopped at all stations between Shin-Osaka and Okayama). In addition, there were "local Shinkansen" and "Hikari" trains which ran between Shin- Osaka and Hakata during early morning and also late at night when "direct Hikari" trains are not running.

The maximum speed of Shinkansen trains at that time was 210 km/h. The shortest time taken to travel between Shin-Osaka and Hakata was 3 hours and 44 minutes, and the shortest traveling time between Tokyo and Hakata was 6 hours and 56 minutes (in October 1980 reduced-speed running between Mihara and Hakata was stopped, resulting in a traveling time of 3 hours and 28 minutes between Shin- Osaka and Hakata, and a traveling time of 6 hours and 40 minutes between Tokyo and Hakata).

(ii) Upgrading of the "Hikari" (1986 - )

Along with the amendment to the timetable which was carried out in November 1986 immediately before our company was established, the series 100 "Hikari" made its appearance. The maximum speed of this train including that of the previous series 0 was increased by 10 km/h to 220 km/h. As a result, the necessary time to travel from Shin-Osaka to Hakata was 2 hours and 59 minutes, and the time taken to travel from Tokyo to Hakata was 5 hours and 57 minutes.

Along with the amendment to the timetable which was carried out in March 1989, the series new 100 rolling stock "Grand Hikari" was adopted as the first rolling stock after the establishment of our company. The maximum speed type "Hikari" made its appearance between Tokyo and Hakata. The maximum speed of this train was 230km/h for the Sanyo Shinkansen section, which shortened the traveling time between Shin-OSaka and Hakata by 10 minutes to 2 hours and 49 minutes and reduced the total travelling time between Tokyo and Hakata to 5 hours and 47 minutes thus making possible high-speed operation for both sections.

(iii) Adoption of the "Nozomi" and the pursuit of higher speed (1993 - )

In order to further enhance our competitive strength, at the time of the amendment to the timetable in March 1993 we newly adopted series 300 rolling stock which has a maximum speed of 270 km/h, and ran one train every hour between Tokyo and Hakata as a "Nozomi." As a result, the traveling time between Shin-Osaka and Hakata was 2 hours and 32 minutes, and between Tokyo and Hakata was 5 hours and 4 minutes, which are both significant reductions.

Along with the amendment to the timetable in March 1997, the series 500 "Nozomi" which realized the world's highest commercial running speed of 300 km/h made its debut, and resulted in a traveling time between Shin-osaKA and Hakata of 2 hours and 17 minutes, and between Tokyo and Hakata of 4 hours and 49 minutes, which indicate major increases in running speed.

At the time of the timetable amendment in March 1999, the starting acceleration within the Sanyo Shinkansen section was improved, and the series 700 "Nozomi" which had a top speed of 285 km/h made its debut. As a result, the traveling time between Shin-OSaka and Hakata was reduced by 7 minutes compared to the "Nozomi" which used series 300 rolling stock.

(iv) Speed-up based on local trains (2000 - )

Along with the amendment to the timetable in March 2000, we adopted the "Hikari Rail Star" which was an 8-car train consisting of series 700 rolling stock. We set the maximum speed to 285 km/h aiming at achieving a traveling time of 2 hours and 45 minutes between Shin-OSaka and Hakata, which is a considerable reduction compared to the conventional "Hikari." The "Hikari Rail Star" makes 18 two-way journeys between Shin-OSaka and Hakata and also the "Nozomi" makes 16 two-way journeys. The resulting high-speed transportation system was aimed at increasing the frequency of the train service between Shin-OSaka and Hakata.

(v) New timetable system based on the "Nozomi" (2003 - )

When the timetable was revised in October 2003, the series 100 rolling stock was removed from the section spanning the Tokaido Shinkansen, and instead the rolling stock used in this section was unified to the series 300, the series 500 and the series 700. Along with this, the number of "Nozomi" trains was greatly increased from 1 Tokaido Shinkansen direct-service "Nozomi" train per hour to 2 to 3 trains per hour. The newly added "Nozomi" trains enabled the journey between the Okayama and Hiroshima sections to the Tokyo metropolitan area to be reduced by 30 minutes compared to the same journey made by a conventional "Hikari" train, thus realizing a significant increase in speed.

At the time of the amendment to the timetable in July 2007, the
series N700 "Nozomi" made its appearance, and along with the amendment to the timetable in March of the following year, this train ran every hour in both directions between Tokyo and Hakata. This train had greater ability to negotiate curves in the Tokaido section and ran at a maximum speed of 300 km/h in the Sanyo section. As a result, it traveled between Shin-Osaka and Hakata in 2 hours and 23 minutes, and between Tokyo and Hakata in 4 hours and 50 minutes, which times were significant shorter than the corresponding traveling times of the series 700 "Nozomi.”

(v) Finding new demands with the opening of the Kyushu Shinkansen (2011 - )

In March 2011, the section of the Kyushu Shinkansen between Hakata and Shin-Yatsushiro was opened, and as a result Tokyo Station of the Tokaido Shinkansen was connected by a single rail to Kagoshima-Chuo Station of the Kyushu Shinkansen via the Sanyo Shinkansen. Along with the opening of the Kyushu Shinkansen, two new types of direct-service trains between Shin-Osaka and Kagoshima, the "Mizuho (maximum speed type) and the "Sakura" (high-speed type), made their debut. This made for great convenience in transporting passengers from the Sanyo section to the Kyushu section, and led to the oneearthing of new demands. The "Mizuho" was able to travel between Shin-Osaka and Kagoshima-Chuo in 3 hours and 45 minutes, thus contributing to increased competitive vis-à-vis air transportation.

(b) Rolling stock development

Since the establishment of our company, we have striven to increase the speed of the Tokaido and Sanyo Shinkansen trains in order to improve passenger transportation service and reduce travelling time. In March 1989 we adopted the "Grand Hikari" which had a maximum speed of 230 km/h, and in March 1993 we adopted the "Series 300 Nozomi" which had a maximum speed of 270 km/h. In March 1997, the "Series 500 Nozomi" which had a maximum speed of 300 km/h and incorporated the results of various technical developments carried out using the "WIN350 (West Japan Railway’s Innovation for Operation at 350)" test train was put into service. In March 1999, the "Series 700 Nozomi" which had a maximum speed of 285 km/h and was developed jointly by us and JR Tokai went into operation, and in July 2007 the "Series N700 Nozomi" which had a maximum speed of 300 km/h and was also developed jointly by us and JR Tokai went into operation. In March 2011, the "Series N700 8-car Mizuho-Sakura" which has a top speed of 300 km/h and was developed jointly by us and JR Kyushu based on the "Series N700" was adopted in order to realize a mutual through-train service between the Sanyo Shinkansen and the Kyushu Shinkansen.

By adopting these new "Nozomi" trains, we have contributed greatly to increasing our competitive strength compared to other modes of transport such as air and automobile, between major cities. Accordingly, the development of our rolling stock is described below.

(i) Development of the "Series 100 Grand Hikari"

When our company had just been established, all of the rolling stock was series 0 (series 0 and series 100 in the case of the Central Japan Railway Company), then in 1989 the series 100N "Grand Hikari" made its debut. At that time, the utilization of this train was high, and the acquisition of transportation capacity (particularly that of Green Cars) was an issue. In the light of this background, we coupled four (two in the case of the conventional series 100) double-decker cars together to enable three Green Cars to be coupled to each other, while retaining the dining car.

Also, although the maximum speed of the Tokaido and Sanyo Shinkansen trains was 220 km/h in 1986, reduced speed operation at 210 km/h was stopped, and the maximum speed was increased to 220 km/h, along with the adoption of the series 100N, the maximum speed of the Sanyo Shinkansen was increased to 230 km/h. This was realized by having the ATC220 signal read by the on-board equipment as a 230 signal by the series 100N alone, and a transponder was installed near the boundary between the two companies, thus realizing a system which automatically switches over the signals. As a result, the time taken to travel from Shin-Osaka to Hakata was reduced from 2 hours and 59 minutes to 2 hours and 49 minutes.

The main difference from the series 0 was the debut of the double-decker cars. All of the Green Car seats were on the second floor, providing a quieter environment, and the ordinary class seats were on the first floor. In order to make up for the reduction of comfort compared to the ordinary seats in a single-decker car, we provided a video service and also an audio service, and the seats were arranged in a 2 & 2 configuration to enable passengers to relax and enjoy their trip.

We also installed information displays above the automatic doors in the passenger area, and used them to provide various kinds of information.

(ii) Development of the "Series 300"

The series 300 rolling stock was developed by the Central Japan Railway Company with the aim of achieving a traveling time between Tokyo and Shin-Osaka of 2 hours and 30 minutes. In order to realize a maximum speed of 270 km/h, we employed new technology including a VVVF induction motor drive method and also aluminum alloy cars for reduced weight. In 1992, the series 300 went into commercial operation between Tokyo and Shin-Osaka, and in 1993 it went into commercial operation between Tokyo and Hakata. As a result, the traveling time between Shin-Osaka and Hakata was reduced from 2 hours and 49 minutes to 2 hours and 32 minutes.

The largest feature of the series 300 was its greatly increased maximum speed, which opened a new era of the Shinkansen. The elimination of the dining car and the adoption of reserved seats alone resulted in the creation of a new category of train which was designed with the ability to seat as many active businessmen as possible in mind.

Concerning the aspect of facilities for passenger service, the toilets were improved: The previous system in which flushing water was circulated was replaced with a system in which a small quantity of flushing water was injected at high pressure in order to flush the bowl. In addition, odors were reduced partly as a result of the installation of a shutter on the discharge part of the bowl, thus enabling the toilet to be maintained in a clean condition.

(iii) Development of the "Series 500"

The series 500 Shinkansen rolling stock was developed from the accumulation of the results of running tests carried out using the WIN350 which was manufactured by us in 1992 as a test train. It realized the world’s highest maximum speed of 300 km/h. In order to achieve this high speed, all cars of the train were motor cars. In order to reduce noise and vibration, wing type pantographs and also small insulator covers were used. In addition, the front of the train had a long nose of some 15 m and also the cross-sectional area of the body was reduced, aiming at maintaining harmony with the surrounding environment. Furthermore, semi-active suspension and yaw dampers between car bodies were used for enhanced riding comfort, and aluminum honeycomb which is both light and rigid and does not readily transmit sound was used in the car body, aiming at creating better riding comfort. In 1997, this train started commercial operation as the "Nozomi," and as a result, the time taken to travel between Shin-Osaka and Hakata was reduced from 2 hours and 32 minutes to 2 hours and 17 minutes.

This train is listed in the Guinness Book of Records for having recorded the world’s highest average speed between two adjacent stations and also the world’s highest average speed between the beginning and end of the line. In addition, we received the Blue Ribbon Award, the Brunel Award and the Good Design Award. Thus this train was the focus of attention in a variety of situations.

It can be said that the top speed of the series 500, the shape of the long nose front end, and the unique coloring which cannot be seen in the conventional Tokai or Sanyo Shinkansen greatly changed the image of railways up to that time.

(iv) Development of the "Series 700 Hikari Rail Star"

The "Hikari Rail Star" was able to travel between Shin-Osaka and Hakata in 2 hours and 45 minutes, which is on average 32 minutes less...
Ill Efforts made aiming at higher speed

(iii) Rolling stock

At the time of the division and privatization of the Japan National Railways (1987), we commenced operation in the Kansai region, which is said to be "the place where private railways reign supreme," and also in the West Japan region where many expressways and airports have been constructed, and we were forced into competition with other modes of transportation. Particularly, concerning the section of the Sanyo Shinkansen between Shin-Osaka and Hakata, Itami Airport and Fukuoka Airport are close to urban areas, making air transportation very convenient. Because of this, it was necessary for us to improve service, comfort and speed.

The Sanyo Shinkansen which we operate uses series 0 Shinkansen rolling stock which we inherited from the Japan National Railways. This resulted in a difference in grade of service between the Sanyo Shinkansen and the Tokaido Shinkansen which inherited the series 100 Shinkansen rolling stock. Also, because the timetable was centered on Tokyo, the convenience of the Sanyo Shinkansen was not as high as that of the Tokaido Shinkansen, and the Sanyo Shinkansen acquired a reputation of being "slow." This in fact is manifest in the way in which passengers used Shinkansen trains, while between Tokyo and Osaka, the proportion of passengers using the Shinkansen compared to those who fly was 9 : 1. In contrast, between Osaka and Hakata the proportion was 6 : 4, which indicated that the Sanyo Shinkansen was at a considerable disadvantage. Increasing the convenience of the Sanyo Shinkansen in order to increase the number of passengers using the line was an urgent management-related issue, and we were confronted with the necessity of renewing the old image of the Sanyo Shinkansen and establishing a new image to the effect that "the Shinkansen is fast," by all means possible.

Accordingly, we made efforts at improving transportation capacity. In March 1988, the "West Hikari," which was an series 0 Shinkansen train with improved carrying capacity, traveled between Shin-Osaka and Hakata in 2 hours and 59 minutes, and in March 1989, the "Grand Hikari," which was a series 100 Shinkansen train with enhanced passenger comfort and higher speed did the same journey in 2 hours and 49 minutes, and as a result it acquired a favorable reputation.

However, because curved parts of the track were constructed with a radius of at least 4,000 m, and also because of the linearity of the Sanyo Shinkansen which is suitable for high-speed operation, there was still room to increase the speed further. Intrinsically, the series 100 Shinkansen rolling stock was capable of running at 270 km/h, however the actual maximum speed was held at 230 km/h. The reason for this was because a higher speed than this would prevent the rolling stock from meeting Japan’s severe environmental standards concerning noise and vibration, so it was difficult to overcome this issue in the case of the series 100 Shinkansen which used a steel car body. Amidst the increasing severity of competition from other modes of transportation, such as the opening of the Kansai Airport and the opening of the Sanyo Expressway, in order to realize further increase of speed it was necessary to develop rolling stock based on a completely different way of thinking to that of Shinkansen rolling stock up until then.

Accordingly, in 1990, we established a Speed-up Committee with the vice-president of the company as leader and the relevant department managers as sub-leaders, and formulated the basic policy and also the schedule for running the Shinkansen at a higher speed. In order to realize higher speed, a project team was established, aiming at attaining a traveling time between Shin-Osaka and Hakata of 2 hours and 10 minutes and also a maximum commercial operating speed of 350 km/h, and in 1992 we fabricated the series 500 WIN350 Shinkansen test train (Photo 6). Along with the inauguration of the test train, we established a test implementation department inside the Hakata General Rolling Stock Depot, and took up the challenge of realizing higher speed. The fabricated test train had 6 cars, all of which were motor cars. To enable the necessary data for increasing speed to be acquired, the train was constructed according to specifications
which permitted two kinds of profiles to be used for the leading car and pantograph covers of various profiles to be installed.

The main issues on the rolling stock side are securing of safety, conformity with the environment, realization of high-speed performance, and improved comfort. We developed technology to overcome these issues, verified its effectiveness using the WIN350, and reflected it in the subsequent mass-produced series 500 Shinkansen trains.

The main issues concerning securement of safety were "running safety and running stability" and "reduction of braking distance in an emergency." Concerning running safety and running stability, it is necessary to aim for appropriateness of the toughness of the rubber supporting the bogies and also the attenuation coefficient of the dampers to ensure that the relationship between the wheel load and the side thrust remains within the safe range, and also that hunting does not occur, even under the worst conditions, and a grasp of these values was obtained. Also, concerning the reduction of braking distance, it is necessary to secure adequate adhesion force to prevent skidding even when a large braking force is output. By installing a Cerajet unit which injects ceramic particles between the rail and the wheel, it was possible when a large braking force is output. By installing a Cerajet unit which injects ceramic particles between the rail and the wheel, it was possible to obtain adequate adhesion force.

The main three issues concerning conformity with the environment are "micro-pressure waves," "external noise," and "ground vibration." First, regarding micro-pressure waves, when a train enters a tunnel at high speed, the air inside the tunnel is compressed. As this compressed air (pressure wave) propagates to the exit of the tunnel, the pressure gradient gradually increases, and at the exit of the tunnel, the air escapes accompanied by a loud sonic boom. These pressure waves are called micro-pressure waves. They adversely affect the environment along the tracks, and constitute a particularly large issue along the Sanyo section where there are many tunnels. In this connection, it was known that the use of a sharp profile for the front of the train and also reduction of the cross-section area of the car body were effective for suppressing the generation of the pressure wave itself, or for reducing the pressure gradient even if a pressure wave was generated. This led to the adoption of a front nose shaped like a fighter aircraft (15 m long nose) and also a circular body cross-section (10.2 m²) in the subsequent series 500 Shinkansen.

Next, external noise is broadly divided into current collection system noise emitted from the current collector, and aerodynamic noise from the car body. Current collection system noise is classified into 3 kinds: sliding noise caused by contact between the pantograph and the overhead contact line, sparking noise caused by the pantograph separating from the overhead contact line, and aerodynamic noise caused by the body of the pantograph cutting through the air. It was found that, of these, sliding noise could be reduced by improving the lubricating performance of the contacting parts in order to reduce the coefficient of friction, while sparking noise could be reduced by pulling through the bus line so as to electrically connect multiple pantographs to each other, and thus reduce the electrical contact loss ratio. Concerning the body of the pantograph, we developed a wing type pantograph which has excellent aerodynamic characteristics, and also an insulator cover as a windproof cover which prevents wind from getting into contact with the body of the pantograph, thus realizing reduced noise. During the development of the wing type pantograph and the insulator cover, we established an aerodynamic issue study committee consisting of persons with experience in aircraft design, persons of learning and experience, and related persons belonging to the RTRI, and carried out various studies including wind tunnel tests and tests with pantographs mounted on an automobile. During these studies, we learned many things from nature, and actually adopted a feather of an owl. The main cause of car body aerodynamic noise is surface irregularities, this noise can be reduced by eliminating these surface irregularities as far as possible. For this reason, we adopted a profile that had as few surface irregularities as possible, from the roof to the underside of the floor. Also, sharpening of the profile of the front of the train to reduce micro-pressure waves reduces the disturbance to the air flow to the rear, so it is also effective from the viewpoint of reduction of noise resulting from car body aerodynamic pressure as well.

Lastly, there is the issue of ground vibration. When a train runs at high-speed, the energy possessed by it is naturally large. Consequently, reduction of weight, which has a great effect on the energy, is highly effective for reducing vibration. For this reason, we adopted light materials such as aluminum, and also used a honeycomb construction which provides strength. Regarding the bogies, we used aluminum material for some parts in order to reduce weight. In addition, we employed new technology such as the use of GTO devices in the main circuit and also reviewed the method, thus realizing weight and size reduction of the equipment, and in turn reducing ground vibration. Enhanced high-speed performance was realized by using main motors with greater output. Regarding comfort, because there are many tunnel sections and the vibration due to air pressure is applied to the sides of the car body, deterioration of riding comfort was very noticeable. For this reason, we used semi-active dampers and yaw dampers to reduce the shaking of the car body in order to improve riding comfort in tunnels. We also adopted a circular cross-section for the car body in order to minimize the effect of air pressure on the body.

Early in the morning of August 8, 1992, the WIN350 train reached a top speed of 350.4 km/h on the up-line of the Sanyo Shinkansen (between Ogori and Shin-Shimonoseki). This was the highest speed recorded by a train in Japan at that time. During the 4 years from when testing was started until it was completed in May 1996, the test train traveled a total of 330,000 km. After this, the baton was passed to the subsequent series 500 Shinkansen pre-production W1 train set. In March 1997, using the series 500 Shinkansen which inherited the above test results, we achieved a maximum commercial speed of 300 km/h which was the highest in the world at that time.

As a result of this project, we overcame the issues attendant to increasing speed, and acquired much test data and knowledge. These achievements were utilized not only in the series 500 Shinkansen, but also in the development of later rolling stock, and are presently contributing to the growth of the present Sanyo Shinkansen.

(b) Facilities

The improvement in train speed along with the progress made in technical development greatly affects the environment along the tracks in the form of noise, vibration and micro-pressure waves. Here, we have set out a description of countermeasures on the ground side which we carried out in parallel with the abovementioned countermeasures on the rolling stock side.

Regarding noise along the track, noise emanating from beneath the cars has been greatly reduced by periodically re-profiling the rails and also by installing interference type or reverse L-shaped anti-noise walls in addition to the normal shield plates. Furthermore, by combining these countermeasures with the use of sound absorbing material, it was possible to reduce noise over a wide frequency band. An effective method of reducing structure noise generated along the slab track section of a viaduct is the installation of low spring track pads. Concerning ground vibration, the level of vibration along the track has been greatly reduced by systematically laying elastic sleepers up to now.

Since the commencement of the through-service of the series 300 Nozomi into the Sanyo section in 1993, we have striven to accelerate countermeasures for micro-pressure waves such as by installing tunnel entrance hoods or extending existing ones. At present, tunnel entrance hoods are installed at the entrance of the majority of tunnels. In the area of track maintenance, when the Sanyo Shinkansen was inaugurated, control of riding comfort was not yet developed. However, along with the speeding up of the Sanyo Shinkansen we made greater efforts aimed at increasing passenger comfort, and as a result of the adoption of a method of performing long wavelength
control and maintenance using a 40-meter chord, for example, we now provide stable riding comfort.

Regarding track maintenance, we have purchased various maintenance machines, aiming at implementing high quality large-scale repair work using reduced labor and at reduced cost. Aiming at improving the riding comfort of a slab track, we utilized the lining function of a multiple tie tamper, and in addition purchased a slab liner which has mechanisms for slackening and tightening the tie plate fastening bolts and also adjusting and measuring the track gauge, in fiscal 1999.

In order to improve the safety of ballast renewal work, in 2007 we purchased a new type ballast renewal machine (Photo 7) which has a mechanism for simultaneously removing and replenishing track ballast.

In order to improve the safety and efficiency of transporting and laying 200 m rails, in 2009 we purchased a long-rail wagon (Photo 8) which has a mechanism for laying a rail at any desired location.

The feeding method used was an auto-transformer feeding system, and the booster section, which was a weak point of the conventional Shinkansen overhead contact line, was not used on the main Sanyo Shinkansen line. From the outset, feed section control using train detection in change-over sections was carried out at substations (SS) and feeding sections (SP).

In high-speed sections of the Shinkansen, arcing always occurred due to continuous contact loss resulting from 200 mm pitch corrugations in the overhead contact line. However, in 1990 we increased the width of the pantograph contact strip by 15 mm, and after about 2 years we had succeeded in eliminating corrugation of the overhead contact line along the whole line. Also, at the commencement of commercial operation of the "Nozomi" in March 1993, we improved the tensile strength of the overhead contact line in the high-speed sections where the train speed exceeds 230 km/h. Subsequently, during the WIN350 running test, the performance of the TA overhead contact line which used aluminum was carried out, and when the series 500 went into commercial operation in 1997, a copper alloy CS overhead contact line containing a steel core was used.

We used an MF contact line whose cross-sectional profile was designed to facilitate detection of wear exceeding the threshold value which is an important part of maintenance of the overhead contact line.

(i) Transition of train protection system

When Okayama Station of the Sanyo Shinkansen was inaugurated in 1972, a power synchronous single frequency type ATC was used. Subsequently, based on the signal trouble which occurred at Shinagawa in 1974, we used a dual frequency combination type ATC when renewing the train protection system in 1993.

Also in 1993, commercial operation of the "Nozomi" at 270 km/h commenced. When a single frequency type was used, speed signals could only be output as far as 220 km/h. With the adoption of a dual frequency combination type ATC, signal indications for speeds exceeding 220 km/h could be realized. In order to realize an appropriate timing for route control in this case, a transponder that enabled each type of rolling stock to be recognized on the ground was installed.

In 1997, 300 km/h operation of the series 500 Nozomi commenced. However, because speed signals exceeding 275 km/h could not be accurately recognized by single frequency type on-board ATC, it was decided to use a transponder to identify the wayside equipment and output corresponding signals.

Table 1 Comparison between the construction standards used for the Tokaido Shinkansen and the Sanyo Shinkansen

<table>
<thead>
<tr>
<th></th>
<th>Tokaido Shinkansen</th>
<th>Sanyo Shinkansen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum design speed</td>
<td>210 km/h</td>
<td>250 km/h</td>
</tr>
<tr>
<td>Minimum radius of curvature</td>
<td>2,500 m</td>
<td>4,000 m</td>
</tr>
<tr>
<td>Steepest gradient</td>
<td>20%</td>
<td>15%</td>
</tr>
<tr>
<td>Radius of vertical curve</td>
<td>10,000 m</td>
<td>15,000 m</td>
</tr>
<tr>
<td>Track spacing</td>
<td>4,200 mm</td>
<td>4,300 mm</td>
</tr>
<tr>
<td>Formation width</td>
<td>10.7 m</td>
<td>11.6 m</td>
</tr>
<tr>
<td>Rail</td>
<td>53 kg/m</td>
<td>60 kg/m</td>
</tr>
</tbody>
</table>

Table 2 Comparison of the extension proportion for each kind of structure

<table>
<thead>
<tr>
<th></th>
<th>Tokaido Shinkansen</th>
<th>Sanyo Shinkansen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunnel</td>
<td>13%</td>
<td>51%</td>
</tr>
<tr>
<td>Viaduct</td>
<td>22%</td>
<td>28%</td>
</tr>
<tr>
<td>Bridge</td>
<td>11%</td>
<td>9%</td>
</tr>
<tr>
<td>Embankment and cutting</td>
<td>53%</td>
<td>12%</td>
</tr>
<tr>
<td>Slab track ratio</td>
<td>0%</td>
<td>50%</td>
</tr>
</tbody>
</table>

2. Hokuriku Shinkansen

(1) Rail and features of the Hokuriku Shinkansen

Of the section of the Hokuriku Shinkansen that is scheduled to be extended soon, the Hokuriku section which is our area is located in a region of very heavy snowfall. In order to carry out countermeasures
which are based on removing snow by keeping the trains running, we have provided space on viaducts to collect removed snow. In addition, we have purchased new type snowplows and also installed snow removal and snow melting equipment at railway stations and car depots to cope with snow. Also, in order to carry out a mutual through-train service with the previously opened section belonging to East Japan Railway Company, we intend to adopt and run each of the systems (DS-ATC, COSMOS, etc.) that have been adopted by the East Japan Railway Company instead of the facilities that we have adopted on the Sanyo Shinkansen which we have managed until now.

(2) Hokuriku Shinkansen facilities

I Rolling stock

Aiming at the opening of Kanazawa Station on the Hokuriku Shinkansen, we carried out joint development with the East Japan Railway Company of new type series W7/E7 rolling stock (Photo 9). The series W7/E7 is intended to run at a maximum speed of 260 km/h during commercial operation. One train has 12 cars, and the rolling stock has equipment which enables it to operate at both 50 Hz and 60 Hz. We are aiming to adopt the “Gran Class” which has a good reputation in the East Japan Railway Company’s series E5, and also to improve riding comfort by using an active suspension. We installed a full range of service facilities including barrier-free facilities, power outlets in each passenger room, and toilet seats with a warm water washing function on all western style toilets in the cars. The maximum commercial running speed of the Hokuriku Shinkansen is 260 km/h, and as a safety measure in the event of an earthquake we increased the braking force in order to reduce the braking distance. In April 2014 the first train was completed, and subsequently a total of 10 trains were manufactured.

II Facilities

The basic countermeasures against snow damage consist of a snow-storing method in which the height of the roadbed concrete beneath the track is increased so as to form a structure that enables the snow to be accumulated on both sides of the track, and also self-snowplowing running to remove snow from the track, in order to provide running space.

In sections where there is a relatively large snowfall, we have installed snow covers of 1 m width at the top of the noise barrier in order to reduce the amount of snow falling into the viaduct. Also, in sections of heavy snowfall where it is assumed that the amount of snow that falls is likely to exceed the amount that can be accumulated, during maintenance work at night the snow on the viaduct is pushed off it by a rotary snowplow (Photo 10), enabling the snow accumulation space necessary for commercial operation in the daytime to be secured. Note that in sections such as an intersection between a viaduct and a road beneath it, we install warm water panels for circulating anti-freeze which is heated over the cable ducts, thereby melting the snow that was pushed off the viaduct.

III Electricity

In the case of the Hokuriku Shinkansen, electric power fed from power companies to substations at 50 Hz and also to substations at 60 Hz, respectively, is applied directly to the overhead contact line without frequency conversion. In addition, power facilities and signaling facilities have been specially designed so that in the case where a 50 Hz substation stops functioning, 60 Hz power will be fed to that section from the adjacent substation, enabling the train to continue operating (Fig.3).

In the case of the Shin-Joetsu substation, an indoor type gas simultaneous insulating system (GIS) is utilized for installing all power conversion equipment other than power receiving facilities substandard indoors, aiming at realizing snow damage countermeasures and more compact facilities.

(3) Hokuriku Shinkansen timetable

We are studying the timetable based on the demands from passengers, while inquiring about the needs of people living near the line. In addition to regular trains which run directly between Tokyo and Kanazawa, we also set unscheduled trains according to the passenger utilization situation in order to provide adequate transportation capacity. The types of trains which we set were the “Kagayaki” express type which stops at a limited number of stations between Tokyo and Kanazawa enabling the traveling time of 2 hours and 30 minutes, the “Hakutaka” stopping type which stops at many stations in addition to those at which the express type stops, and also the “Tsugaru” shuttle type which runs once every hour in order to maintain convenience for traveling between Toyama and Kanazawa and also Kansai-Chukyo and Toyama.

3. Conclusion

The foregoing describes our activities from the background of construction of the Sanyo Shinkansen to the present, and also an outline of the Hokuriku Shinkansen up until its inauguration in March.
In the future as well, we intend to carry out activities aimed at improving safety and reliability, with a view to offering transportation services that can be selected by passengers and also creating a more substantial network.