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The Features of Shinkansen System and Infrastructures Japanese Engineers Challenging in Recent Three Decades

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Abstract: Sinkansen is the first High Speed Railway system in the world. The most typical features of Shinkansen system is the design concept, All Shinkansen trainsets are made up of EMU. Other features of Shinkansen system are well known as follows; high level safety, strict punctuality, large traffic, high capacity per trainset, etc.

We can observe many features in the Shinkansen system. But, it is difficult to find some documents written in English about those features, especially infrastructures or construction technology. I hope this paper can help you for your understanding about the Shinkansen system, especially infrastructure construction technology.

Keywords: Shinkansen, High Speed Railway System, Infrastructure, Construction Technology

1. INTRODUCTION

Tokaido Shinkansen was constructed by Japanese National Railways (JNR).The commercial operation of Tokaido Shinkansen (between Tokyo and Shin-Osaka) was started at the first day of October 1964. Since then, JNR had constructed another Shinkansen lines; Sanyo (between Shin-Osaka and Hakata), Tohoku (between Omiya and Morioka), and Joetsu (between Omiya and Niigata).

According to the Nationwide Shinkansen Railways Development Act established on 1970, five Shinkansen lines are defined as next Shinkansen expansion project. But, this plan had been suspended over the course of one or one half decades.

After privatization and separation event from JNR to JR companies, Shinkansen railways development projects were re-started. New Shinkansen lines were constructed as public project. Those projects were subsided by Japanese government and regional prefectures, under the vertical separation scheme.

・Infrastructure constructor / owner:

JRTT (Japan Railway Construction, Transport and Technology Agency)
*former JRCC (Japan Railway Construction Public Corporation)

・Shinkansen trains operator: JR companies (Kyusyu, West, East, and Hokkaido)

JRTT has developed Shinkansen network expansion consistently for three decades.

Shinkansen is the first high speed railway system in the world. We can observe many features in the Shinkansen system. But, it is difficult to find some documents written in English about those features, especially infrastructures or construction technology.

The mission of this paper is to be as a “bridge” between transportation study and as a technical review of Shinkansen system, especially infrastructure construction. I hope this paper can help you for your understanding about the Shinkansen system, especially infrastructure construction technology.

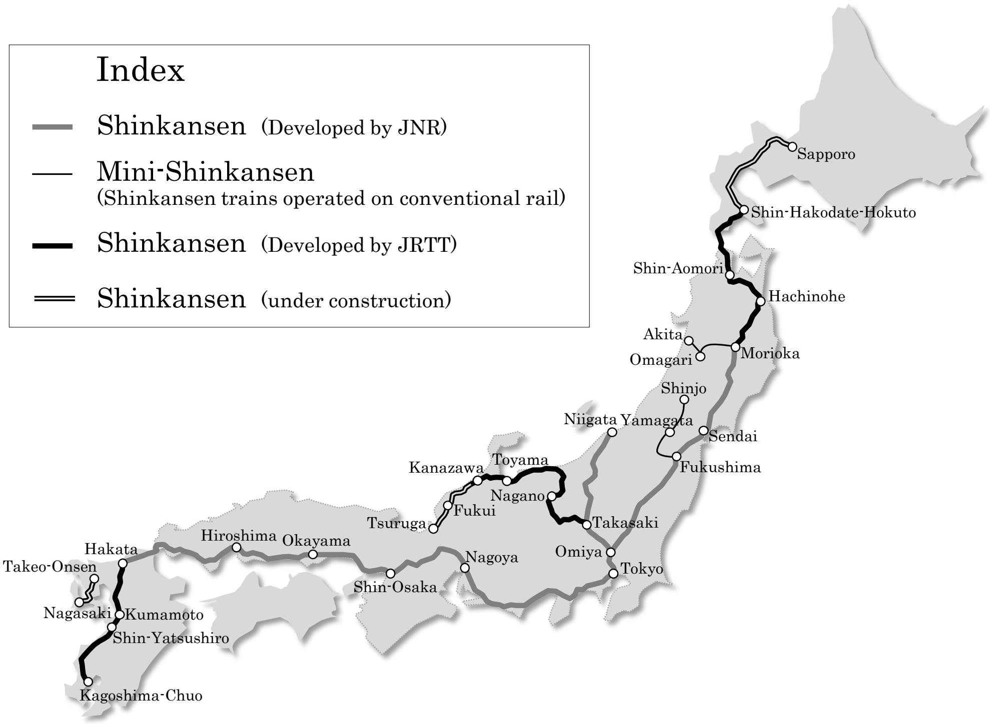

Figure 1. Current Shinkansen Network Map

2. OVERVIEW

All Shinkansen trainsets were, are, and perhaps will be made up by EMU. The most typical features of Shinkansen system are based on this design concept. Thanks to this concept, design axle load of Shinkansen can be lighter, acceleration / deceralation specific of Shinkansen trainsets can be higher, and length of turnout can be shorter.

Shikansen network has few junction track layout or link line, and Shinkansen rail track has fewer crossovers. Shinkansen network (1,435mm gauge) is independent from conventional railway network (1,067mm gauge). Therefore, track capacity of Shinkansen can be higher.

After privatization and separation event, technical standard of Shinkansen system were modified, so current Shinkansen system get other features.

The most typical feature of current Shinkansen is specific regulation of gradient. Specific regulation of the former Shinkansen defined that the steepest gradient should be less than or equal to 1.5% (or 1.2% as 10 kilometers section average). Thanks to new generation Shinkansen rolling stocks with higher-powered motors, specific regulation of the current Shinkansen allows that the steepest gradient of 3.0% (or 3.5% in special cases).

Even though train operating speed is restricted on the steep gradient section, it is able to reduce schedule time and construction cost, because of infrastructure construction length with steep gradient can be the shortest route, comparing with lower gradient alignment.

Specification advance of new Shinkansen rolling stocks were achieved by JR companies. They have made efforts to upgrade specification of Shinkansen rolling stocks. Current Shinkansen trainsets are going to be faster, lighter, less noisy, etc. The fastest operating speed of Shinkansen is 320km/h (JR East E5 series “Hayabusa”, Tohoku Shnkansen between Utsunomiya and Morioka).

The Shinkansen system can be regarded as a grand integration of various technical areas; infrastructure construction, rail track, rolling stocks, power supply, signal and control, facilities, etc. In this paper, I focus on and describe about infrastructure construction technology mainly.

Photo 1. JR East E5 series “Hayabusa” (in the Maximum Speed Operation)

3. INFRASTRUCTURE CONSTRUCTION TECHNOLOGY of SHINKANSEN

3.1 Tunneling

3.1.1 NATM

In Japan, for these three decades, NATM was established as a standard method for mountain tunneling. NATM is such a convenient method that it can be applied for not only hard rock, but also unconsolidated ground or low depth overburden tunnel.

Almost all recent Shinkansen tunnel were constructed by NATM. For example, the over 20 kilometers tunnels are constructed by NATM as follows;

・Hakkoda (26,455meters, Tohoku)

・Iwate-Ichinohe (25,808meters, Tohoku)

・Iiyama (22,251meters, Hokuriku)

These three tunnels are longer than Dai-Shimizu (22,221meters, Joetsu), the former longest mountain tunnel of Shinkansen.

In several cases, constructors tried rapid excavation. They achieved successful record at that time, for example Gorigamine, and Mineyama (both Hokuriku) cases.

Photo 2. A case of Shinkansen Tunnel constructed by NATM (under excavating work)

Seikan tunnel (53,850meters, Hokkaido) is an under-channel tunnel and the longest tunnel in Japan (former the longest tunnel in the world). Of course, Seikan tunnel is longer than any other mountain tunnels on Shinkansen network.

Train operation service via Seikan tunnel was started at March 1988 as JR Hokkaido Tsugaru-Kaikyo line and JR Freight (1,067mm gauge trains only). About three decades later, combined operation (1,435mm gauge Shinkansen trains and 1,067mm gauge freight trains) on Seikan tunnel was started at 26 March 2016 with three-rail track.

3.1.2 Shield Tunneling Method

In three great metropolitan regions in Japan, rail transport has had a great role as a main public transportation mode. We can observe that the modal split of railway has been over 70% (commuter to urban center in Tokyo metropolitan region). To develop and expand urban railway network, shield tunneling method has been advanced.

There is no shield tunnel belonging to recent Shinkansen development section. But, Japanese engineers have successful and various experiences about shield tunneling method of urban railway development. Even though Shinkansen tunnel under metropolitan area are few, those urban railway development experiences can be applied for Shinkansen construction.

3.1.3 Next Challenging Method

In Japan, NATM was, is, and perhaps will be as a standard tunneling method for mountain. Background of wide spread of NATM, it is regarded and trusted that infrastructures constructed by sophisticated worker have enough quality, like as machine/factory made.

Of course Japanese engineers know NATM is advantageous for mountain tunneling, and they have a consciousness to seek “much better” method. So they have advanced new tunneling methods for higher safety on construction site, higher quality of infrastructure, and wider application to various ground, etc.

One of the most successful new tunneling methods is SENS, abbreviation Shield ECL (Excavation and Concrete Lining) NATM System. SENS can be applied to marginal ground between NATM and shield. The features of SENS are as follows;

- Shield machine do excavating works.
- SENS don’t need segment lining.
- Primary concrete lining is casted in the machine as a parallel working of excavating.

SENS were applied to Sanbongihara (Tohoku), Tsugaru-Yomogita (Hokkaido), and several tunnels under construction. SENS can be applied for not only Shinkansen but also urban railway development. One of tunnel excavated by SENS will be opened soon later, as a new urban railway line East-Kanagawa rail (linking railway service between Sagami Railway and JR East).

TBM (Tunnel Boring Machine) has been one of an auxiliary method for Japanese railway’s mountain tunneling, such as a pilot tunnel. There is no Shinkansen tunnel excavated by full-face TBM for double track.

Photo 3. SENS Machine of the Tsugaru-Yomogita Tunnel, Hokkaido Shinkansen
(this photo on the JRTT web site)

3.2 Bridge

3.2.1 Pre-stressed concrete bridge

Many long span pre-stressed concrete (PC) bridges were constructed in recent decades. Extra-dosed type is a kind of outside cable PC bridges, and is structured by high stiffness girders. So, features of Extra-dosed PC bridges are defined as follows;

- High stiffness structure
- Suitable for long span bridge
- Lower height of main tower
- Smaller amount of deflection
- Reasonable cost
- Each features are as comparison with another structures (Cable stayed bridge, Metal structure, etc.)

Extra-dosed type PC bridges are applied to current Shinkansen network expansion. The first case for Shinkansen is Yashiro bridge (Hokuriku), the longest span case is Sannai-Maruyama over-road bridge (Tohoku, 150m), the second longest span case is Jinzu-gawa river bridge (Hokuriku, 128m).

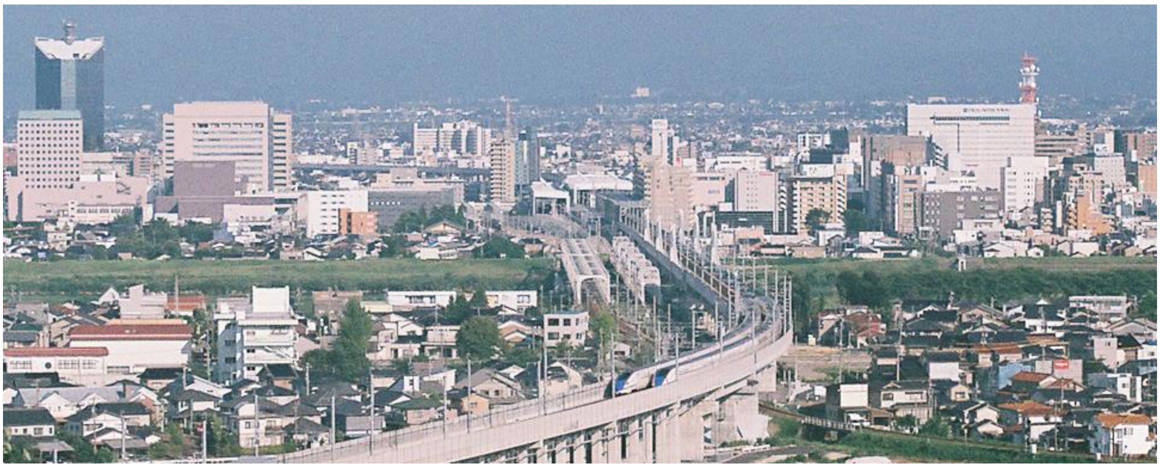

Photo 4. Jinzu-gawa River Bridge, Toyama Station, and Central area of Toyama City

3.2.2 Metal bridge

The advancement of the long span PC concrete bridge technology provides many benefits; more reasonable cost, high latitude of design (especially exterior), etc. On the other hand, some kinds of metal bridge types are still suitable structure for long span bridge. The most typical metal bridge type of current Shinkansen network is composite girder. The span of composite girder bridges has been longer.

The longest span case is Asou over-road bridge (Hokuriku, 110m), the second longest span case is 5th Chikuma-gawa river bridge (Hokuriku, 103.25m), and the longest bridge length case is Matsubara over-bridge (Kyusyu, bridge length 1,243m, total 21 spans, the longest span 85m).

Photo 5. 5th Chikuma-gawa River Bridge, and Iiyama station

4. THE "NEW SEISMIC DESIGN STANDARD"

Early in the morning 17 January 1995, the great Hanshin-Awaji earthquake attacked Osaka / Kobe metropolitan region. Many railway infrastructures, including bridges and viaducts of Sanyo Shinkansen, were damaged by this great earthquake, some of those were collapsed.

Caused by extreme external force stronger than conventional seismic design standard, various unanticipated damage cases were observed. Therefore, seismic design standard was revised, and has been improved until now. Current seismic design standard is called as the "new seismic (design standard)".

Under the "new seismic", all railways infrastructures were designed, and already existing infrastructures were reinforced.

After the great Hanshin-Awaji earthquake, infrastructures of Shinkansen network were damaged by several earthquakes. Typical cases were as follows;

Case1: The great Hanshin-Awaji earthquake.

Case2: 23 October 2004, infrastructures of Joetsu Shinkansen were damaged by Chuetsu earthquake.

Case3: 11 March 2011, infrastructures of Tohoku Shinkansen were damaged by the Great East Japan Earthquake.

Case4: 14 April 2016, infrastructures of Kyusyu Shinkansen were damaged by Kumamoto earthquake.

Thanks to design / reinforcement based on "new seismic", simplified damage index value (Σ (suspended section length * number of commercial train operation suspended days)) of each earthquake cases were tend to be smaller. Especially on case4, Kyusyu Shinkansen trains between origin (Hakata) and terminal (Kagoshima-Chuo) could be recovered after only

14 days suspended.

There is one more remark about earthquake and Shinkansen. On Chuetsu earthquake case, because the distance from hypocenter was very short, reduction time of train speed by UrEDAS (Urgent Earthquake Detection and Alarm System) was not secured enough. As a result, the first derailment accident of Shinkansen commercial train was occurred. After Chuetsu earthquake, various preventive measures for Shinkansen commercial train derailment were established and applied.

5. RELATIONSHIP BETWEEN SHINKANSEN STATIONS AND URBAN/REGIONAL DEVELOPMENT

Shinkansen stations development contribute to urban/regional development. We can find successful cases current Shinkansen network expansion.

Hokuriku Shinkansen Sakudaira station is one of the most famous successful cases of current Shinkansen station. Nearby Sakudaira station area was highly urbanized from fertile agricultural field to just as the new regional center. We can find all kinds of buildings around Sakudaira station; business offices, public offices, hotels, shopping centers, restaurants, residences, etc.

Kyusyu Shinkansen Shin-Tosu station is placed on suburban area of Tosu city. Shin-Tosu is not only a transfer station between Shinkansen and conventional railway. Tosu city specified the west side area of Shin-Tosu station as a neighborhood commercial district under the City Planning Act, and attracted high level medical institute “SAGA Heavy ion medical accelerator in Tosu”.

To focus station functions, Hokuriku Shinkansen Toyama station is well known. We can define Toyama station as a good collaboration case between Shinkansen development and continuous grade separation of conventional railway crossing projects. The Toyama station layout plan was decided as follows;

Photo 6. Tram Station under Shinkansen Toyama Station Viaduct

・Conventional railway station was restructured from four platforms and seven tracks (with one notch) to two platforms and four tracks (with one notch). Two passing tracks were abolished.

・Conventional railway station was downscaled about half width. Hokuriku Shinkansen Toyama station, as an intermediate terminal with two platforms and four tracks, was constructed on the empty area. This area was the south half part of the conventional railway station before restructuring.

・Conventional railway Toyamako line was transformed to Toyama Light Rail. A part of new Toyama Light Rail was constructed on the urban planning road of Toyama city.

・In near future, Toyama Light Rail and existing city tram network will be connected. Right now, conventional tram terminal constructed previously under the Hokuriku Shinkansen Toyama station viaduct. This viaduct structure is like a solid umbrella against rain or snow, and shorter transfer distance is convenient for passengers.

6. THE TYPICAL FEATURE OF SHINKANSEN INFRASTRUCTURES

As all we know, Shinkansen is a kind High Speed Railway system. The typical feature of Shinkansen is the “fast”, more specifically to achieve shorter travel time. Thanks to high speed of Shinkansen, isochrone map of Japan were going to be smaller.

Absolutely, Shinkansen provided, provides, and will provide social impacts to each region, such as traffic volume increase, number of residents increase (at least sluggish decrease), regional economy conditions brisk, etc. Ex-post evaluation of current Shinkansen network expansion should be done under the outline of government, and have published by JRTT.

Kojima Y. et al., Imai et al., Takatsu et al. and Kojima S. et al. authored on WCTR papers of ex-post evaluation about individual Shinkansen expansion case.

We can find another feature of Shinkansen system as high level safety, strict punctuality, large traffic, high capacity per trainset, etc.

The features of Shinkansen can be defined as described above. When, can we regard the typical feature of Shinkansen infrastructures?

Japan consists of small islands. Landform of Japan is not only steep, but also bold mountainous. On the other side, metropolitan regions of Japan are on the unconsolidated ground. We can find many difficult terrains over the country as mountain, valley, cliff, difference of elevation, channel, soft ground like a marsh or mayo, etc.

We can regard the typical feature of Shinkansen infrastructures as technological system to overcome those geographic barriers. As a result, Shinkansen commercial trains have provided the “fast”, extreme shorter travel time comparing with conventional train service.

Therefore, we can define Shinkansen network as a kind of the “bridge” to connect distant regions isolated by natural barriers.

REFERENCES

JREA 70th anniversary committee (2018) The advancement of Japanese railway infrastructures technology described on “JREA” (from 1988 to 2016) the first part, JREA (monthly journal of Japan Railway Engineer's Association), Vol.61, No.6, 48-55 (in Japanese)

JREA 70th anniversary committee, (2018) The advancement of Japanese railway infrastructures technology described on “JREA” (from 1988 to 2016) the second part, JREA, Vol.61, No.8, 48-56 (in Japanese)

Sasaki, Y., Yoshioka, K., Makiyama, S., Asami, H. (2016) Technical Development through construction of Hokuriku Shinkansen (from Nagano to Kanazawa), 14th WCTR 2016

Kojima, Y., Matsunaga, T., Yamaguchi, S. (2016) The impact of new Shinkansen lines (Tohoku Shinkansen (Hachinohe – Shin-Aomori) and Kyusyu Shinkansen

(Hakata—Shin-Yatsushiro)), 14th WCTR 2016
Imai, H., Kariyazaki, K., Saiki, I. (2013) Ex-post evaluation of new Shinkansen line projects (Tohoku Shinkansen and Kyushu Shinkansen), 13th WCTR 2013
Takatsu, T., Suehara, J., Takahara, H. (2010) The impact of the partly-opened Kyusyu Shinkansen (Shin-Yatsushiro—Kagoshima-Chuo),12th WCTR 2010
Kojima, S., Tsuzuki, Y. (2001) The Impact of Starting Operation of the Hokuriku Shinkansen Line (Takasaki - Nagano), 9th WCTR 2001
Hayashi, T., Kase, M., Fujii, S., Asami, H. (2016) Collaboration between Shinkansen development and continuous grade separation of railway crossing projects ----- The Case Study of Hokuriku Shinkansen Toyama Station, Proceedings of Infrastructure Planning, Vol.54, No.211, Nagasaki University, Japan (in Japanese)