High-speed Rail Technology as Revealed by the Shinkansen

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1. Introduction

In the year 2001, the Tokaido Shinkansen marks its 38th year of safe operations since going into service. Of course, the design concept behind the Tokaido Shinkansen is superb, but we must thank the countless people who have taken up this technological legacy, developed and expanded it, and operated this immense rail system safely and precisely for 38 years. Today I would like to look back at the line's 38 years of operation and tell you in my own words about the essentials of high-speed rail technology.

2. Features of the Tokaido Shinkansen

The Tokaido Shinkansen began operations in 1964 with two trains per hour, running the 515 kilometers along Japan's major transportation artery between Tokyo and Osaka in 3 hours, 10 minutes. Today it carries 360,000 people on 285 trains per day, operates at a maximum speed of 270 km/h, and covers the same distance in 2 hours, 30 minutes, but the average delay for each train is somewhere between 0.3 and 0.6 minutes. Moreover, most of these delays are due to natural disasters, such as torrential rainfall, typhoons, or heavy snowfall. The Shinkansen is an extremely safe and reliable means of transportation, boasting *no* passenger fatalities or serious injuries due to train accidents. Another characteristic is its environmental friendliness, especially in terms of its low energy consumption and low level of CO2 emissions.

3. The Concepts behind Technological Development at JR Central

Our Series 300 rolling stock has made it possible to run trains at 270 km/h since 1992, but we would like to maintain and improve the Tokaido Shinkansen's ranking as a high-speed mode of transportation. In order to shorten the running time, improve on-board comfort, and increase environmental friendliness further, we will need to investigate technologies for rolling stock and ground facilities. The biggest help to us in this respect is our 38 years worth of data on actually operating and maintaining a high-speed rail system. A railway needs good rolling stock, tracks, overhead lines, and signal facilities. However, these are not enough to ensure safe, reliable operation from day to day. Just as important as the "hardware" is the "software," the intangible aspects_such as traffic control, the education of train crews and inspectors, and maintenance. It is only when these two aspects are integrated that we can operate a railway safely and dependably. Appropriate integration of the "hardware" and "software," or, in other words, managing the railway as a whole in a unified manner, is essential. When developing technology or improving the railway, we like to keep the following points in mind:

The first point is to let nothing fall between the cracks, either in the hardware or the software, when we put the results of our R&D to practical use because the causes of accidents are found in these very cracks.

The second point is that if we make advances in only one area—for example, trying to solve a problem by improving the performance of the rolling stock alone—we inevitably introduce distortions in another area, and these distortions accumulate. In other words, we must solve problems guided by an awareness that a railway is an organic system in which all the parts affect one another.

The third point is that acquiring an accurate grasp of boundary phenomena and solving problems in a comprehensive and reasonable manner are major issues in railway transport.

4. The 300X Shinkansen Project

(1) Objectives

As one of our efforts to find and explore the essential nature of high-speed rail, JR Central launched the 300X Shinkansen Project in 1990 based on the concepts outlined above with the aim of developing the technology for a better and more advanced high-speed railway system.

Since July 1990, we have been surveying, studying, and designing rolling stock and ground facilities, and we began test runs with experimental rolling stock in January 1995. The substance of the test may be broadly divided into two parts: a first part, Test runs to further increase speed, and a second half consisting of tests under changing conditions and validation tests for the technical components. At present, we are implementing the tests under changing conditions.

In the incremental speed tests in the first half, we raised the speed steadily without modifying the rolling stock conditions and gathered data on the relationships between speed and such factors as running stability, on-board comfort, current collection performance, and aerodynamic phenomena. On July 26, 1996, in the process of conducting these tests, we recorded the highest speed ever for a railway in Japan, 443.0 km/h.

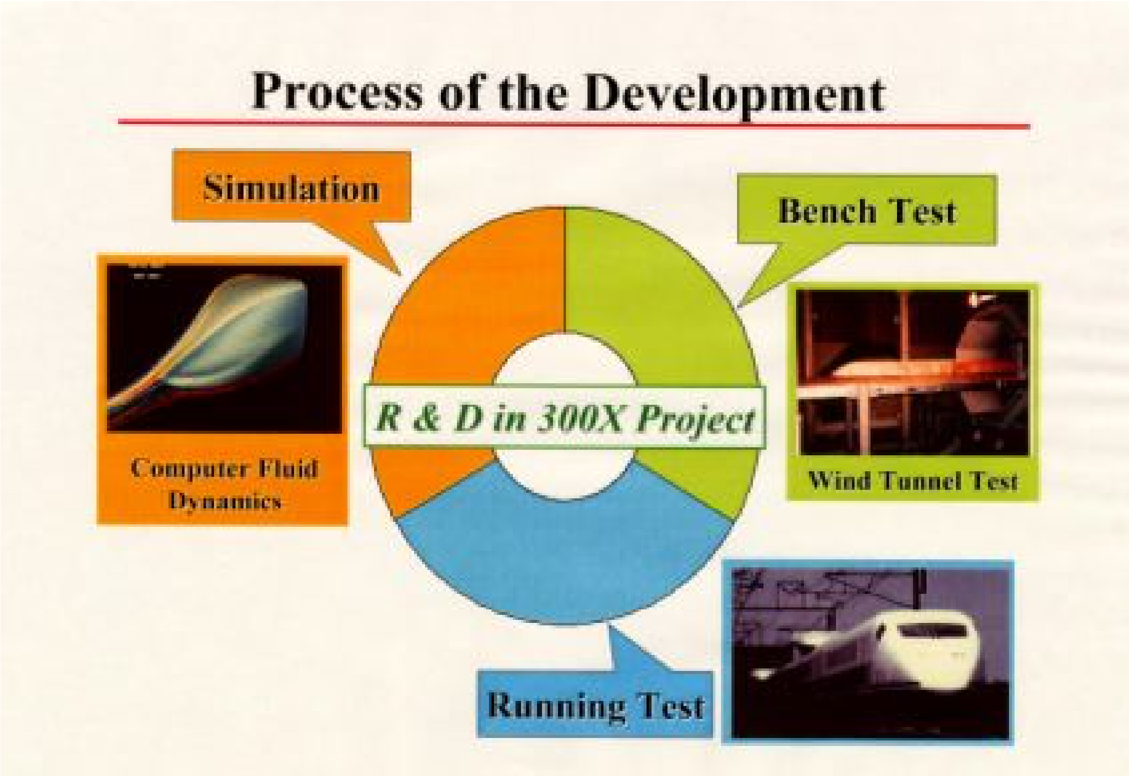
After that, we conducted line tests at speeds of 300 to 350 km/h modifying the infrastructure and rolling stock conditions in order to identify the relationship between changing conditions and the railway system. At present, we are continuing our tireless exploration of all the technological fields needed for constructing a railway system.

Later, I will discuss the effect of lightening the unsprung mass as a typical example of our experiments.

(2) Our Efforts in Research and Development

In developing a railway, we must naturally keep actual operations in mind. That is, we cannot merely conduct experiments in achieving the highest possible speed. Instead, it is important to manage these experiments in a holistic manner, keeping in mind such achievable results as harmony with the wayside environment, improved performance of the rolling stock and ground facilities, improved on-board comfort, and cost reduction. We identified all the phenomenon at work when we conducted high-speed line tests as part of the Project, and we worked on increasing both speed and comfort while maintaining safety and the wayside environment.

Our specific research and development techniques included multiple uses of three types of techniques and combinations thereof: all sorts of simulations; bench tests, including wind tunnel tests with models; and running trials with test vehicles. This is because, depending on the item or area under development, there were some cases in which we could not check the on-track tests and, on the other hand, situations which had to be checked with test runs because the simulation methods were not sufficiently well-established. In addition, feeding back the valuable data from the actual test runs into the simulations, benchmark tests, and other parts of the process of developing elemental technology has allowed us to establish more highly refined development techniques.

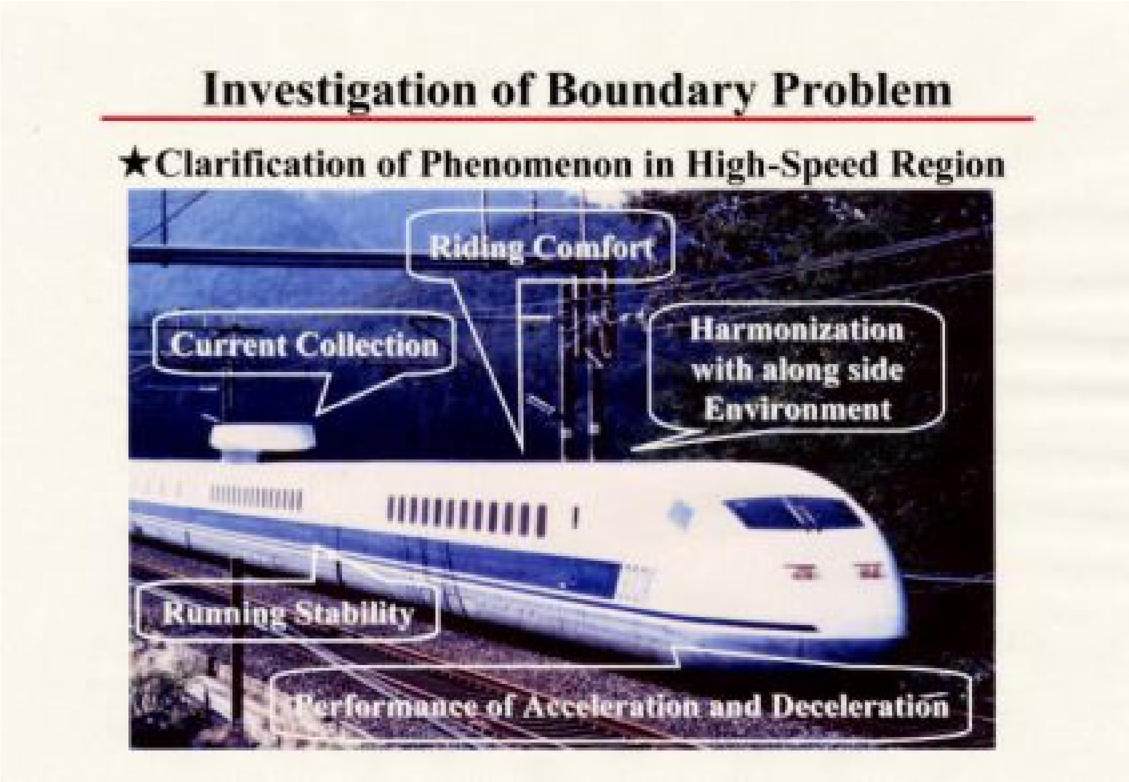


Process

The test runs are conducted at night between Kyoto and Maibara when the normal service has ceased, and the first revenue trains of the day run on that the same section about five hours after the conclusion of the test. In other words, we do not use a dedicated test line, but a section of track on which 285 revenue-operating trains run per day. We have already conducted about 500 test runs at the rate of two per week.
In specific terms, the tests are strictly managed and the technicians concerned with the rolling stock, tracks, overhead lines, and signal communications participate in preparing, analyzing, and evaluating the tests for each technological area. On-track tests are conducted only in situations where the technicians feel confident. This is precisely what happened when we recorded the maximum speed of 443.0 km/h.

(3) The Fruits of the 300X Shinkansen Project

In the 300X Shinkansen Project we have carried out our research and development through theoretical studies including simulations, constituent technology, and test runs, or combinations of the three, and we have been able to provide quantitative confirmation of things in railway technology that were said to be merely qualitative or theoretical. Furthermore, we have made it possible to use simulations to predict ahead of time situations that formerly could be checked only with on-track tests. In particular, we have acquired a great deal of knowledge and insight into “boundary” problems which span a number of technological fields. This has been extremely advantageous in further improving the railway system, an organism dependent on many technologies, including civil engineering, mechanics, electricity, and information system. The 300X Shinkansen Project will come to an end as of this fiscal year, but as I look back I think that fortunately, the key to its success was our comprehensive planning and management. This only deepened our firm belief that railways should be administered as a total system in a unified manner.



Investigation

(4) A Specific Example of Success: the Effect of Reducing the Unsprung Mass

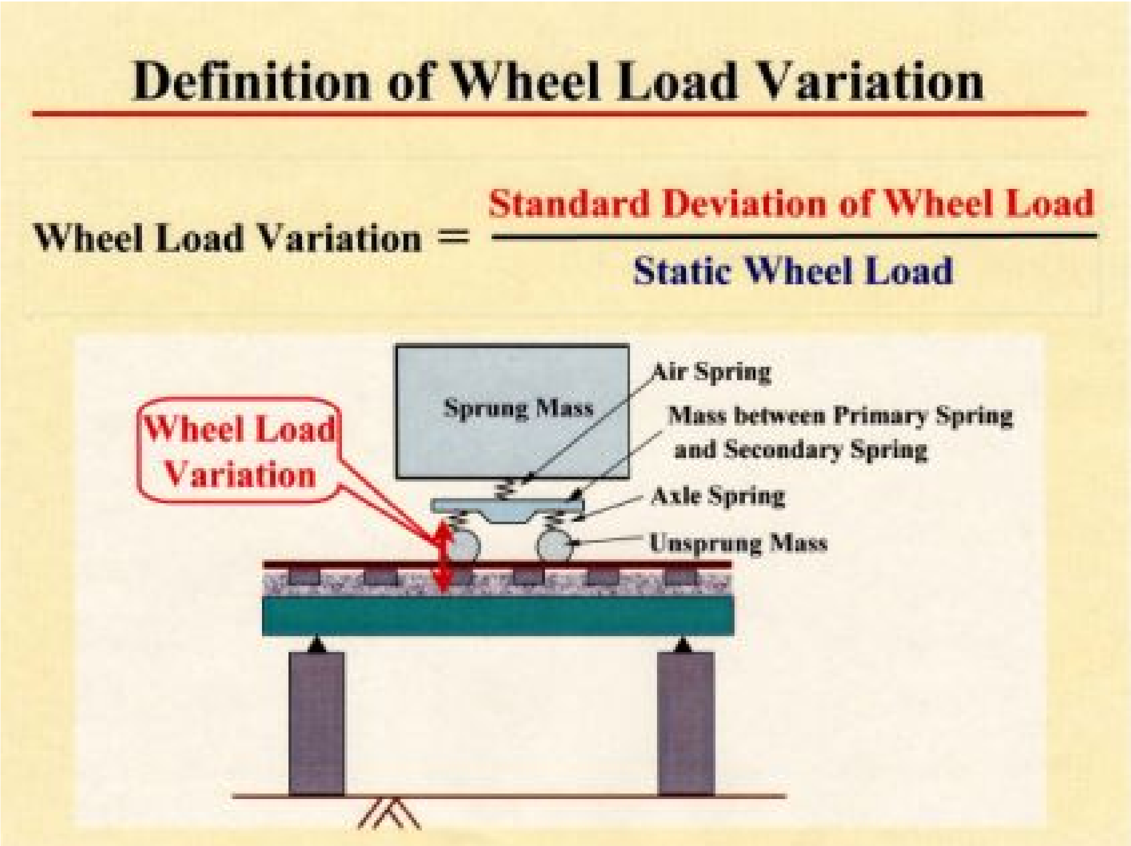
The 300X Shinkansen Project studied the effect of reducing the unsprung mass, and the results, which previously had been confirmed only theoretically or in simulations or models. Yet the Project's experiments on-track tests provided quantitative confirmation of the phenomenon.

1) The Method of Lightening the Unsprung Mass

The mission of our company is to maintain and improve rapid, high-volume, high-density transport safely and reliably on Japan's great transportation artery, the Tokaido Shinkansen. However, since the Tokaido Shinkansen was constructed as a pioneering project among high-speed rail networks, there are severe constraints on its infrastructure and other facilities, so that even if we are able to achieve high speeds, it is essential to keep the effects on the wayside environment and the existing ground facilities at something like the current level. In this sense, building more lightweight rolling stock and lightening the unsprung mass are methods for controlling fatigue and destruction of the rolling stock and tracks, as well as means for lessening the effects on the wayside environment. For these reasons, we are engaged in research and development in these areas.

One of the experiments in the 300X Shinkansen Project involved quantitative evaluation of how lightening the unsprung mass affected running stability and ground vibration along the tracks, and I would like to report on some of the knowledge that we gained.

In specific terms, we lightened the unsprung mass in three cars in a six-car test vehicle and measured and analyzed wheel load variations and ground vibrations. The method of lightening the unsprung mass was to reduce the wheel diameter from 910 mm to 840 mm and change the disk brakes from forged steel to aluminum, thus achieving a reduction of about 400 kg per wheel.

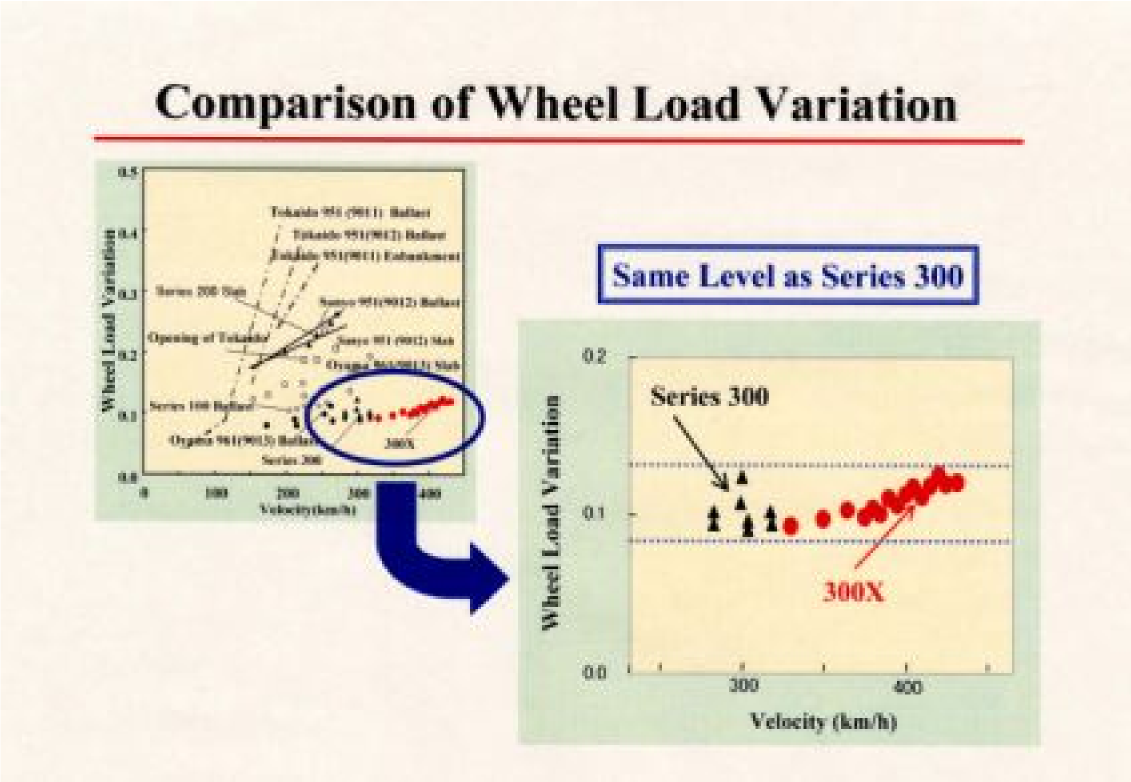


Definition

2) Effects on Changes in the Wheel Load and Other Phenomena

When a train travels at high speed, the force (wheel load and horizontal pressure) that its wheels exert on the rails fluctuates so that excessive wheel load or wheel unloading occurs, possibly leading to damage to the tracks. That is why it is essential to evaluate the rate of wheel load variation during high-speed trial runs. For wheel load variation, we compute the standard deviation from the wheel load value in the measured interval, and divide this standard deviation value by the static wheel load.

During the days before privatization of the rail system, results of trial runs showed that the rate of wheel load variation exceeded 0.2 in the domain over 250 km/h, but with the Series 300 rolling stock and 300X test vehicles, lightening the weight of the rolling stock and the unsprung mass made it possible to keep the rate of fluctuation in the wheel load at about 0.1, even at speeds exceeding 400 km/h.



Analysis

In addition, we acquired some new knowledge from the results of our experiments in lightening the unsprung mass on the 300 X test vehicles. In light of our experiments with wheel load fluctuations, we realized that lightening the axle load 1t was equivalent to lightening the unsprung mass 100 kg. In other words, in order to prevent fatigue and damage to the tracks, lightening the unsprung mass is ten times more effective than lightening the wheel load.

Thus, measures to lighten the unsprung mass shows an even greater effect on ground facilities and the wayside environment than simply lightening the weight of the rolling stock.

3) The Effects of Lighter Weight

Since 1992, JR Central has used its Series 300 rolling stock to raise the maximum speed by 50 km/h. These Series 300 rolling stock are about 25% lighter than the cars of the previous Series 100 rolling stock, and their unsprung mass has been lightened by 30%. A look at trends in track maintenance expenses after the increase in speed shows that in 1998, track maintenance expenses were only 85% of those in 1993, despite the increase in speed of 50 km/h. In other words, the effects of lighter weight made it possible to reduce track maintenance expenses despite higher speeds, prevented and fatigue and damage on the tracks, and reduced the effects on the wayside environment.

In addition, now that we have this knowledge about the effects of reducing unsprung mass, it will be possible for us to delve even more earnestly into means of further reducing destruction of tracks and effects on the wayside environment. The Tokaido Shinkansen will become even more reliable and will evolve further in the direction of providing safe and stable high-speed, high-volume, mass transport.

5. Future R&D at JR Central

We at JR Central have been making a conscious and continuous effort to carry out research and development on our railway system, especially these 300X Shinkansen Projects. Yet we have decided that we want to compile the expertise about high-speed rail technology that we have accumulated and develop it more effectively and efficiently. In concrete terms, this means that we will be opening a research institute on a spacious 73 hectare site in the green belt surrounding the city of Nagoya, Aichi prefecture in 2002. The technological evaluations and proposals will, of course, have their effects on the technological aspects of the railway system, and we plan to offer comprehensive advice to other sections in our company. We are now fully prepared for the opening of the research institute.

In the future we intend to pursue even more projects, so that we will be able to provide more information on high-speed rail technology to the rest of the world.