When thinking of "disaster resilience", a saying by RIKEN researcher Torahiko Terada in the early 20th century that “natural disasters strike when forgotten about” may come to mind for many people in Japan. Those words cannot be found in the works Terada has left behind; they are thought to have been paraphrased by his student and famous glaciology researcher Ukichiro Nakaya from Terada’s "Natural Disaster and National Defense" published in 1934. The increased frequency of natural disasters recently may make us want to say that that “natural disasters strike when forgotten about”, but it is worth mention that the term “disaster resilience” does not actually appear at all in Terada’s works.

“Disaster resilience” probably came to be the commonly seen term it is today when Disaster Prevention Day was established in Japan in 1960 following the devastation of Typhoon Vera the previous year and the promulgation of the Disaster Countermeasures Basic Act in 1961.

The term “disaster prevention” used up until recently literally means to take on nature with brute force to prevent disasters from occurring or to complete countermeasures by the time a disaster strikes, giving the term a nuance of inferring “protection”. Prevent, the verb form of the word “prevention” is formed from the Latin prefix “prae” (before) and the verb veniō (to come). In other words, the meaning of prevention is assumed to have shifted from “coming first” to “standing in the way”. From this perspective, prevention can also be obstruction.

The Japanese economy grew in the approximately 30 years after the establishment of the Disaster Countermeasures Basic Act, and that period saw a lull in natural disasters (Fig. 1). “Protective” disaster resilience exemplified by assertive public works investment and earthquake prediction research could be driven forward, and sufficient results were thought to have been achieved then. However, the 1995 Great Hanshin-Awaji Earthquake poured cold water on that belief, and the 2011 Great East Japan Earthquake was an even greater shock. Subsequent unanticipated disasters also have seemed to occur almost every year, resulting in major damage. Those include landslides on Izu Oshima Island in 2013 and in Hiroshima City in 2014, heavy snowfall in 2014 in Yamanashi Prefecture and other areas of that do not usually see much snowfall, flooding of Kinugawa River in 2015, and the Kumamoto Earthquake and a string of typhoons in 2016. In this way, the increased frequency and intensity of natural disasters since the Great Hanshin-Awaji Earthquake gives an impression of having entering an active period of global-scale cataclysms, and reliance on physical disaster resilience measures such as levees and dams by society exposed to those disasters has actually made it fragile. Reflecting on this, the important of resilience (enhancement of ability to minimize damage and quickly recover to life as usual, in other words, to “adapt” to disasters) has come to be recognized more in recent years.

Such change in disaster resilience concerns is reflected directly in the way of thinking of national agencies and in R&D related to disaster resilience. For example, the National Research Institute for Earth Science and Disaster Resilience (NIED) where I am presently employed has advocated being an all-encompassing central organization for research and development on earth science and disaster resilience science and technology since its establishment in 1963 as a national testing and research organ of the former Science and Technology Agency. This year, it replaced “Prevention” with “Resilience” in its name and shifted its pivot from basic research in investigating the mechanism of disaster geomorphic agents. The new pivot includes enhancing NIED’s function as a hub for creating disaster resilience services that are a benefit to society by R&D and coordination with diverse stakeholders with an aim of raising individual citizens’ adaptability to disasters by sharing information in real time using ICT.
Reflecting on disaster resilience for railways, we find that its technical elements can probably be broken down roughly into the following three types.

i) Constructing track in locations not easily susceptible to disasters

ii) Enhancing and maintaining yield strength of track in relation to disasters

iii) Detecting or predicting hazards and stopping trains

Restricting people from residing in or developing locations with high risk of disaster can be called the most basic rule of disaster resilience for society in general, and response to this by railways is selection of track location in Type i, above. Even today, it is a very important judgment criterion in constructing new lines. However, the current JR conventional line network was pretty much completed in the late 19th and early 20th centuries, and constraints in selection of track location were much greater than today in that age when the country was not as prosperous and the greatest reason why this was not always possible with the line could not run inland through a large tunnel. While that was considered the best choice of a location at the time it was built, the 1923 Great Kanto Earthquake struck with a seismic intensity of about seven on the Japan Meteorological Agency seismic intensity scale, creating a debris flow from the hillside failure upstream on the Shiraito River. That brought a large volume of earth rushing down the valley, severing the piers and sending bridge girders to the bottom of the sea. The entire yard of Nebukawa Station too was washed into the sea due to a landslide just as a train came in, with the train falling down the cliff into the sea resulting in many passenger fatalities.

The bridge is also located in an area susceptible to strong winds, so even today it is a vulnerable location in terms of disaster resilience, requiring additional countermeasures against strong winds, such as windbreak fences and stricter operation control than ordinary areas. Conversely, the Tokaido Shinkansen constructed after constraints against long tunnels were overcome runs in almost a straight line nearby, emerging above ground in the short section between tunnels upstream of Shiraito River Bridge.

One example is Shiraito River Bridge (Fig. 2) near Nebukawa Station, located near the sea shore in geography where it is close the mountains and the ocean. That bridge’s red-painted form against a background of the sea and sky makes it a popular photo subject for railway fans. The greatest reason for the bridge to have been erected in that location was that the fact that passengers and crew would suffocate if the train stopped in the middle of a long tunnel in the age of steam locomotives.

Fig. 1 Trends in Number of Fatalities and Missing Persons due to Natural Disaster (1945-2012)

Fig. 2 Wind Observation by Doppler Lidar near Shiraito River Bridge on Tokaido Main Line
Structure planning, design, construction, maintenance, and more are included in Type ii technical elements, with particularly large effects achieved by disaster resilience investment in equipment for protection against slope failures, rockfall, avalanches, and the like. The scale of individual countermeasures such as slope protection work, protective fences, and protective shelters is small and they do not stand out, but diligent accumulation of those brought about a dramatic decrease in disasters at Japanese National Railways (JNR) and the JR companies from the 1960s to 1990s (Fig. 3). Uniform classifications of judgment on soundness for all railway civil engineering structures and “slope rating tables” have come to be widely used, and those have contributed greatly to appropriate and efficient investment in equipment for disaster resilience. The judgment classifications are those shown in concepts of replacement of civil engineering structures, commonly called “replacement standards”, published in 1974, and slope rating tables are for quantitatively finding allowable rainfall volume from conditions such as slope height, gradient, and soil based on statistical data such as past examples of disasters and for objectively judging necessity of protective equipment.

![Fig. 3 Annual Number of Disasters Affecting JNR and JR](image)

In the area of countermeasures against earthquakes, design yield strength for structures — concrete viaducts in particular — has been gradually increased in light of the lessons learned from the damage caused by the 1964 Niigata Earthquake, 1968 Tokachi Offshore Earthquake, and 1978 Miyagi Offshore Earthquake. Especially after the 1995 Great Hanshin-Awaji Earthquake, design specifications were revised for structures to have resilience and ability to resist seismic motion where, while they may deform in seismic motion in excess of that anticipated in design acts on them, they do not suffer failure of a type where shearing occurs first and the structure comes down all at once. Moreover, large-scale seismic reinforcement work on existing viaducts also started.

In contrast to the physical measures of Type i and Type ii, those of Type iii can be called applicational measures. Specifically, those include disaster alerts and train operation control in times of disaster. The standards prescribed throughout JNR were very sloppy for those applicational measures until the 1960s when Type ii physical measures were established in earnest. Much of the details on how they were employed were left up to the judgment of individuals, and observation of disaster geomorphic changes was by low-tech means with disaster resilience technology for safely running trains (stopping trains when dangerous) relying on the abilities of many people. For example, while cup anemometers were introduced at an early stage, earthquakes were observed by human senses and rain volume by storage vessels made out of cut-down sake bottles.

Disaster resilience by applicational countermeasures was technically studied properly for the first time and countermeasures were introduced as systems with the Tokaido Shinkansen. Observation instruments such as rain gauges, anemometers, and seismometers were located at places at the wayside from the start of operation, and measurement data was sent in real time to the operations control center. However, dispatchers gave instructions to stop trains to crews by telephone. Consideration on introducing the Seismic Early Warning System for Shinkansen started just three months after start of Tokaido Shinkansen operation in light of the 1964 Niigata Earthquake, with that system being introduced in November 1965, about a year after start of operation. With that system, feeding power is stopped when seismic motion exceeding a certain level is detected by wayside seismometers, and that power outage triggers emergency braking.

For conventional lines, on the other hand, observation instruments such as rain gauges, seismometers, and anemometers started to be introduced somewhat later in the 1970s. Many were initially stand-alone types not connected by communications lines, but the Prevention of Disaster Alarm System (PreDAS) system where data from observation instruments can be displayed in the operations control center via network circuits was introduced soon after the inception of JR East. With the introduction of that system, observation data on disaster geomorphic change over a wide area could be quickly shared with high accuracy and judgment on stopping or restricting speed of trains — an operation that previously relied on the judgment of the situation by individuals — could be done based on objective observation data. And in response to recent increased demands from society as a whole for safety and advances in observation and monitoring technologies related to about natural disasters, “criteria for train operation control in times of disaster” in which procedures for judgment on stopping or restricting speed of trains are prescribed, have become standards that must be strictly adhered to in handling of train operation.

![3 Calls for “Smarter” Experience Engineering](image)

Just as the concept of disaster resilience for society in general has changed from “protection” to “adaptation”, a shift has been made in technologies safeguarding railways against natural hazards. The emphasis has changed to emphasis on applicational measures based on information and knowledge. This is switch from physical measures taken over a long time, such as selecting location and constructing lines, installing equipment for disaster resilience, and reinforcing structures. That trend will probably pick up even more speed in the future. So, in this chapter I would like to cover what the essence of technologies safeguarding railways against natural hazards is and how it should evolve in the future.
Core technologies showing promise for the future include advanced meteorological and terrestrial observation technologies and sensing and monitoring technologies for operating trains safely in severe natural environments that might cause disasters. Suddenly occurring meteorological phenomena such as wind gusts and extremely severe localized torrential rain (so-called “guerilla rainstorms”) have been gaining much attention in recent years. Those differ from typhoons and the like, for which the approach is known in advance, in that they are spatially localized and that their impact is sudden. It is thus assumed that it may become difficult to appropriately respond to those with conventional meteorological observation structures and operation control rules of railways. An example of a new technology already in actual operation to deal with such extreme weather threats is the X-band polarimetric (multi parameter) RAdar Information Network (XRAIN) of the Ministry of Land, Infrastructure, Transport and Tourism based on a detection algorithm developed by NIED. XRAIN enables rainfall intensity and wind speed to be identified in high resolution (250 m, 1-minute intervals).

Weather radar such as the X-band multi parameter radar used by XRAIN gains information on rain intensity and wind speed by estimating rain droplet size and speed from information of signals reflected from rain droplets in clouds. For that reason, effective observation is only possible after cumulonimbus clouds that lead to gusts and guerilla rainstorms form. It is often too late to prepare for gusts and guerilla rainstorms after cumulonimbus clouds form, so research is underway on weather Doppler lidar as an even more advanced method of detection. Doppler lidar uses laser as the observation medium instead of radio waves; and atmospheric condition in fair weather can be observed with it by using information on reflection from atmospheric aerosols that cannot be detected by radio waves, which are smaller than water droplets. If atmospheric conditions that cause cumulonimbus clouds can be identified in the future and observed by lidar, guerilla rainstorms and gusts could possibly be detected at the indication stage instead of after formation of cumulonimbus clouds that cause those extreme weather phenomena. Fig. 2 shows observation testing at Shiraito River Bridge by Doppler lidar JR East Yokohama Branch carried out jointly with my JR East endowed course at The University of Tokyo on risk management of transport infrastructure for large-scale disasters.

Another possibility that could be deployed to technologies safeguarding railways against natural hazards from a perspective of using information and knowledge is “mustering of empirical knowledge”. Internet of Things (IoT), big data, and artificial intelligence (AI) are buzzwords used in discussion of innovation today, and those technologies hold great possibilities for disaster resilience technology as application measures based on information and knowledge. In the area of AI, the go program AlphaGo recently beat a human world champion, but the problems that AI can solve (at least for the time being) are those where rules for solving can be written as algorithms, even if those algorithms are complex and the volume of calculations large. This includes, go, shogi, voice recognition, and image recognition. So-called “problems that cannot be calculated” are thought to be unsolvable by AI. The railway disaster resilience example of, “At how many millimeters of rain between certain stations will slope failure occur?” is a typical example of a problem that calculations cannot be applied to. It may seem on the surface to be incalculable by AI, and an empirical answer cannot be given without data on past slope failures either. However, when considering from a perspective of “disaster resilience in order to safely run trains”, we find that the question that should be asked is “At up to how many millimeters of rain will disaster not occur?” With this, what needs to be focused on is the tremendous volume of data where “disasters do not occur”—normal value data—instead of examples of disasters or accidents that rarely occur.

In distinguishing counterfeit currency, for instance, preparing many examples of real bills in different conditions such as new, used, dirty, and partially ripped and comparing specimens to see how much they resemble those examples allows counterfeit currency to be distinguished from real currency. The types of counterfeit is unlimited, and even one type of counterfeit could be distinguished at a glance, new ones would soon be created; so there is no end to researching counterfeit. In the area of disaster resilience as well, the approach befitting the age of big data is to first identify the space as a whole gained from large volumes of normal value data and then use data other than that in identifying signs of hazards rather than considering the few examples of abnormal value data individually.

In the age when physical measures were given priority, the ideal form of things that should be made came first, and reaching solutions by deductive reasoning invoking universal rules and theories was the conventional thinking of engineering methodology. In the area of disaster resilience, it was reluctantly accepted that such scientific methodology does not apply as it employs experience engineering. And in the mainstream of science as well, experience and data were seen as being on a lower level as they involved error and prejudice removed from theory and principle.

But the situation is different now. Things called theory and principle are merely approximations of reality, and understanding has progressed that difference between reality and theory/principle is caused by “uncertainty” that lies in the system instead of “error” where responsibility lies in the observer. As so, the importance and effectiveness of an inductive approach that infers the mechanisms operating the system from real data has come to be recognized.

And in response to that, various technologies to execute this approach using AI and other computers have been developed at blinding speed. That gives a feel that the time has arrived to innovate methodology of disaster resilience technology to run trains with experience and data as the starting point. I am convinced that the key to protecting railway systems from increasingly severe natural disasters lies not just in the latest observation and monitoring technologies, but rather in data and experience accumulated by safe operation.

Reference:
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