Damage to JR East from Great East Japan Earthquake and Current Situation

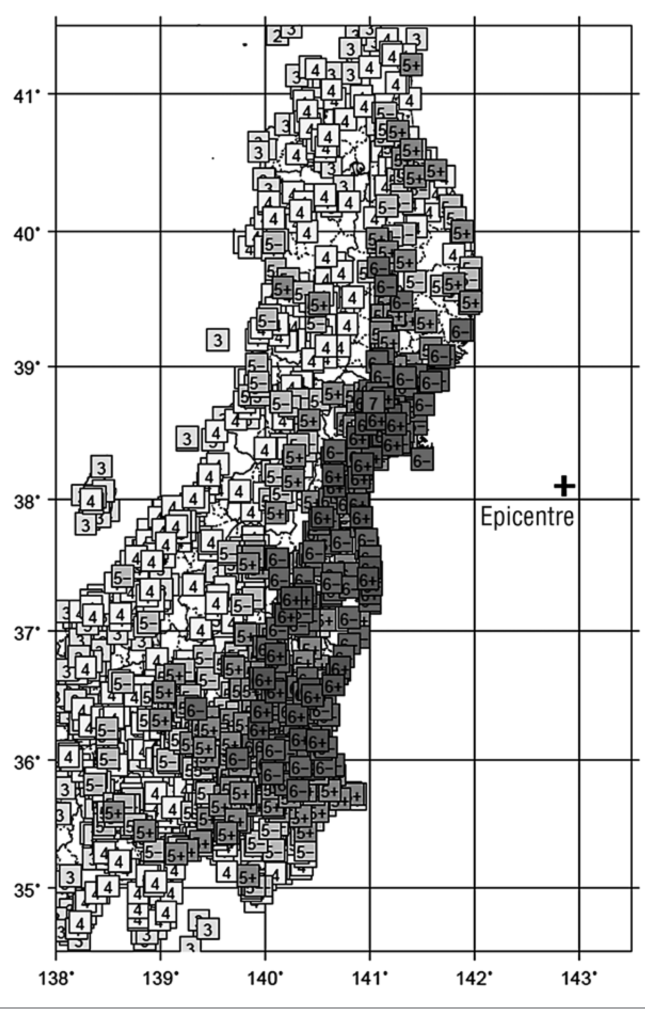
JR East Reconstruction Planning Dept. Facilities Dept. Construction Dept.

Extent of Damage

Overview

At 14:46 on 11 March 2011, a Richter Magnitude 9.0 submarine earthquake struck off Japan's Sanriku coast. Tremors measured the maximum 7 on the Japan Meteorological Agency's seismic intensity scale at Kurihara City in Miyagi Prefecture and high 6 in 37 cities in the four prefectures of Miyagi, Fukushima, Ibaraki, and Tochigi. Shaking was observed over a wide area from Hokkaido to Kyushu, with the worst tremors felt in east Japan (Figure 1). A high tsunami wave was also triggered mainly on the Pacific coast side of Japan over a broad area from the Tohoku to Kanto regions, causing tremendous damage. The Meteorological Agency named this disaster 'the 2011 off-the-Pacific coast of Tohoku Earthquake', and the disaster is officially called the Great East Japan Earthquake by cabinet decree. It was the largest earthquake ever recorded in Japan.

Figure 1 Distribution of Japanese Seismic Intensity Scale on 11 March 2011



Effectiveness of the Earthquake Early warning System for Shinkansen

There were 27 trains running on the Tohoku Shinkansen when the earthquake struck, but all made successful emergency stops under control of the earthquake warning system. The success of this system and the fact that there was no catastrophic damage to track structures prevented injuries and fatalities among passengers.

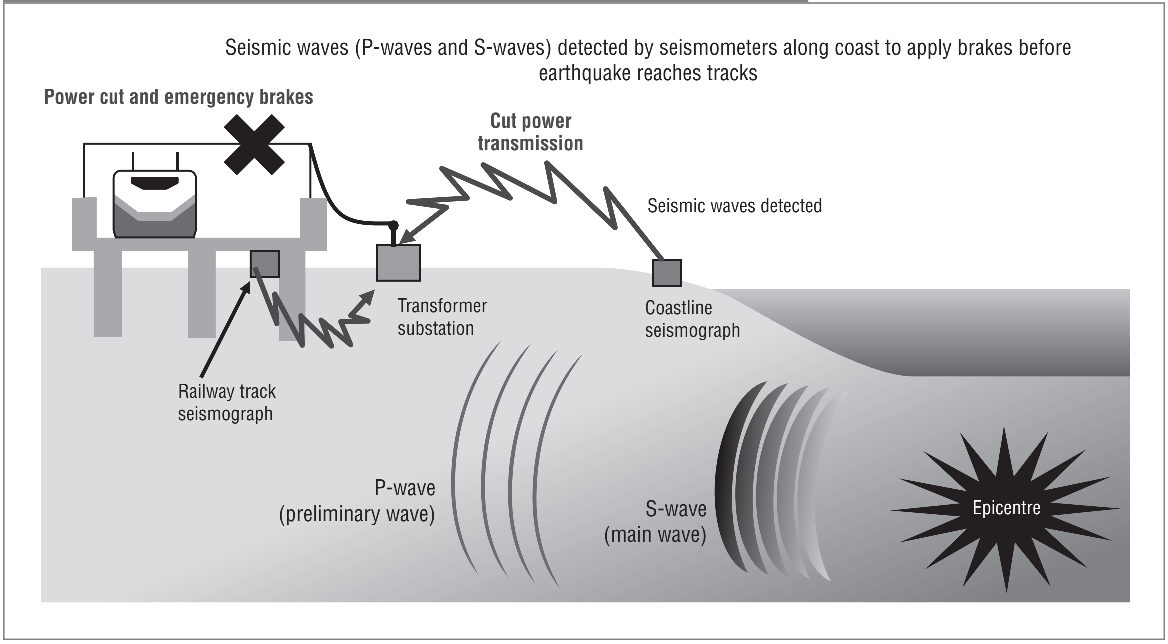
Using lessons learned from previous earthquakes, JR East had already developed earthquake countermeasures based on three points: stop running trains quickly; build collapse-proof structures; minimize damage after derailment. These in-place measures proved very effective in the Great East Japan Earthquake.

To stop running trains quickly, JR East had installed the Earthquake Early warning System that triggers automatic shinkansen emergency stops. It uses Coastline seismograph to detect seismic waves (P- and S-waves), shuts off the power to trains before the tremors reach the tracks, and automatically activates the emergency brakes (Figure 2). In this earthquake, the emergency brakes of the shinkansen train closest to the epicentre were activated approximately 3 seconds after detecting the seismic waves and the train had already decelerated from 270 to about 100 km/h when the strongest tremors arrived, so there was no derailment.

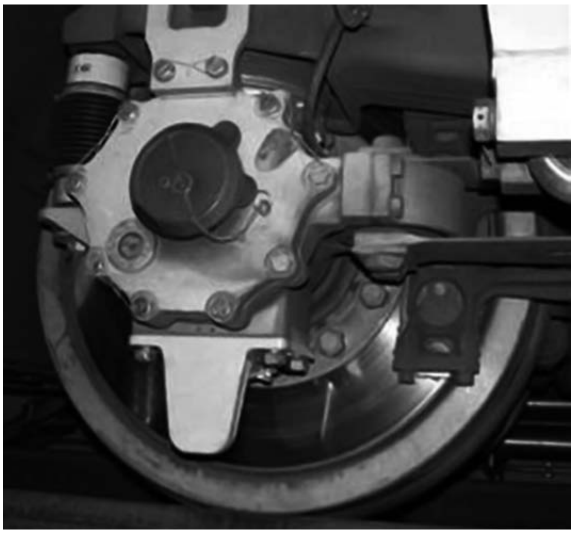
Following the 1995 Great Hanshin Earthquake, aseismic reinforcing had been implemented on some 12,500 columns and 1750 piers of rigid-frame viaducts on the Tohoku Shinkansen where severe damage might occur in shear-critical concrete columns, which are susceptible to failure at sudden earthquake buckling. As a consequence, there was no catastrophic structural failure.

To minimize damage after derailment, JR East had progressed with application of L-shaped guides

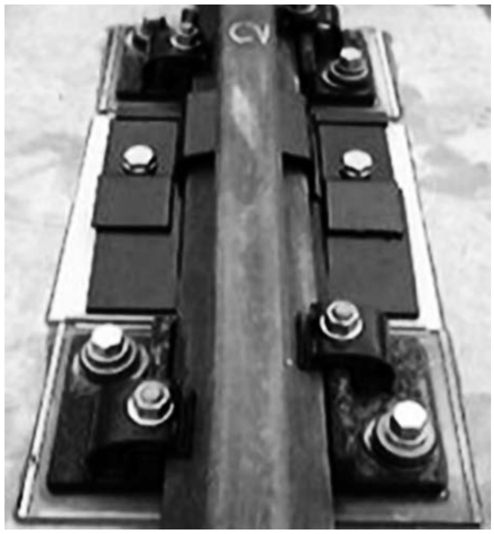
Figure 2 Overview of Earthquake Early Warning System for Shinkansen



Aseismic reinforcement of viaducts (JR East)



L-shaped guide (Also refer to Figure 13 on page 39) (JR East)



Rail rollover prevention device (JR East)

where a guide prevents wheels from deviating laterally too far from the rails in a derailment. Rail rollover prevention devices where wheels are guided by the rails even when a carriage derails and damages the rail fastenings had also been implemented.

All these countermeasures functioned well with the result that there were no railway-related fatalities or injuries even in such a huge earthquake.

Table 1 Damage to Shinkansen

Major damage	Number of sites damaged (approximately)		Total
	11 March earthquake	7 April and later aftershocks	
Collapsed, tilted or cracked electric poles	540	270	810
Snapped overhead lines	470	200	670
Damage to viaduct columns, etc.	100	20	120
Displaced/damaged track	20	20	40
Failed transformers	10	10	20
Collapsed, tilted, or flaked noise barriers	10	2	10
Damaged or fallen ceilings	5 stations	2 stations	7 stations
Displaced bridge girders	2	7	9
Damaged bridge girder supports	30	10	40
Damaged track in tunnels	2		2
Total	1200	550	1750

The number of damaged sites is an approximation if 10 or more sites.

Damage to electric poles (JR East)

Damage to viaducts (JR East)

Damage to supports (JR East)

Earthquake Damage and Emergency Restoration Work

Damage to Tohoku Shinkansen

Damage occurred to viaduct columns and wayside equipment, such as electric poles and overhead lines, at about 1200 locations between Omiya and Iwate-Numakunai (approx. 500 km). It was particularly heavy between Fukushima and Sendai near the epicentre, with damage at about 390 locations (Table 1). Emergency restoration work proceeded to restart railway services as soon as possible, and sites still needing work had been reduced to about 90 by 7 April. However, a very strong aftershock late that night, damaged some further 550 sites.

While damage sites were spread over a broad area, earlier aseismic reinforcements prevented the catastrophic viaduct collapses seen in the January 1995 Great Hanshin Earthquake and tunnel collapses seen in the October 2004 Mid Niigata Prefecture Earthquake.

Unlike previous large earthquakes, there was much damage to electric utility poles over a wide area, especially at the connection of poles to viaducts. There was no shear failure due to brittleness, but there was some slight damage, such as flexing failure at the ends of columns and displacement of girders due to damage to bridge supports.

Landslide between Toyohara and Shirasaka on Tohoku main line (JR East)

Embankment subsidence between Mito and Katsuta on Joban Line (JR East)

Liquefaction on Ecchujima Line (JR East)

Table 2 Damage to Conventional Lines

Major damage	Number of sites damaged (approximately)		Total
	11 March earthquake	7 April and later aftershocks	
Track irregularity	2200	620	2820
Collapsed, tilted or cracked electric poles	1150	90	1240
Displaced ballast	220	1	220
Deformed platforms	220	50	270
Collapsed earthworks such as embankments and cuts	170	10	180
Failed signals and communications equipment	130	10	140
Damaged bridges and viaducts	120	30	150
Damaged stations	80	20	100
Damaged tunnels	30	2	30
Failed transformers	30	10	40
Landslides	20	10	30
Damaged transfer over-bridges and other station equipment	20	4	20
Snapped overhead lines	10	10	20
Total	4400	850	5250

The number of damaged sites is an approximation if 10 or more sites.

Damage to conventional lines

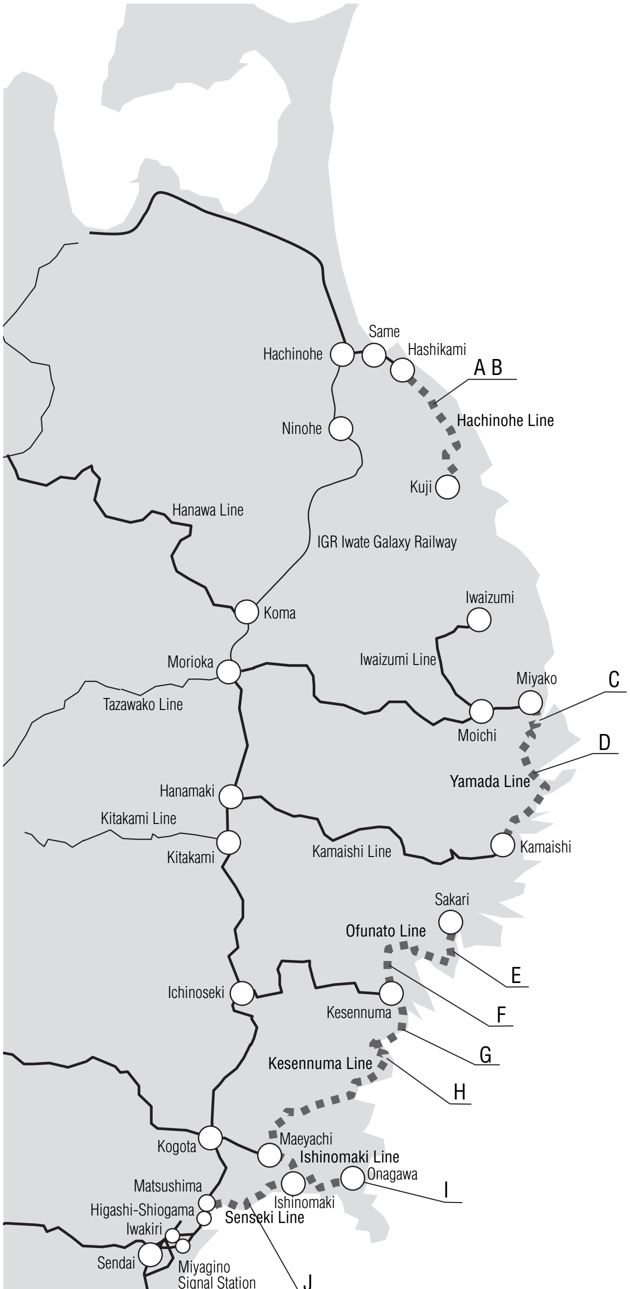
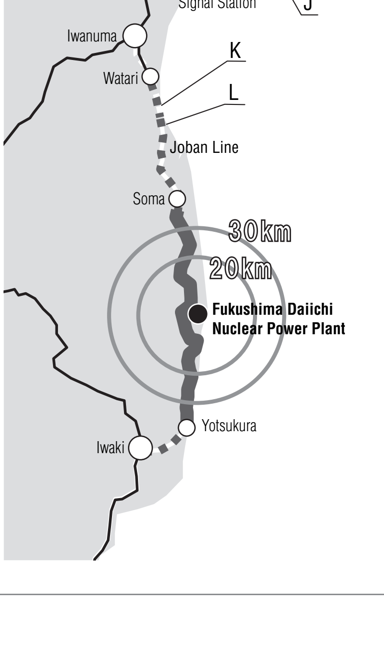
Meanwhile, conventional narrow-gauge lines suffered damage from the earthquake and aftershocks across a wide area from the Kanto to Tohoku regions. Failures included track irregularities where track buckled, damage to earthworks such as embankments and cuttings, damage to civil-engineering structures including platform deformations, collapse, and tilting of electric utility poles, and damage to stations. The 36 lines mainly running through Iwate, Miyagi, Fukushima, and Ibaraki prefectures, suffered damage such as track irregularities and pole collapse at about 4400 sites. Subsequent aftershocks caused more damage at about 850 sites (Table 2).

One typical failure was large-scale collapse and deformation of embankments near the offshore epicentre from the Tohoku region. In parts of Greater Tokyo, some buildings subsided due to liquefaction under foundations.

Restoration work

Immediately after the earthquake, local engineers were working day and night on recovery with limited means of communications and transport, using what heavy equipment,

Figure 3 Tsunami Damage to Conventional Lines


A [Bridge girders swept away]
Hachinohe Line between Shukunohe and Rikuchu-Yagi


B [Track swept away]
Hachinohe Line between Shukunohe and Rikuchu-Yagi


C [Track swept away]
Yamada Line between Sokei and Tsugaruishi


D [Bridge girders swept away]
Yamada Line between Rikuchu-Yamada and Orikasa


E [Track swept away]
Ofunato Line in yard at Hosoura


F [Track swept away]
Ofunato Line between Rikuzen-Yahagi and Takekoma


G [Track swept away]
Kesennuma Line in yard at Oyakaigan


H [Bridge girders swept away]
Kesennuma Line between Rikuzen-Koizumi and Motoyoshi


I [Track swept away]
Ishinomaki Line in yard at Onagawa


J [Roadbed swept away]
Senseki Line in yard at Nobiru


K [Bridge girders swept away]
Joban Line between Shinchi and Sakamoto


L [Track swept away]
Joban Line in yard at Shinchi

fuel, and materials they could get their hands on. Due to the lack of engineers in affected areas, JR East dispatched personnel from across the company to conduct emergency restoration work to restart services. Restoration of electric utility poles was a deciding factor in scheduling resumption of services. Much human and material support was received from businesses involved in railways, such as other JR companies and private railways, and restoration work progressed in harsh conditions as aftershocks continued. About 8500 people a day were involved in restoration work on both shinkansen and conventional lines.

Technical support on restoration methods was also received from the Railway Technical Research Institute. Much support was received from many other organizations, especially in procuring hard-to-come-by-fuel to allow use of automobiles, heavy construction equipment, and maintenance vehicles. Based on this cooperation from across Japan, services resumed on the entire Tohoku Shinkansen on 29 April, just 49 days after the earthquake. Service resumed on the Tohoku main line on 21 April, 41 days after the earthquake, and gradually thereafter on other lines, except those damaged by the tsunami.

Tsunami Damage and Restoration

Damage from tsunami

Unfortunately, the huge earthquake caused more than just heavy ground shaking. It generated a giant tsunami along the Pacific coast of east Japan. At Soma City in Fukushima Prefecture, the wave was more than 9.3 m. At Miyako City in Iwate Prefecture, the maximum vertical wave height onshore was more than 40 m.

JR East suffered major damage on some 325 km of seven coastal lines; stations were swept away and tracks and bridge girders were buried or swept away (Figure 3). Fortunately, there were no fatalities or injuries to train passengers, probably as a result of repeated training including evacuation drills. When crews of trains running near the coast were informed of the tsunami warnings, they stopped the trains and guided passengers to local government evacuation sites.

Restoration of tsunami-damaged lines

Recovery coordination conferences were set up for each damaged line with the participation of the Ministry of Land, Infrastructure, Transport and Tourism, and local governments. The purpose was to consider restoration of the seven lines that suffered extensive damage while maintaining a balance with recovery of urban areas.

Many recovery coordination conferences have been held for individual lines as venues to exchange information and coordinate recovery and restoration. JR East sees a need to consult actively with parties such as the national government and local governments in planning overall recovery of the region and community development in the restoration process. The company participated in conferences on community development for recovery held by individual local governments as well as in recovery coordination conferences.

In parallel with these discussions, JR East gradually proceeded with construction in sections where safety could be secured and resumed services on the sections shown below (Table 3). As of June 2012, tsunami-damaged sections of coastal lines and sections in the nuclear plant evacuation zone where services are suspended have been reduced from an initial 400 km to about 260 km (Figure 4).

The direction of restoration on sections where service is currently suspended will be decided through continued discussions with local governments and other bodies. In the meantime, JR East is working to secure local transport in the sections where trains are not running using substitute bus services and other measures.

Railway restoration involving line relocation

Extensive tsunami damage such as swept-away tracks and damaged stations has suspended services on the Senseki Line (between Takagimachi and Rikuzen-Ono) and Joban

Table 3 Sections of Seven Tsunami-Damaged Lines where Operations Resumed

Line	Section (Date Operations Resumed)
Hachinohe Line	Hashikami to Taneichi .... (8 August 2011) Taneichi to Kuji .... (17 March 2012)
Kesennuma Line	Maeyachi to Yanaizu .... (29 April 2011)
Ishinomaki Line	Maeyachi to Ishinomaki .... (19 May 2011) Ishinomaki to Watanoha .... (17 March 2012)
Senseki Line	Higashi-Shiogama to Takagimachi .... (28 May 2011) Yamoto to Ishinomaki .... (16 July 2011) Rikuzen-Ono to Yamoto .... (17 March 2012)
Joban Line	Iwaki to Yotsukura .... (17 April 2011) Yotsukura to Hisanohama .... (14 May 2011) Hisanohama to Hirono .... (10 October 2011) Hamanomachi to Soma .... (21 December 2011)

Figure 4 Sections of Lines where Service Currently Suspended (5 June)

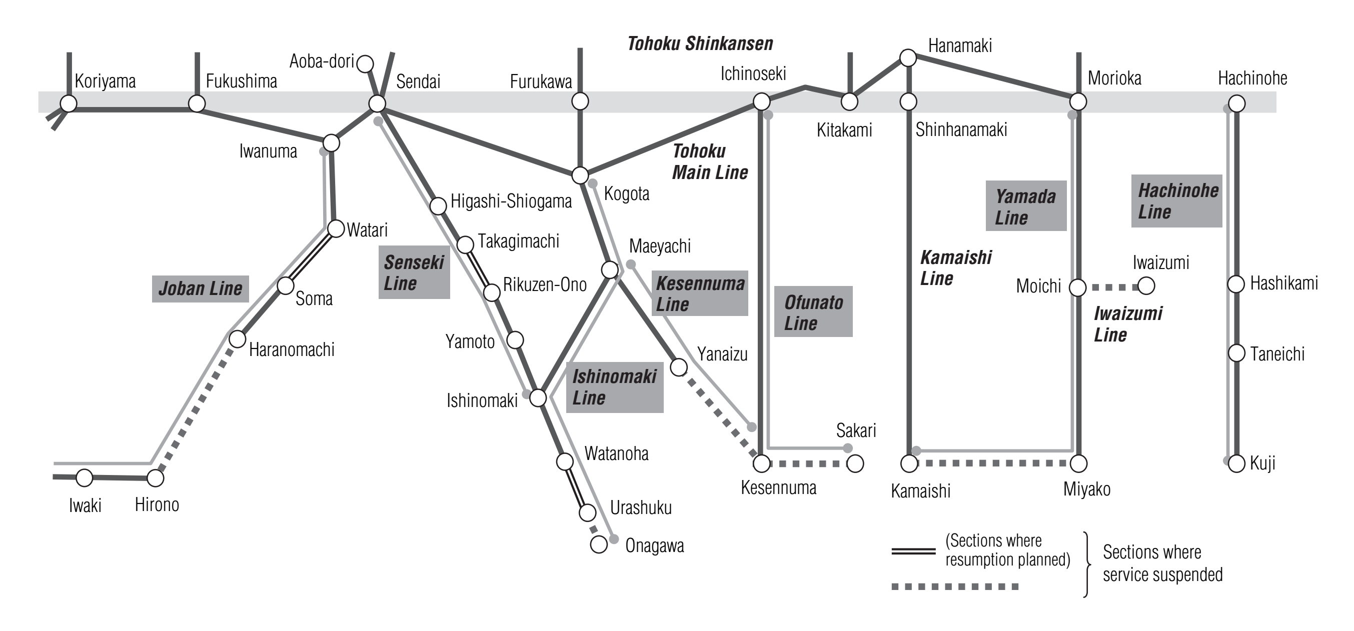


Figure 5 Higashimatsushima City Recovery Community Development Plan (26 December 2011)

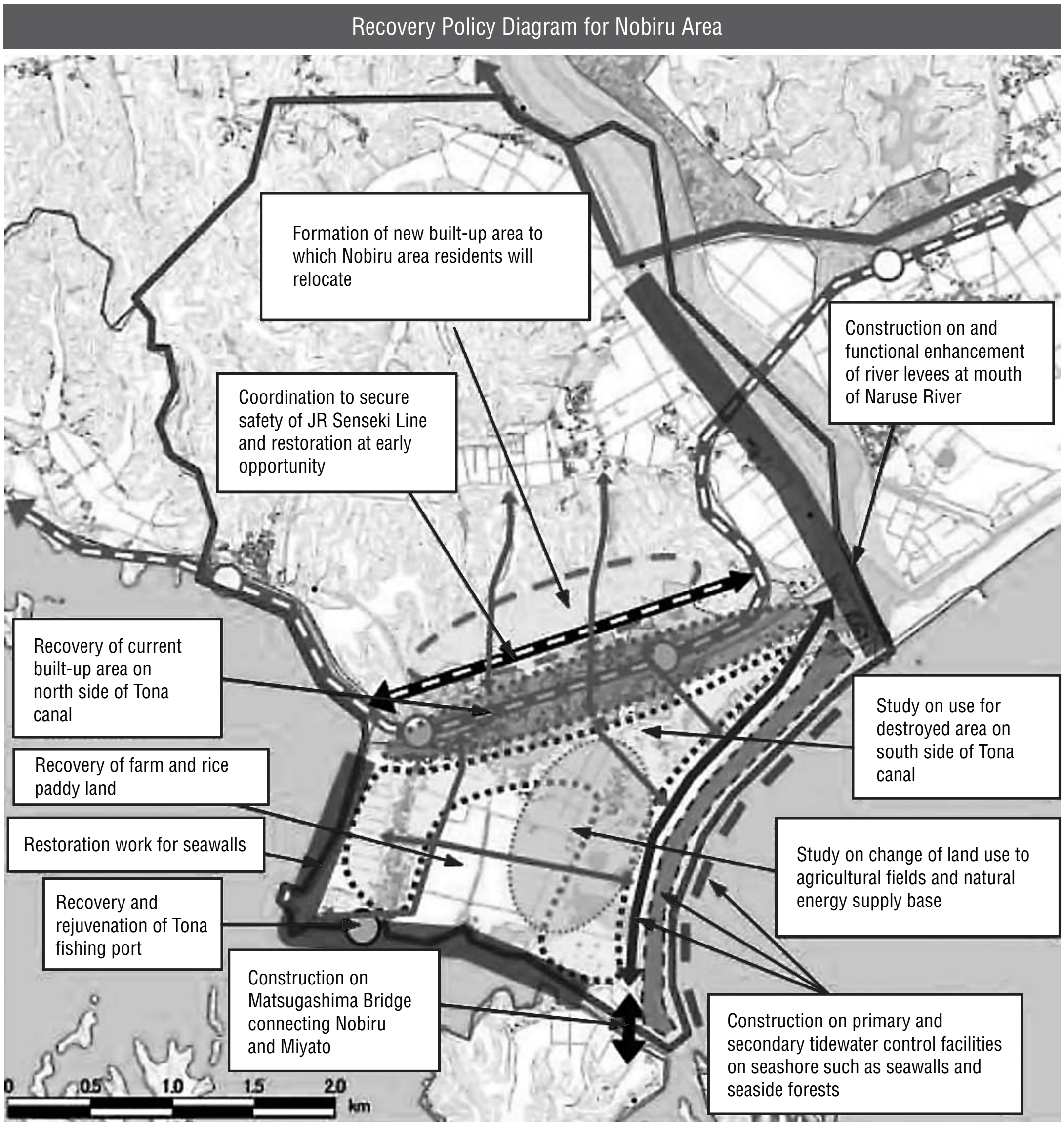
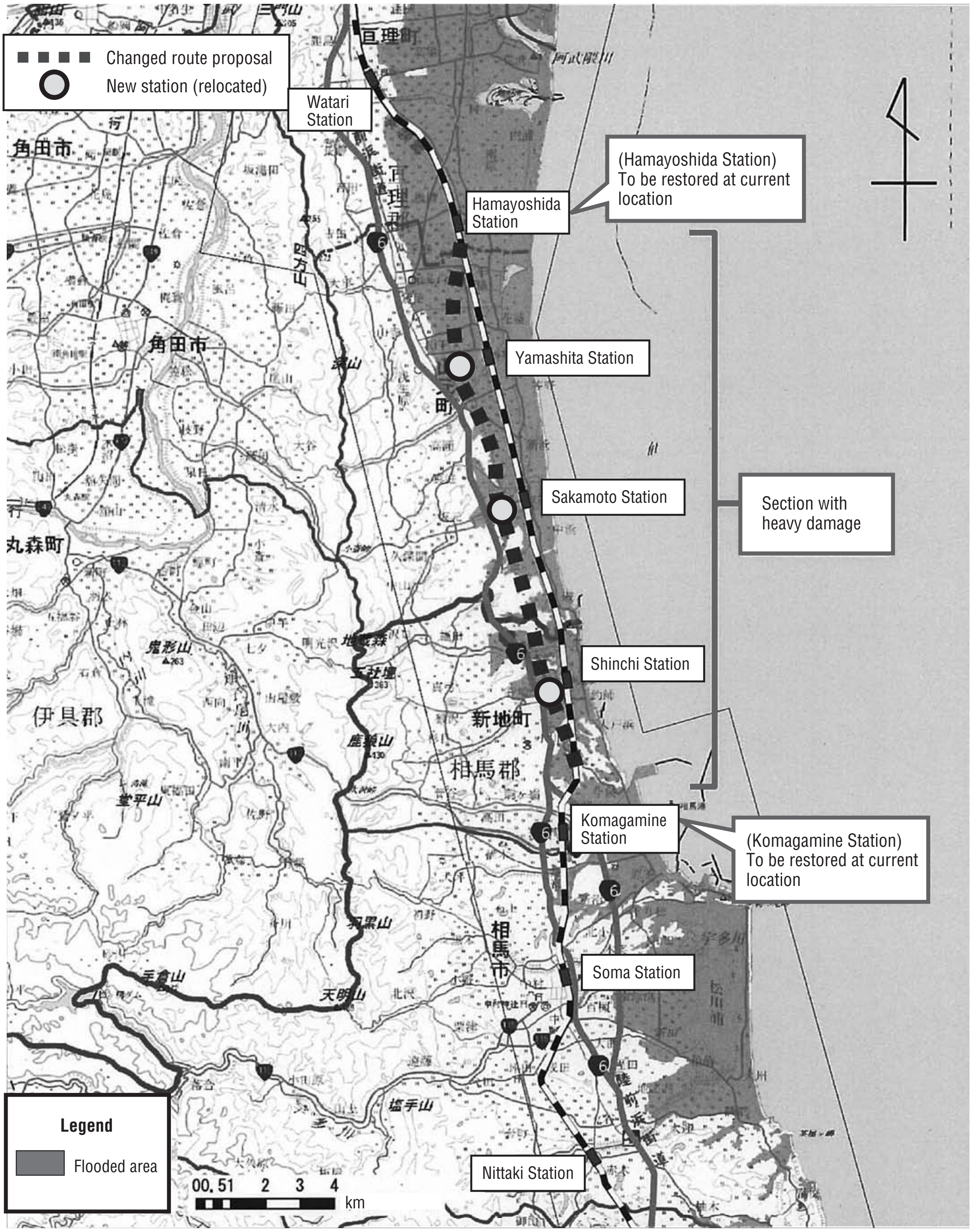


Figure 6 Joban Line Recovery Coordination Conference Materials (March 2012)

JR Joban Line Route Change (Proposal) Reference materials

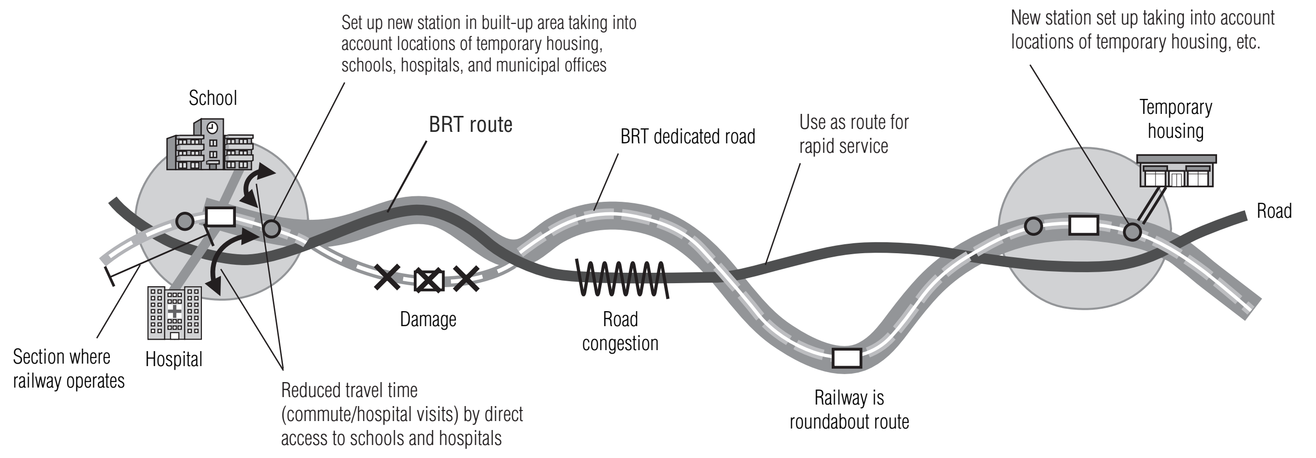


Note 1: Materials from the fourth Joban Line recovery coordination conference (secretariat: Tohoku District Transport Bureau) made up of JR East, municipalities along line, prefecture, and others (prepared in March 2012 by Tohoku District Transport Bureau)
Note 2: Content may change upon future detailed studies, coordination with concerned parties, and other factors.

Line (between Soma and Watari). Discussions were held with local governments on restoration policy; based on a policy of relocating lines to higher ground, agreement was reached on changing railway routes, and a decision was made to proceed with restoration in conjunction with community development plans (Figures 5 and 6).

Services are expected to resume about 2 years after the start of construction on the Senseki Line and after about

Figure 7 Image of Temporary Restoration by BRT



3 years on the Joban Line. However, on-site surveying, planning, purchase of land for relocation, and other work are needed along with construction for community development, such as site preparation for relocated sections. For these reasons, a memorandum of understanding will be concluded between JR East and local governments, and work will proceed as soon as possible.

Work is expected on the Joban Line between Hirono and Haranomachi ahead of the return of residents with revision of the Fukushima Daiichi nuclear plant evacuation zone. Discussions and policy decisions for restoration will probably be needed in the future.

Temporary restoration by bus rapid transit

The Kesennuma, Ofunato, and Yamada lines all suffered serious damage over long stretches and recovery of the trackside communities is expected to take a long time. Many restoration issues must be studied, such as securing safety for passengers and consistency with community development plans. Much time is expected to pass before full restoration.

In this light, JR East considered temporary restoration using bus rapid transit (BRT) from the standpoints of taking responsibility for local stable transport at the earliest opportunity. The company proposed BRT to local governments along the Kesennuma Line at the third Kesennuma Line recovery coordination conference late last year, 9 months after the earthquake.

BRT is a transport mode that uses established routes and dedicated lines and allows faster and more frequent service than regular buses while coexisting with normal automobile traffic (Figure 7). Benefits of BRT include use of railway beds to secure speed and on-time service. Flexible support can be provided, such as setting routes and adding stations in stages as the community develops. Passengers can be evacuated more easily in earthquakes and tsunami because buses run under their own power. And service can be resumed quickly because buses run on regular roads.

The agreement of local governments to use BRT was achieved at the fifth Kesennuma Line recovery coordination conference in May, 14 months after the quake, and preparations are underway to start service soon.

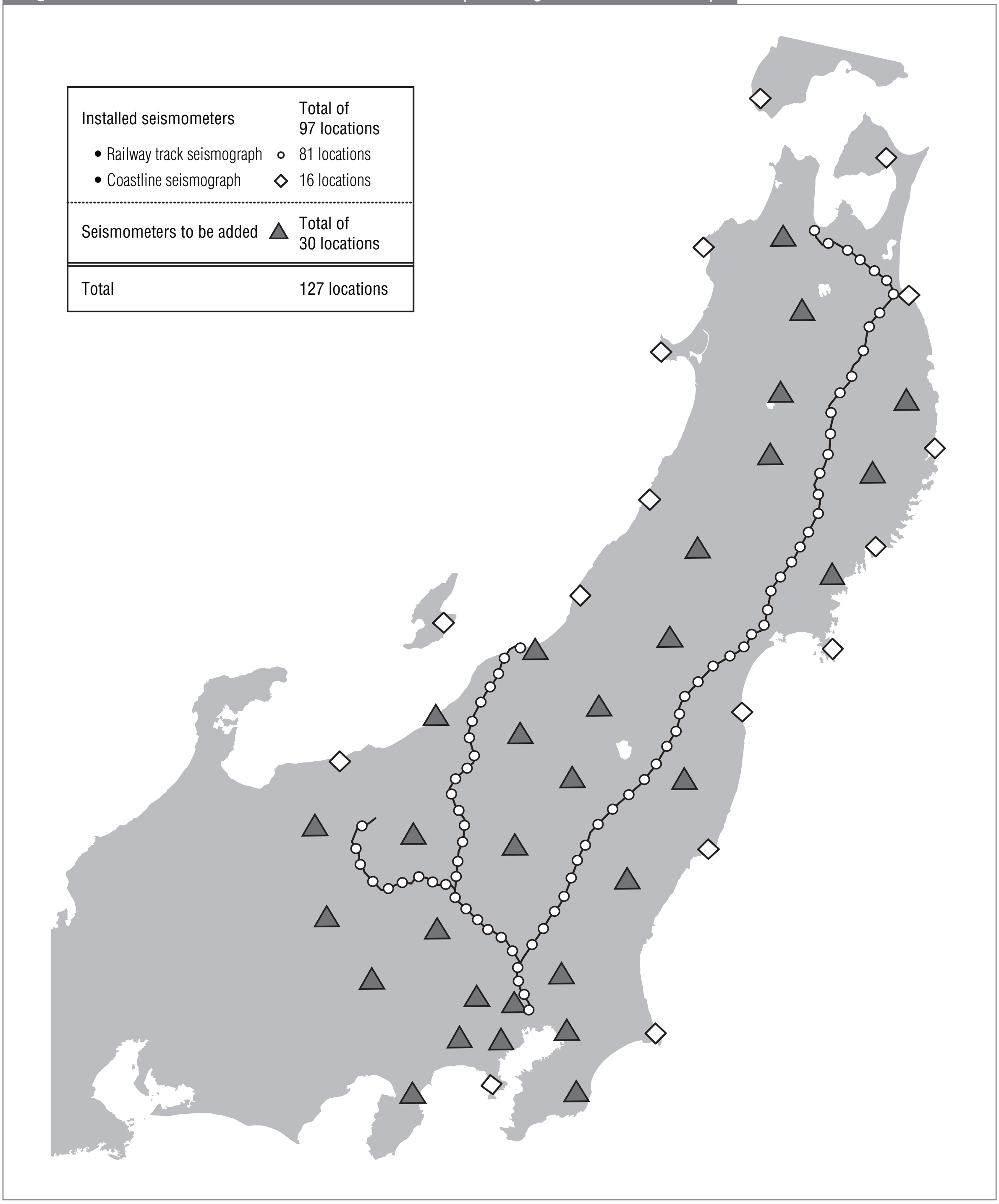
Discussions are planned with local government officials and others regarding securing alternative modes of transport for the Ofunato and Yamada lines too.

Dealing with Risk of Possible Future Major Earthquakes

Passenger fatalities and injuries as well as catastrophic damage to railway facilities were avoided mainly due to aseismic reinforcements, derailment prevention measures, and steady implementation of the earthquake early warning system following the lessons learned from the Great Hanshin Earthquake in January 1995, the Sanriku-Minami Earthquake in May 2003, and the Mid Niigata Prefecture Earthquake in October 2004.

JR East has been proceeding with a second round of aseismic reinforcements on viaducts since 2009, and there are plans for further aseismic reinforcements in case an earthquake strikes directly under Tokyo. As well as bringing forward the schedule and expanding the scope of aseismic reinforcement of viaducts, work will be performed on embankments, cuttings, bridges, and station platform roofs and ceilings on some 220 km of 9 lines including the Yamanote Line and Chuo Line. To enhance seismic observations, 30 additional seismometers will be installed and the Earthquake

Figure 8 Enhancement of Seismic Observation Points (Installing More Seismometers)



Early warning System introduced on conventional lines using the Japan Meteorological Agency Earthquake Early Warning System will be expanded to shinkansen lines (Figure 8). JR East is doing its best to prepare for any future earthquake strikes through such measures.

Conclusion

Restoration work is still underway on damaged lines, and JR East is making further efforts to help recover the affected areas as soon as possible in cooperation with overall regional recovery and community development planning. ■

Acknowledgment

This article was contributed by the JR East Reconstruction Planning Dept, the Facilities Dept, and the Construction Dept.