DEFORMATION OF RAILWAY TRACK AND RUNNING STABILITY OF TRAIN IN EARTHQUAKE

by

Yoshihiko SATO[I] Dr. Eng. and Shigeru MIURA[I]

SYNOPSIS

Our studies so far performed concerning the title are reviewed. These include a survey for train damages in ten recent heavy earthquakes in Japan, actual conditions for the train damage, the calculated tolerance of the deformation of railway structures with use of the vehicle model on the SHINKANSEN, the behavior and amplification factor of structures' displacement in earthquake in the longitudinal direction and the stability of ballasted track and the deformation of it in earthquake. Finally, an equipment simulating the railway track movement in earthquake for the further analysis of the running stability of railway vehicle is demonstrated.

INTRODUCTION

In destructive earthquakes which hit the developed countries in recent years, railway as well suffered serious damages. However, most of these damages are these of railway stations, railway structures, track or other ground installations and fortunately trains in operation, especially passenger vehicles which are mounted on bogies, have seldom suffered serious damage.

Running stability of railway vehicles has implicitly been considered all right unless railway structures suffer destructive damage. Consequently, the greatest effort has been so far directed to designing of earthquake-resistant railway structures.

However, the increase of operating speed in these days indicates that an earthquake-resistant design which considers mainly the strength of structures is not adequate and it is necessary to consider deformation of track to maintain running stability of railway vehicles in the event of destructive earthquake.

SURVEY OF TRAIN DAMAGES IN EARTHQUAKES

Various types of train damage have observed in earthquake. The most tragic one happened in Kanto Earthquake in 1923. The train approaching Nebukawa station on the Atami-line was plunged into the sea by a collapse of slope.

Excepting such a disastrous case, train damages which relate to the running safety are

(1) the derailment and/or the overturn of a train caused by the track deformation,
(2) those caused by the destruction of track in earthquake under the train weight and
(3) in a rare case those directly caused by the violent track movement in earthquake without conspicuous destruction of track.

[I] Chief Researcher, Track Laboratory, Railway Technical Research Institute, Japanese National Railways

Though the occurrence of train damages is not always recorded, a general trend of those which have been investigated in the reports on recent earthquake is shown in Fig.1.

As the cause of the derailment and/or the overturn of train, the track deformation including that of sub-structure must be called important. Such cases are shown together with the seismic intensity in Fig.2. Most of train damages in this type happened in the earthquake of more than V on the seismic intensity scale. The overturn of trains with bogies without conspicuous damages in track is supposed to have occurred only in Fukui Earthquake in 1948. It is noteworthy that running trains were never damaged in Niigata Earthquake in 1964 (Magnitude: 7.5, Seismic intensity scale: V).

DEFORMATION OF RAILWAY STRUCTURES

As the structures for the Nationwide SHINKANSEN Network, the use of the elevated rigid frame structure either with simple beams between adjacent ends or with same foundation at adjacent ends is expected considering the use of the slab track, the riding quality and the running safety. Prior to the adoption of these structures the tolerance of the deformation must be determined.

For the calculation of the tolerance, five types of deformation as shown in Fig.3 were supposed. However, for the practical use two types were calculated depending on the actual deformation of structures in earthquake. These are the parallel displacement and the dented deformation. As the model of vehicle, one in Fig.4 (a) was conceived, but one in Fig.4 (b) was found sufficient for the supposed deformation of structures.

The results are shown in Table[1)]. The structure adopted is expected to deform within the tolerance for the supposed seismic coefficient depending on the conditions of both the foundation and the importance of the line.

Further, to know the behavior of structures in the longitudinal direction, both the dented angle and the difference of displacement between structures are calculated supposing the seismic movement of foundation as a sine wave. Conditions for the analysis are as follows;

(1) Elevated structures displace as rigid bodies following the movement of fundation.
(2) Sum of the differences of displacement in a structure between each part of structure and the corresponding foundation is supposed to be zero (Equilibrium for displacement).
(3) Sum of the moment of the above-mentioned differences is supposed to be zero (Equilibrium for rotation).
(4) Difference of length of elevated structure due to rotation of it to the track axis is negligible.

General aspect of displacement of structures is shown in Fig.5. Maximum dented angles and displacements between ends of structures are shown in Fig. 6 for the case that

(1) the displacement of foundation is 5 cm and
(2) the types of structures are
    K_1: Structures of 30 m long wet without gap between their ends and
    K_2: Structures of 30 m long set 35 m apart between centers of

structure.

Fig.6 shows that the calculated value has a peak at a wave length near 50 m, the dented angle is under 8 ‰ and the difference of displacement between ends of structures is under 10 cm.

STABILITY OF BALLASTED TRACK AND ITS DEFORMATION

A number of large lateral deformations resembling a buckling of track occurred in Niigata Earthquake in 1964.

This large lateral deformation of track is such that the deformation happens just in track without any conspicuous deformation of foundation. Though the records of its occurrences are few due to the lack of investigation by the concerned specialist, it is likely to have occured in Kanto Earthauake (1923) and Fukui Earthquake (1948) as well as in Niigata Earthquake.

Through the investigation of damages in earthquakes, conditions for its occurrence are found to be as follows;

(1) Longitudinal force in rail which seems to have developed, because of summer season (Kanto: September 1, Fukui: June 28, Niigata: June 16) and daytime (Kanto: am 11°58', Fukui: pm 4°00', Niigata: pm 1°25') and hot temperature (Niigata: fair, Fukui: 25°C).
(2) The track on bad foundation.
(3) The track on wood ties and gravel ballast.

To make clear the condition of its occurrence, the variation of lateral ballast resistance in vibration was investigated using the real track of 1.20 m long laid on a large vibration table of 5.0 m wide and 5.0 m long[2). According to these tests the lateral ballast resistance is reduced along with vibrational acceleration. Results are shown in Table 2. In the table, the statical lateral ballast resistance of the track on wood ties and gravel ballast is one half that of the track on concrete ties and crushed stone ballast, although the reduction due to vibration is not so different. Thus, the lateral deformation of track seems to have occurred in the form of track buckling both due to the large longitudinal force caused by temperature and seismic earth strain and due to the low statical lateral ballast resistance.

For the track of Tokaido SHINKANSEN, the lateral ballast resistance for the seismic coefficient 0.2 amounts to 0.83 of the statical one. This garantees a buckling strength up to 92 t for a rail. Thus, the track has enough stability for the earthquake against which structures are designed.

In the survey of track damages in Off-Tokachi Earthquake in 1968, a flow-out of ballast as shown in Fig.7 was observed on the high embankment. To make sure at what acceleration such phenomenon could occur, vibrational tests were performed using the above-mentioned track. Results are shown for the case of lateral excitation in Fig.8. The flow-out of ballast occurs at the vibrational acceleration of more than 0.8 g for the lateral excitation and of more than 1.3 g for the vertical excitation.

From this experiment, it has been confirmed that at high embankment the acceleration in earthquake exceeds these values, but it is also certain that if with proper design of structures the acceleration in earthquake can be under the aimed value, the stability of track will be held.

CONSTRUCTION OF STANDING TEST EQUIPMENT

Through such studies, we are now convinced that the displacement controled design is important in the design of structures for high speed railways. Especially, the study is important for the realization of 250 km/h operation on the Nationwide SHINKANSEN Network.

So far, our analyses are limited to the simple model as mentioned above and to the seismic coefficients which are used for the design of structures, but in reality, as pointed out recently, bigger accelerations in earthquake were observed and the bogie type vehicles which are in use on the SHINKANSEN seem to be more earthquake-resistant. These are our standpoint for the further study from now.

To promote the study, we are now constructing a new standing test equipment for a 1/5 scale model running vehicle. A general view of the equipment is shown in Fig.9. Items are as follows; weight of vehicle model: 600 kg; rolling speed: 1~40 m/sec variable; exciting axes: 4 independent components (vertical, lateral, rolling and yawing); frequencies: 0~30 Hz independent at each component; maximum acceleration: 1 g; maximum amplitudes: ±30 mm for vertical and lateral directions and 0.05 rad for rolling and yawing; distances between centers of track unit: 400~4000 mm variable; gauge: 200~300 mm variable. Four track units support wheels of vehicle model. Rolling and excitation are performed by an electro-oil pressure servo system.

CONCLUDING REMARKS

So far the studies done meeting our concern are very few. Thus, we must develop these works independently. Herewith, we demonstrate our studies so far made. It is our pleasure to be able to have discussions and comments.

REFERENCES

1) Yoshihiko SATO & Shigeru MIURA, "Tolerance of Bent-Angle between Railway Structures Determined by Running Safety and Running Comfort", Quarterly Reports of RTRI, JNR, Vol.14, No.3, 1973.
2) Yoshihiko SATO, "Lateral Ballast Resistance and Stability of Track in Earthquake", Quarterly Reports of RTRI, JNR, Vol.11, No.1, 1970.

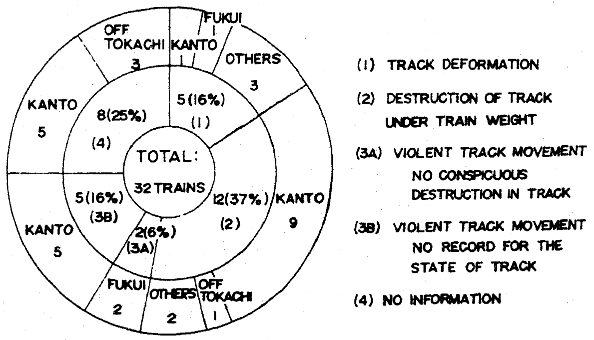


FIG. 1 CAUSES OF TRAIN DAMAGES

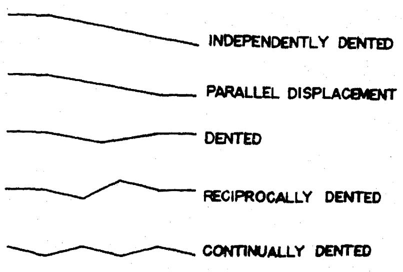


FIG. 3 SUPPOSED DEFORMATION OF STRUCTURES

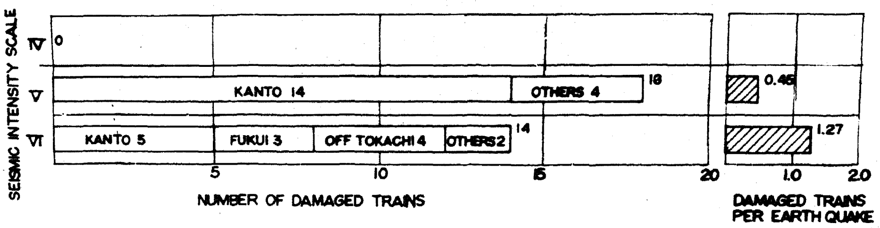


FIG. 2 NUMBER OF DAMAGED TRAINS ACCORDING TO SEISMIC INTENSITY SCALE

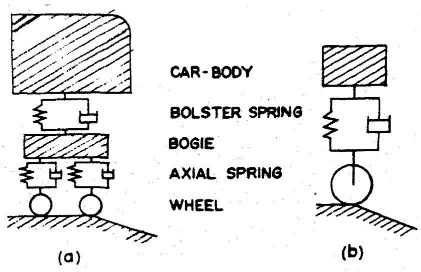


FIG. 4 DYNAMICAL VEHICLE MODEL

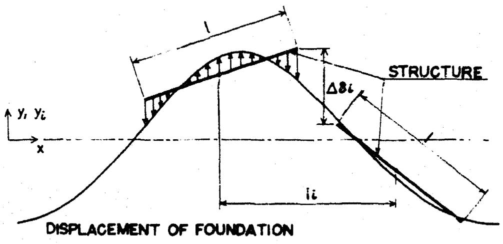


FIG. 5 DISPLACEMENT OF FOUNDATION AND STRUCTURES

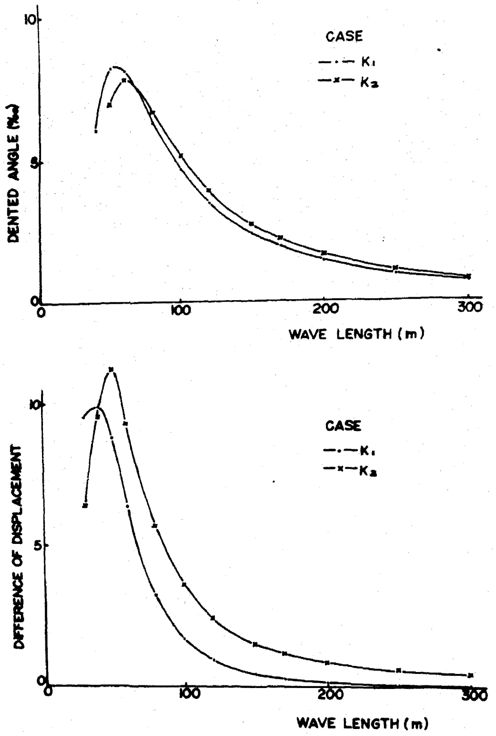


FIG. 6 MAXIMAM DENTED ANGLE AND DISPLACEMENT

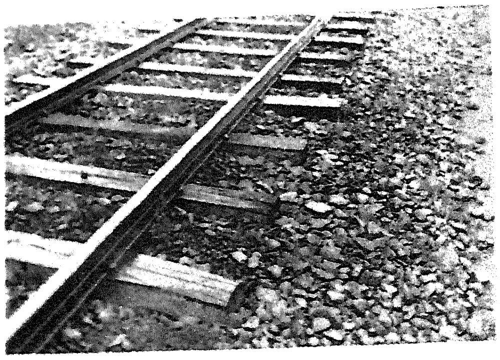
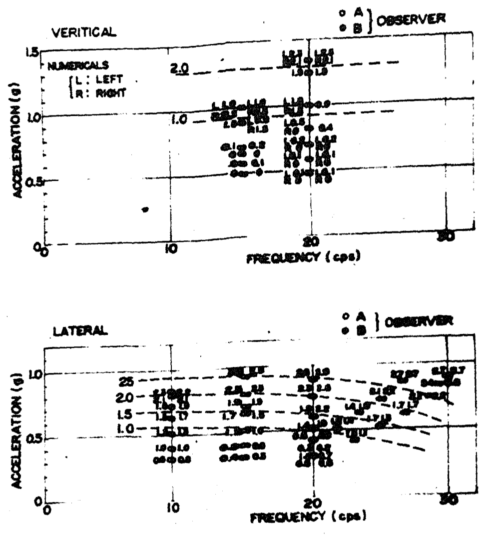


FIG.7 BALLAST IS FLOWN OUT FROM THE TRACK ON THE HIGH EMBANKMENT



INDEX FOR THE FLOW-OUT OF BALLAST

1. SEVERAL INSTABLE STONES BEGIN TO VIBRATE AT SITE.
2. FLOW-OUT OF BALLAST BEGINS AT THE SHOULDER OF BALLAST.
3. BALLAST AT SHOULDER FLOWS OUT AND ENDS OF TIES ARE EXPOSED.

FIG.8 FLOW-OUT OF BALLAST

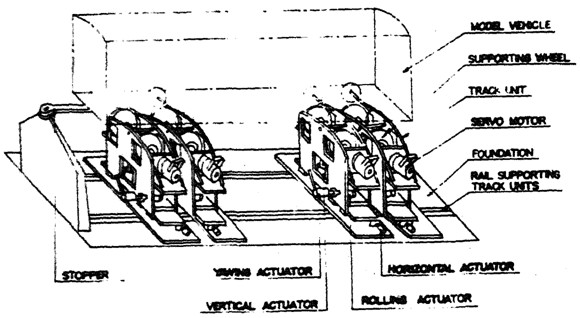


FIG.9 EQUIPMENT SIMULATING THE RAILWAY TRACK MOVEMENT IN EARTHQUAKE

TABLE.1 TOLERANCE FOR DEFORMATION OF RAILWAY STRUCTURES

(θ‰)

DIRECTION / VELOCITY (km/h)		VERTICAL				LATERAL			
		120	160	200	250	120	160	200	250
PARALLEL DIS-PLACEMENT	30 > L	23	18	13	9	8.5	6.5	5.5	5
	30 ≦ L	30	16	11	7.5	11	7.5	5	4
DENTED	30 > L	28	21	15	10	10	8	6.5	5.5
	30 ≦ L	33	18	12	8	12	9.5	6.5	4.5

TABLE.2 REDUCTION OF LATERAL BALLAST RISITANCE IN VIBRATION

LINE	TRACK	COEFFICIENT FOR REDUCTION				STATICAL LATERAL BALLAST RESISTANCE
		TRAIN STOP		SEISMIC COEFFICIENT FOR STRUCTURE DESIGN		
		I	II	STANDARD	MAXIMUM	
NARROW GAUGE LINE	WOOD TIE — GRAVEL BALLAST	0.944	0.894	0.858	0.821	0.55 TON
	WOOD TIE — CRUSHED STONE BALLAST	0.923	0.852	0.801	0.748	0.63
	CONCRETE TIE — CRUSHED STONE BALLAST	0.929	0.868	0.826	0.777	1.02
SHINKANSEN	CONCRETE TIE — CRUSHED STONE BALLAST	0.966		0.834		1.70