STUDY ON SEISMIC RESPONSE OF TRAIN CAR

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1. Introduction

As Japan is prone to earthquakes, it's vitally important that safety measures against railroad derailment are formulated thoroughgoing. Because in recent years, larger earthquakes, which are scaled 7 on seismic intensity, have been occurring, and even much larger earthquakes are said to occur in next few decades, the study on seismic response of train car, especially when the train car is running, is demanded. So, in this study, seismic response of running train car was observed by a vibrated train model (on a scale of 1 to 10).

2. Train Model

2.1 Bogie

In this study, bogie that is capable of running on 5-inch-gauge rail was used. As shown on Fig.1, sets of oil-cushion are used for primary suspension, considering two modes of train car, lower center rolling for first mode and upper center rolling for second mode. The mass of this bogie is 1/1000 (=1/10^3) of actual train, considering geometrical similarity.

2.2 Train Body

The width of train body is 300mm, which is 1/10 of actual train, considering geometrical similarity. The length of train body is 280mm, which is shorter than 1/20 of actual train. The reason why the length is shorter than half of supposed body length is so that the model would not take too much space on vibrating table. Although the length of train body is not 1/10 of actual train, geometrical similarity is satisfied by adjusting the moment of inertia of train body.

2.3 Connection Between Bogie and Body

As shown on Fig.2, soft-type tennis balls are used for secondary suspension, considering two modes of train car. The body is supported by a rod, which is held by Teflon pad connected to steel angles. Then, additional mass is put on the rod to adjust the center of gravity of the model.

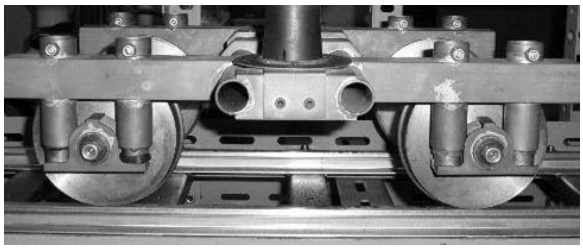

Fig.1 Bogie Model

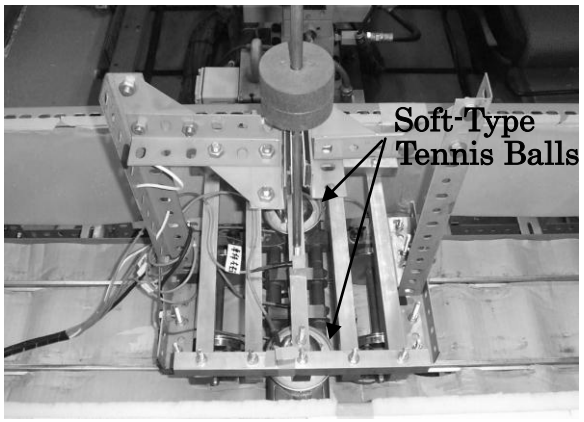

Fig.2 Bogie and Body when Assembled

2.4 Mechanical Similarity

By using π-number already proved[(1)], time ratio, speed ratio, acceleration ratio were derived as following:

$$t_j = f^* t_m , \quad V_j = \frac{V_m}{V^*} , \quad a_j = \frac{a_m}{a^*} \quad (1), (2), (3)$$

where t is time, V is speed, a is acceleration, and j stands for actual train and m for model. Relation among non-dimension numbers were derived as following:

$$L^* \equiv \frac{L_m}{L_j} , \quad f^* \equiv \frac{f_m}{f_j} \quad (4), (5)$$

$$V^* = L^* f^*, \quad a^* = L^* \left(f^*\right)^2 \quad (6), (7)$$

where L is geometrical length. For the model used in this study, L^*=0.1, since the model is on a scale of 1 to 10. Also, since the second natural frequency is 7Hz for the model and 2Hz for actual train, f^*=3.5. Therefore, conversion coefficients, which can be used for converting train model data to actual train data, were calculated as

follows: 3.5 for time, 3 for speed, and 1 for acceleration.

3. Apparatus

3.1 Vibrating Apparatus

Vibrating table used in this study is hydraulic-type, and capable of vibrating up to mass of 80kg, amplitude of 50mm, and frequency of 30Hz. On this vibrating table, rotating disks shown on Fig.3 were put, perpendicular to vibrating direction. The circle of these rotating disks is simulated rail. So, to replicate the condition of train running is possible by swinging these. Put Train Model on Vibrating Apparatus is shown on Fig.4.

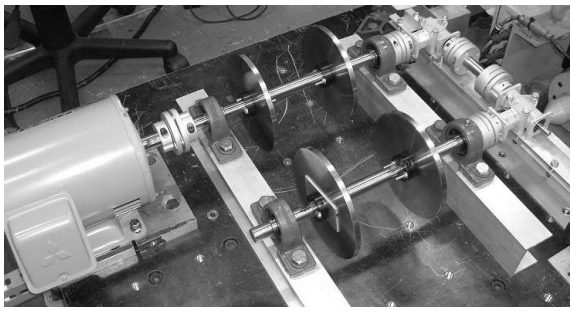

Fig.3 Rotating Disks

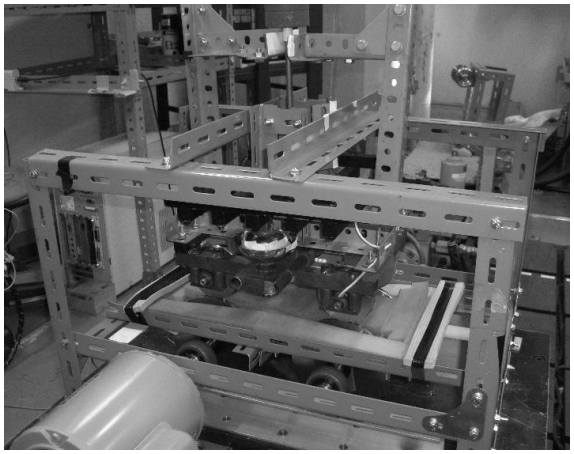

Fig.4 Apparatus

3.2 Measuring Instruments

Vibrating displacement was measured by laser displacement meter, acceleration was measured by acceleration sensor, and speed of the model was measured by pass sensor. Then, the movement of the model was shot by a high-speed camera.

4. Procedures

4.1 Similarity Confirmation Experiment

By this experiment, derailing limit (limit of vibrating displacement) of the model was measured. Results of HO-gauge rail experiment[1] and numerical simulation of actual train[2] were compared to results of the model used in this study, based on mechanical similarity.

4.2 Vibration Experiment

The model was vibrated by the sine wave of frequency 6.5Hz. Then, speed of revolution of rotation disks are set 0～20rps which is equivalent to about 0～100km/h in actual car by mechanical similarity, as explained on section 2.4. This input seismic wave was converted by mechanical similarity, as explained on section 2.4. Two accelerometers are set in the center of the bogey, and the measurement of the vertical and horizontal accelerations are possible.

5. Results and Consideration

5.1 Similarity Confirmation Experiment

The derailing limit curve is shown on Fig.4. Since the data is not converted, ranges of limit are scattered. In contrast, when the data is converted to that of actual train, the data matches as shown on Fig.5. By this experiment, it is shown that mechanical similarity of the model used in this study is satisfied.

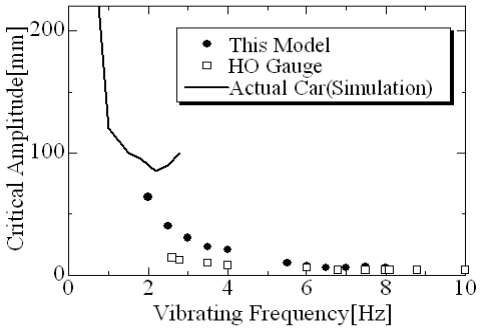

Fig.4 Derailing Limit Curve (Before)

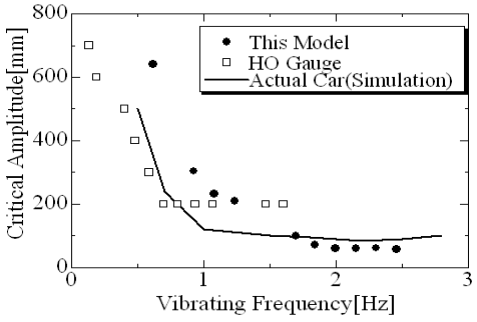

Fig.5 Derailing Limit Curve (After)

5.2 Vibration Experiment

Acceleration of vibrating table and bogie as rotating disks stopped is shown on Fig.6. This result is compared with Fig.7 which is experimental result as bogie put on the 5-inch-gauge rail[3].

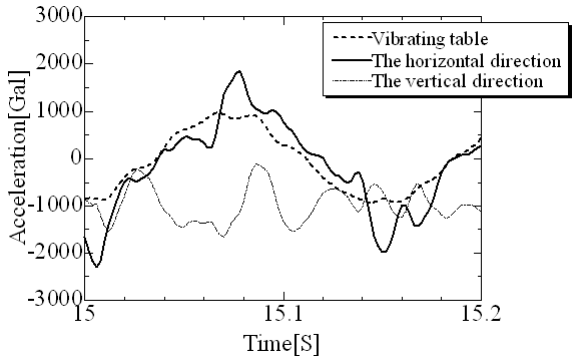

Fig.6 The rotating disk at 0rps(0km/h)

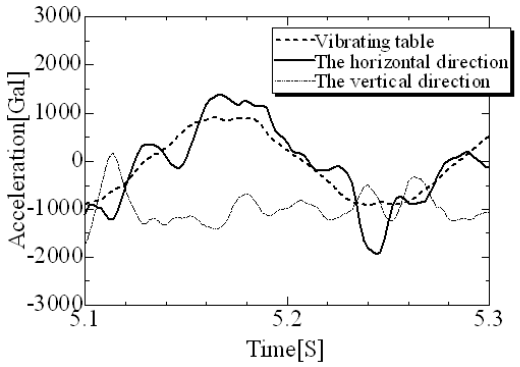

Fig.7 The 5-inch-gauge rail at 0km/h

There is no great distinction between the rotating disk and 5-inch-gauge rail on bogie stopped. This shows that rotating disks can simulate 5-inch-gauge rail.

And Acceleration of vibrating table and bogie as rotating disks running at 20rps(about100km/h) is shown on Fig.8.

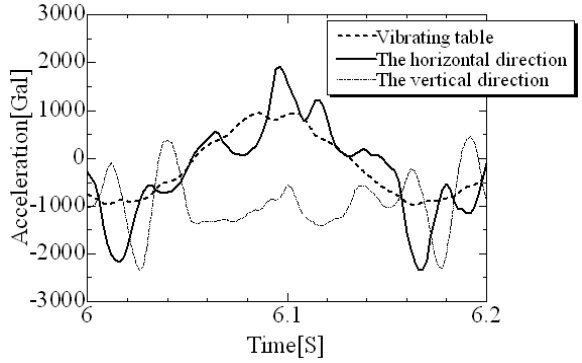

Fig.8 The rotating disk at 20rps(100km/h)

There is no great distinction between the rotating disk stopped and running at 100km/h. But As much as speed of bogie became fast, the variation of the acceleration of bogie became complicated. This shows that considering the velocity of the train car is important when we study seismic response of train car.

6. Conclusions

By this study, it was found that the s reproductive experiment that train car running is possible by using rotating disks instead of the rail and that considering the velocity of the train car is important when we study seismic response of train car.

7.References

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(2) T.Miyamoto, H.Ishida, and M.Matsuo, “The Dynamic Behavior of Railway Vehicle during Earthquake: Vehicle Dynamics Simulation on Track Vibrating in Lateral & Vertical Directions”, *Transactions of the Japan Society of Mechanical Engineers.C* (1998), 236-243

(3) Y.Sato, H.Takada, and Y.Matsuura, “Study on the Seismic Behavior of Railway Vehicle”, *Master thesis of Yokohama National University*