Track Maintenance for Tilting Train’s Safety on Sharp Curves

Abstract
JR Kyushu tested the effectiveness of realigning a track based on the abnormal value detected by the axlebox lateral vibration acceleration measurement on a passenger train, and the alignment irregularity measurement using a 2-meter chord.

Introduction
Tests conducted on passenger trains revealed the tendency of significant lateral force occurring at the joints when a controlled tilting train traveled on curves at a high speed. After a site examination, JR Kyushu concluded that it would be extremely difficult to detect the locations of such lateral forces by applying the conventional method of track inspection with a 10m-chord. In this study, the company has established a method of detecting the locations of significant lateral force from the axlebox lateral vibration acceleration measurement on passenger trains\(^1\), and to build a method for realignment based on the alignment irregularity measurement using a 2m-chord\(^2\). The target was to additionally incorporate both methods into the conventional method in order to control joints on sharp curves in the sections where the tilting trains are operated.

1. Tendency of Significant Lateral Force on Sharp Curves
Increasing train speed on sharp curves is an effective measure for reducing travel time on curvy line sections. Currently in Japan, there are many line sections where a controlled tilting train has been introduced. However, during the tests done on passenger trains, it was found that on such curves with a cant deficiency of 100mm or more on narrow-gauge tracks, tilting trains experienced significant lateral force while traveling over the joints. It was true even with joints which appeared sound in the conventional track irregularity inspection using a 10m-chord. Figure 1 is a measurement chart showing the relation between the lateral force and the alignment irregularity with a 10m-chord by employing a track geometry car. Among those joints with similar levels of alignment irregularity, some displayed significant levels of lateral force based on those measured by utilizing the strain of the wheels. Through an investigation into the causes, it was found that detection and maintenance of the locations of significant lateral force would be extremely difficult with the conventional detection method. This is due to the fact that lateral force is generated by the alignment irregularity which cannot be detected by the characteristics of the measurement method using a 10m-chord.

![Figure 1: Relation between lateral force and alignment irregularity](image-url)
Figure 2 shows photographs of joints on curves with radii of 250m (hereinafter referred to as R250). A significant lateral force was observed at the joint in photo (1), but not at the joint in photo (2). The comparison revealed that significant lateral force occurred at joints showing a slight angular bend.

(1) Joint showing an angular bend
(2) Joint without an angular bend

Figure 2: Joints on curves with radii of 250m

The alignment measurement with a 2m-chord was then conducted to quantitatively express such a phenomenon. The 2m-chord was chosen because the measurement with this chord length would clearly express the behavior of the cars and bogies because the distance between the bogie axles of a tilting train is 2m. Figure 3 shows the image of the alignment measurement with the use of a 2m-chord. Figure 4 is an example of such a measurement, showing the alignment irregularity exceeding 4mm at the joint.

Figure 3: Measurement of static joint shape

Figure 4: Example of alignment irregularity measured with a 2m-chord
## 2. Simple Method of Detecting the Locations of Significant Lateral Force

The locations of significant lateral force described above, or the curves showing angular bends at the joints, were easily detected through speed-up tests towards the introduction of new types of trains, for which the wheel load and lateral force were continuously measured. However, such measurements of the wheel load and lateral force on a train require a considerable amount of labor, cost, and involve a great deal of difficulty if done on trains in operation. In addition, nearly half of a certain 15km section of lines where a tilting train was traveling had continuous curves of R250. It was not cost-efficient to maintain tracks of such length by checking each joint thoroughly. Given these situations, JR Kyushu recognized a critical need to develop a new method to easily detect abnormal locations where significant lateral force may occur, to soundly maintain and repair tracks.

In Japan, in order to grasp the rail surface roughness and to control the locations of significant wheel load, the method of utilizing axlebox vertical vibration acceleration had long been recommended\textsuperscript{[3]} and had brought about many achievements especially for the Shinkansen\textsuperscript{[4]}. Acknowledging this fact, JR Kyushu studied the possibility of expressing the lateral force by the lateral elements of axlebox acceleration. However, we considered that the lateral force to be detected by axlebox acceleration depended on the impulsive vibration generated by short wave track irregularity. Therefore, in this study we excluded measurements by the acceleration, concerning static lateral force attributable to curvature from our target.

As shown in Figure 5, a fairly good correlation is observed between the lateral force continuously measured on the train and the axlebox lateral vibration acceleration. The acceleration herein was obtained by applying the 20Hz low-pass filter to the measured data. The reasoning is that the criterion of the time of lateral force effect is considered to be 1/20 of a second when examining safety in terms of derailment in Japan. Any lateral force with a shorter duration than that is thought to have no real effect on running stability. It was also found that other impulsive vibration, such as that generated by slight gaps in joints, was excluded in the above processing.

![Figure 5: Relation between lateral force and axlebox lateral vibration acceleration](image)
Based on the data processed as above, comparisons were conducted on axlebox lateral vibration acceleration observed at locations where significant lateral force occurred when trains traveled over curves of R250 to R300 with a cant deficiency of approximately 100mm. As a result, with 8m/sec$^2$ as a criterion, most of the locations where a lateral force of 60kN occurred were detected, which shows the design strength of the PC ties.

3. Method Taken for Lateral Force Reduction

Examination was made on how to control rail joints showing angular bends, since these cause most of the significant lateral force on sharp curves. The result revealed a control method whereby tracks should be maintained to keep alignment irregularity within 4mm, measured with a 2m-chord, to keep the lateral force occurring at joints within a PC tie design lateral force strength of 60kN.

(1) Examinations to reduce lateral force

For the purpose of expressing the degree of joint angular bend using a 2m-chord, two methods of quantification were taken. One was to use the alignment irregularity as shown in figure 6; and the other was to use the tangent angle of such an angular bend as shown in figure 7. In establishing the control method, it was necessary to determine the allowable levels for these values.

![Figure 6: Quantification of alignment irregularity](image1)

![Figure 7: Quantification of tangent angle of angular bend](image2)

The allowable levels for variable elements of the lateral force were obtained by the following formula:

\[
\text{(Variable elements of lateral force generated by angular bend in the joint)} < \text{(PC tie design lateral force strength)} - \text{(Static elements of lateral force)}
\]
The above is based on the characteristics below:

i) The design lateral force strength of the PC tie is 60kN;

ii) It is known that static elements of lateral force in the circular curves are fixed; and

iii) It may be assumed that at locations of significant lateral force, variable elements, obtained by subtracting the static elements corresponding to the curvature from the lateral force, are defined as the impact on lateral force caused by the curvature discontinuity on the lateral force.

Examination was then conducted on the basis that once the correlation between the variable elements of the lateral force and the degree of the joint’s angular bend was found, the control value used for the alignment irregularity measured by a 2m-chord would also be obtained.

(2) Static lateral force characteristics of the introduced tilting train

Figure 8 shows the relation between train speed and static lateral force at R250, obtained from the speed-up tests of the introduced tilting trains. It reveals that the static lateral force of the tilting train traveling over a curve of R250 at its target speed of 80km/h was 30kN.

![Figure 8: Static lateral force characteristics of a tilting train](image)

(3) Relation between variable elements of lateral force and joint shape

A correlation between the variable elements of lateral force and joint shape is shown in Figure 9. This correlation was obtained using the method applying the alignment irregularity in Figure 6. Figure 10 shows the correlation as obtained using the method applying the angle of angular bend in Figure 7. Based on the results mentioned above, the allowable variable elements of lateral force are 30kN. The corresponding irregularity is within 4mm for alignment irregularity measurement using a 2m-chord, and approximately 8m rad for the tangent angle method.
4. Conclusion

With the introduction of a tilting train that travels over sharp curves at a high speed, a tendency of significant lateral force to occur at joints has been observed. Such lateral force aggravates alignment irregularity, causes damage to the track materials, and eventually becomes a threat to the safety of tilting trains while traveling. To address lateral force and prevent such trouble, the following countermeasures have been established:

1) Measure the axlebox lateral vibration acceleration on passenger trains, and conduct repairs using a 2m-chord on locations where the values exceed $8\text{m/sec}^2$ at R250 to R300; and

2) Use alignment irregularity with a 2m-chord as the control value, and conduct maintenance so as to keep the value within 4mm.

The speed-up tests were conducted twice on this line section before the introduction of a tilting train. The number of locations where abnormal values were detected was 27 in the first test. However, in the second test conducted after the maintenance work, the number was drastically reduced to three.

Before this study, there were no definite guidelines for lateral force countermeasures, such as maintaining a certain value at a certain level to help prevent abnormal values. This study brought a successful conclusion to problems surrounding JR Kyushu tilting trains when traveling around curves with radii of 250m to 300m. Future research plans to further enhance running stability include a study into curves with 400m and 600m radii.
References

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