Influence of Slab Length on behavior of Floating Slab Track by Rail-slab-isolator Longitudinal Interaction

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Abstract

Many different types of floating slab track have been developed and installed around the world to reduce vibrations and noise originating in the surrounding environment. The main objective of this study is to examine the influence of slab length on behavior of floating slab track based on rail-slab-isolator interaction. The floating slab track is modeled by the connection between rail, slab, isolator, and slab mat in the transition zone. All elements were assembled in a simplified two-dimensional (2D) finite element model (FEM). The maximum length of FST is then investigated based on the maximum additional rail stress criterion as described in UIC 774-3R since no fully accepted design criteria for the slab length in FST systems currently exist.

Keywords: Floating slab track, Rail stress, Interaction analysis

1. Introduction

The passage of railway vehicles generates mechanical vibrations in a wide range of frequencies. Thus, the placement of structural vibration isolation systems is required to reduce vibrations and noise in the surrounding environment. It is widely known that floating slab track (FST) systems are the most effective and reliable solution for prevention of mechanical vibrations and ground-borne noise generated by passing trains (Lombaert et al., 2006). Many different types of FST have been developed and installed around the world (Bilow and Randich, 2000). In Korea, FST such as that shown in Fig. 1 has successfully been developed and tested, and one such is currently being constructed in the test-bed of a commercial railway line.

FST typically consist of simple masses and springs that can isolate vibrations due to wheel-rail interactions. In an FST system, a continuous welded rail (CWR) is fixed to a massive concrete slab through rail pads with isolators under the concrete track. Although FST is more expensive and requires greater section heights because of the isolator, this relatively high cost is more than offset by the reduced noise and vibration.

However, the effect of slab length—an important factor in FST (Yuan et al., 2009)—has not yet been fully researched. The main objective of this study is to examine the behavior of FST and to determine the maximum length of an FST based on the maximum additional rail stress criterion as described in UIC 774-3R. The criterion for the maximum additional tensile and compressive rail stress limit is 92 MPa, as described in the International Union of Railways (UIC) code (2001).

2. Floating Slab Track

The floating slab track considered in this study typically consists of mass and springs that can isolate vibrations due to wheel-rail interactions. In an FST system, a continuously welded rail (CWR) is fixed onto a massive concrete track slab through rail fastenings, and isolators are inserted under the slab. Although FST is more expensive and requires greater section heights because of the thicker slab, this relatively high cost can be offset by the reduced noise and vibration. In Korea, this new kind of FST shown in Fig. 1 has been successfully developed and tested, and is currently being constructed in the test-bed of a commercial railway line.

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3. Interaction Analysis

3.1 Modeling

In this study, the FST system was modeled by the connection between rail, slab, isolator, slab mat in the transition zone, and stopper. All elements were assembled in a simplified two-dimensional (2D) finite element model (FEM). A general-purpose FEM program, ABAQUS (2007), was used as an analysis tool. Fig. 2 illustrates a typical detailed model used in this study.

CWRs and concrete slabs were modeled with Timoshenko beam elements that allow for transverse shear deformation. The length of a CWR can be quite long—up to several kilometers—but the floating slab is many times shorter than the CWR. Therefore, a sufficiently long Timoshenko beam was selected for the continuously welded rail and a finite one for the floating slab. The rail and concrete slab were assumed to be linear, elastic, and isotropic.

The connection between rail and slab was modeled as a two-node spring element. The spring behavior can be linear or nonlinear to represent the action of an actual assembly. Here, the spring exhibit nonlinear behavior in the longitudinal direction (UIC 774-3, 2001). It is a function of the displacement of the rail relative to its supporting structure, as shown in Fig. 3. In vertical direction, linear behavior is assumed for the sake of simplicity.

The isolator, connection between the floating slab and the rigid foundation, was also modeled by a spring element whose stiffness acts in a fixed direction. The isolator spring stiffness was identified by experimental tests in a Land transport and maritime R&D report (2011).

3.2 Load cases

This study considered the following three load cases: changes in temperature, braking and acceleration, and vertical loading.

As the temperature changes, the slab expands or contracts. Assume that the floating slab is subjected to uniform temperature changes, the temperature of the floating slab deviates from the reference temperature as indicated in the UIC code.

Braking and acceleration forces applied at the top of the rail are assumed to be distributed evenly over the length under consideration. These loads were chosen from UIC code as an acceleration force of 33 kN/m per track over a load length of less than 33 m and a braking force of 20 kN/m per track over a load length of less than 400 m. The results of acceleration and braking force will be compared to each other and the maximum values chosen for the final analysis.

Vertical traffic loads cause bending of the floating slab, leading to rotation of the end sections and vertical displacement of the upper edge of the floating slab end. According to railroad-bridge longitudinal interaction analysis guidelines in Korea (Korea Rail Network Authority, 2011), the load arrangement and the characteristic values for vertical train loads were taken to be as shown in Fig. 4.
4. Numerical Results

Finite element analysis of a standard FST was performed to understand the interaction behaviors of the FST system. Fig. 5 shows the maximum additional compressive rail stress for no stopper case. As the slab length increases, the overall rail stress has a similar growth rate to the stress due to changes in temperature; the stresses due to other loads do not show any consistent trends.

The deformed configuration of the FST due to bending is shown in Fig. 7. The maximum rail stresses due to the FST bending always occur at the transition between the embankments and the floating slab track. This can be explained by the sudden change in stiffness from the embankment to the isolator. When the slab length changes, the deformed track shapes change. A shape with a single curve was observed in shorter slab lengths, while multiple curvatures were observed in longer slab lengths. This is a result of the bilinear behavior of the isolator stiffness. When the load increases to a limit value, the isolator stiffness value approaches infinity. At that time, it has maximum reaction force and acts in the opposite direction, raising the slab up. Under these conditions, the position of the maximum rail stress changes in the transition regions between the embankment and floating slab track, thus making the trend in stress inconsistent. Similar to the bending, the maximum rail stresses occur at different locations under acceleration and braking.

This makes the maximum stress trends also inconsistent. However, the variations in these values are small compared to the permissible maximum additional stresses in the CWR in the UIC code, making the contribution of variation in the
maximum additional stresses relatively insignificant. The total maximum additional rail stresses due to load combinations monotonically increase as the slab length increases. Actions due to changes in temperature are the major influencing factor in the combined maximum rail stress.

The additional tensile rail stresses are shown in Fig. 6. Similar trends are observed as compressive rail stress.

The maximum allowable additional compressive rail stress in the UIC code is 92 N/mm². In no stopper case, the maximum additional rail stress rises rapidly over the allowable additional rail stress with slab lengths of 45 m. It is expected that the additional rail stress may decrease significantly by installation of stopper since the floating slab may take significant amount of longitudinal stresses.

Fig. 8 shows the maximum tensile slab stresses with increasing slab lengths. The maximum stress due to bending occurs in the middle span of the floating slab and varies quite a lot with slab lengths between 14.5 and 34.5 m. This can be explained as a result of the slab behavior illustrated in Fig. 7. Additional isolators are added when the slab length is increased; the slab is lifted up under vertical loading when the slab length is between 14.5 and 34.5 m. Beyond this range, stresses increase only gradually. Fig. 8 also illustrates the cumulative tensile slab stress, which, in contrast to the cumulative tensile rail stress, is lower when there are no stoppers. As described earlier, it is expected that installation of stopper may increase slab stresses and decrease rail stresses.

5. Summary and Conclusions

Many different types of floating slab track have been developed and installed around the world to reduce vibrations and noise originating in the surrounding environment. This study investigated the behavior of FST by means of rail-slab-isolator interaction analysis. This paper also determined the maximum length of floating slab based on longitudinal rail stress. The floating slab track is modeled by the connection between rail, slab, isolator, slab mat in the transition zone, and stopper. All elements were assembled in a simplified two-dimensional finite element model.

It is clearly observed that the additional rail stresses increases as slab length increase. The maximum tensile slab stresses generally increases as slab length increased except for the case of short slab. The maximum length of FST is then determined based on the maximum additional rail stress criterion as described in UIC 774-3R. The maximum length for the considered FST was 45m without stopper. Since no fully accepted design criteria for the slab length in FST systems currently exist, the maximum length resulted from this study will provide a good indicator for future FST design.

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References


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