대만 고속전철 교량의 레일-구조물 상호작용 평가

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1. GENERAL

In railway structure, long rail causes the increase of stress. Especially, additional stress and displacement are caused by the discontinuity and variations of the stiffness of substructures in the section of bridges. In the other words, binding forces like the connection strengths and friction force between ties and ballasts play the role of resistance forces.

To check every load condition and the properties of substructure, it is necessary to analyze the rail-structure interaction considering its nonlinear properties by the Finite Element Method.

In particular, not only the safety of the displacement by acceleration and braking force but also the safety of the type II earthquake should be checked according to the Taiwan High Speed Railway Design Specification Volume 9. To check the matters described above, once the deformations of the ground and the structure under earthquake event are computed, the stress and relative displacement of decks should be checked.

In this paper, the response properties of long rails for the Taiwan High Speed Railway are analyzed under the combination of braking and acceleration forces and type II earthquake specified in the Taiwan High Speed Railway Design Specification Volume 9. Then, the stress of the rail and the safety are checked according to the properties of substructures.

The analysis method consists of ground analysis, structure analysis and rail-structure interaction analysis. And main parameters are both of rail stress and relative displacements.

2. SEISMIC ANALYSIS FOR GROUND MOTION

During earthquake event, seismic accelerations are transmitted from the ground to the structure. It means that the ground motion affects seriously the motion of the structure. Therefore, the transfer of earthquake waves has to be defined as considering the region properties and soil properties.

2.1 Soil Classification in Design Specification

As the Taiwan High Speed Railway Design Specification, the response spectrum is shown in Figure 1.

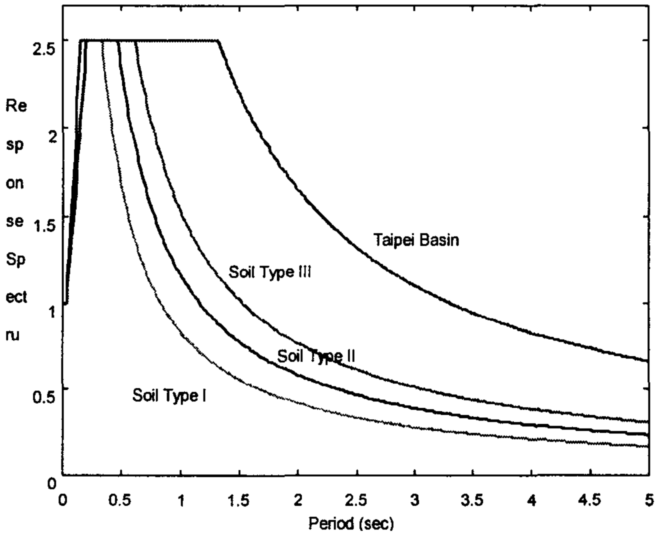


Figure 1. Response spectrum for soil type

2.2 Modeling of Input Ground Motions

As the stiffness of the ground depends on the strain of the ground, input earthquake wave is required to obtain the strain of the ground. Artificial earthquake waves are created for each ground and soil condition.

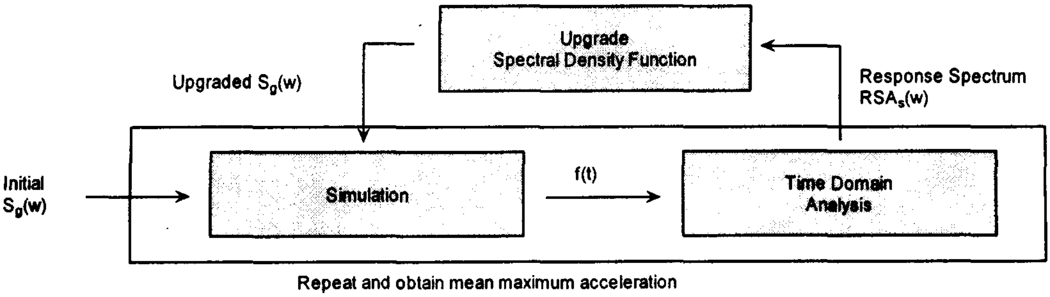


Figure 2 Generation of Spectral Density Model Compatible with Response Spectrum

And the spectral density function is improved by comparing the two response spectra based on Eq.(2.1).

$$S_g(\omega) \rightarrow S_g(\omega)\left[\frac{RSA(\omega)}{RSA_S(\omega)}\right]^2 \qquad (2.1)$$

where $RSA(\omega)$ is the design response spectrum and $RSA_s(\omega)$ is the response spectrum generated from the current spectral density function $S_g(\omega)$.

2.3 Computation of Ground Properties

As the modulus of elasticity in shear, G, is strain-dependent function, iterative procedure is the method to determine G. Strain which is included in the given input range is calculated to determine stiffness and damping of the ground. This procedure is performed in the frequency domain to use the spectral analysis method.

After computation of the stiffness and damping of the ground, the stiffness matrix and mass matrix are formulated as the following equation. $\underset{\sim}{G}^j$ and $\underset{\sim}{M}^j$ are 4×4 symmetric matrices are formulated.

Assembling the matrices for the region $0 \le z \le h$ to get ground period and shape, we obtain:

$$\left[\underset{\sim}{G} - \omega^2 \underset{\sim}{M}\right]\underset{\sim}{\Delta} = \underset{\sim}{F} \qquad (2.2)$$

Then eigenvalue problem are solved by Eq.(2.2).

From these results, site conditions, especially particular sites condition, are determined as described in Taiwan High Speed Railway Design Specification. Then, for the particular site, the ground deformation should be considered.

3. SEISMIC ANALYSIS OF BRIDGE

The relative displacement between decks is computed by the combination of the displacement of the bridge with the earthquake motion.

Spectral analysis method described in the Design Specification Volume 9, is adopted for the analysis of the Taiwan High Speed Railway bridges. Especially, the Multimode Spectral Analysis Method is applied.

3.1 Modeling

The bridge should be modeled as a three-dimensional space frame with joints and nodes selected to realistically model the stiffness and inertia effects of the structure. Each joint or node should have six degrees-of-freedom, three translational and three rotational. The structural mass should be lumped with a minimum of three translational inertia terms.

Foundation conditions at the base of the columns and at the abutments may be modeled using equivalent linear spring coefficients.

3.2 Mode Shapes and Periods

The required periods and mode shapes of the bridge in the direction under consideration shall be calculated by established methods for the fixed base condition using the mass and elastic stiffness of the entire seismic resisting system.

Mode shapes and frequencies should be obtained from the equation:

$$\left[\underline{k} - \omega^2 \underline{m}\right]\hat{\underline{v}} = \underline{0} \qquad (3.1)$$

using standard eigenvalue computer programs; where $\underline{k}$ and $\underline{m}$ are the known stiffness and mass matrices of the mathematical model, respectively, $\hat{\underline{v}}$ is the displacement amplitude vector, and ω is the frequency. This analysis will yield the dimensionless mode shapes $\underline{\phi_1}, \underline{\phi_2}, \Lambda, \underline{\phi_n}$ and their corresponding circular frequencies $\underline{\omega_1}, \underline{\omega_2}, \Lambda, \underline{\omega_n}$. The mode periods can then be obtained using

$$T_i = \frac{2\pi}{\omega_1} \quad (i = 1,2,K,n). \qquad (3.2)$$

3.3 Displacements

The displacements can be estimated by combining the respective response quantities (e.g., force, displacement, or relative displacement) from the individual modes by the Square Root of the Sum of the Squares (SRSS) method.

4. Rail-Structure Interaction

4.1 General & Provisions

In the case of long rail, the stress of the rail itself is increased in a large amount by the continuity of rail.

By the variation of the substructure, additional stress and deformation are generated. Those additional stress and deformation cause the rail-structure interaction.

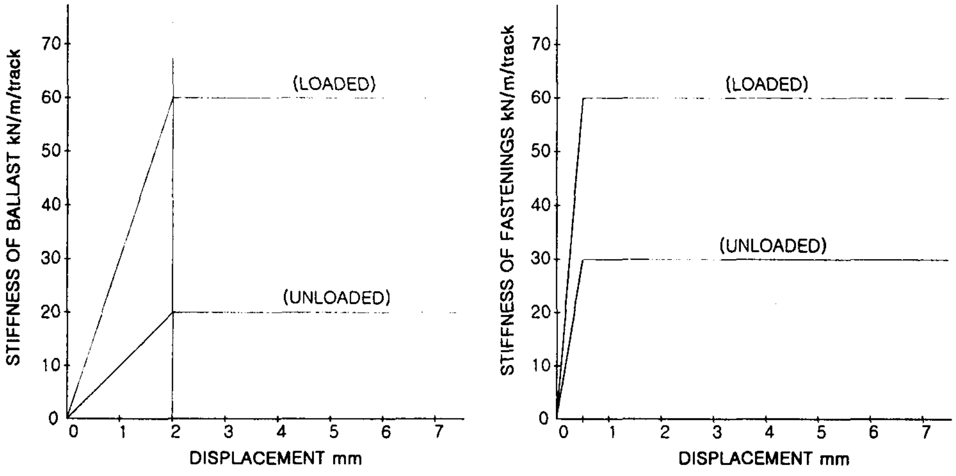
As shown in Design Specification Volume 9, Subsection 3.C.5.0, the provisions to check the rail-structure interaction are:

	Rail Stress	Displacement
Bracking, Traction and 20 C Temperature Variation Between Rails and Deck	-72/+92 N/mm2	7 mm : between decks or deck and abutment, 4mm : between bridge deck and rail.
Bracking, Type II earthquake and 20C Temperature Variation Between Rails and Deck	-147/+167 N/mm2	25 mm : between decks or deck and abutment,

4.2 Modeling for rail-structure interaction analysis

Bi-linear model are used for ballasts and fastenings which connect the rail to the structure as shown in Figure 3, and, under braking force, the 300 m span is represented by the loaded model and the other span by the unloaded model as shown in Figure 4.

For rails and decks, the frame elements are used as shown in Figure 5. In case of 35 m span bridges, the springs connected to decks are nonlinear springs and the intervals between springs are 3.5m long. In case of 30m span, the interval between springs is 3m.



ballast fastening

Figure 3 Element properties

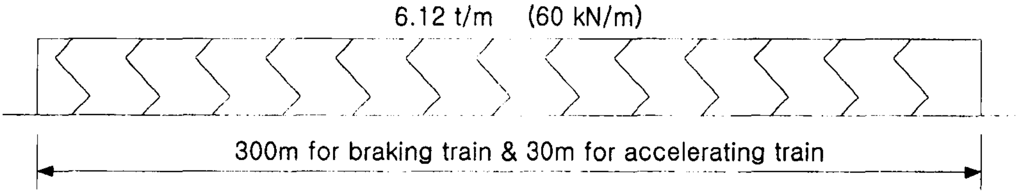


Figure 4 Load status

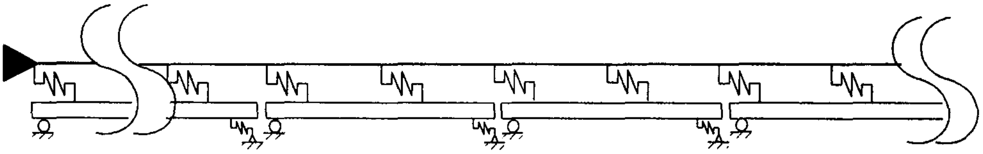


Figure 5 Modeling for rail and decks

4.3 Rail-Structure Interaction Analysis

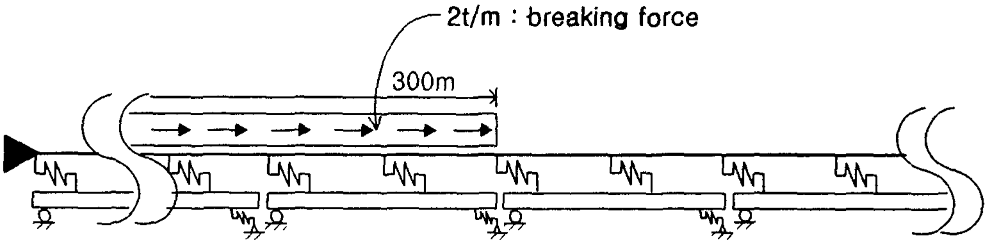


Figure 6 Load status by braking force

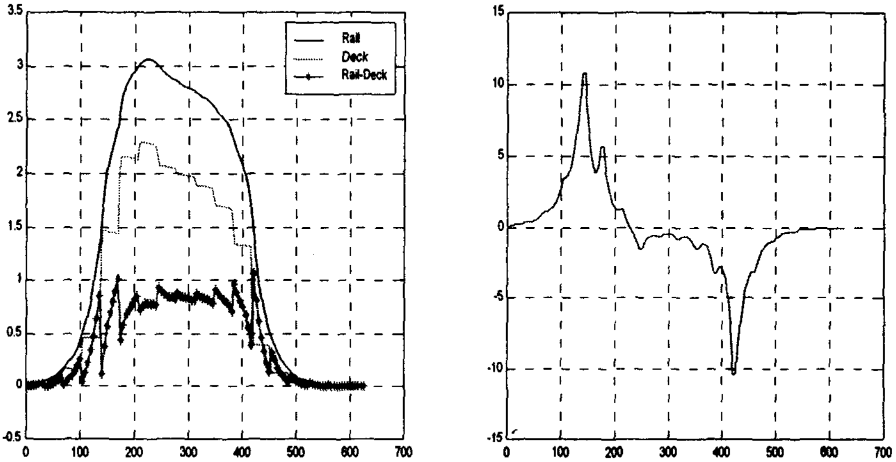


Figure 7 Displacement between rail and deck & rail stress by braking force

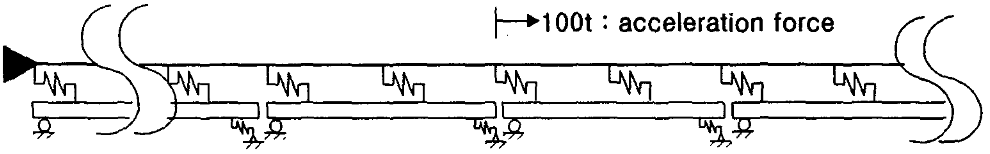


Figure 8 Load status by acceleration force

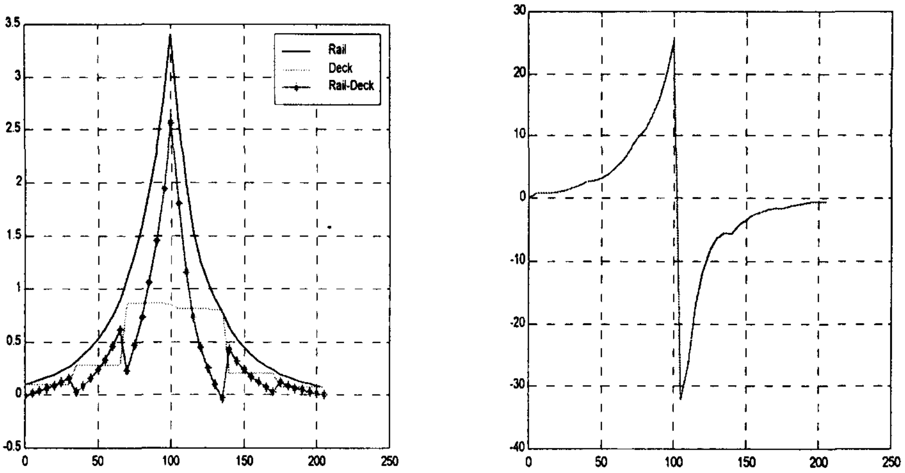


Figure 9 Displacement & rail stress by acceleration force

5. CONCLUSIONS

In Taiwan High Speed Railway Design, the consideration of the earthquake effects is one of the most important factors. So the analysis method for Taiwan High Speed Railway Design is developed as described in this paper and then the method is applied for Design of railway bridge.

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