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ESTIMATION OF EXPOSURE OF DWELLERS TO TRAIN INDUCED GROUND VIBRATION

T Fujikake

Kanagawa Environmental Research Center, Nakahara shimojyuku 842, Hiratsuka City, Kanagawa, 254, Japan

1. INTRODUCTION

Railway vibration is one of the major environmental problems in Japan. This report deals with exposure of dwellers to vibration on the first floor of wooden house which is excited by railway vibration. First, dynamic complex compliance of the ground beneath the foundation is calculated by impedance method [1]–[4]. Next, vibration responses of the foundation and the first floor are calculated. The vibration response of the first floor is assumed to be the vibration response of a beam which supports the first floor. The responses are treated as transient non–stationary vibration response, respectively. The estimation of exposure of dwellers to railway vibration is performed by vibration responses in stationary stage of the first floor.

2. COMPLEX COMPLIANCE OF THE GROUND

It is possible to assume that the simplificated shape of the wooden house foundation is continuous footing type with multi cellular block as shown in Fig.1. And following two assumptions are also introduced. 1; The contact stress distribution between the ground and the foundation is uniform. 2; The load to the foundation is uniform.

Under these conditions, the dynamic complex compliance of the ground beneath the foundation is given by equation (1). Where δ_i means a displacement function at the

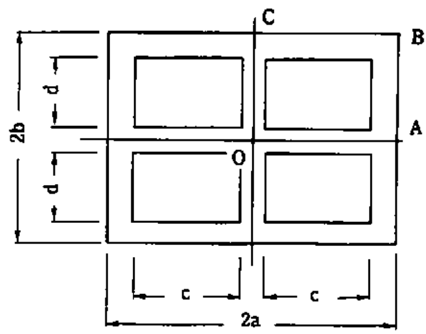

Fig.1 Schematic representation of the foundation. 2a=9.4m, 2b=7.6m, c=4.1m, d=3.4m

point O. Suffix i means 1, 2 ···, 5. j is imaginary unit, μ is Poisson's ratio of the ground and G is a shear modulus of the ground. The displacement function is derived by means of a rectangle–partioning method. For example, in case of i=1, δ_1 is given by equation (2). In equation (2), $k=1.33\,\omega/Vs$ [2].

$$\alpha - j\beta = 4\cdot\frac{1-\mu}{2\pi G}\,\frac{1}{4(ab-cd)}\sum_{i=1}^{5}\delta_i \qquad (1)$$

$$\delta_1 = \int_0^{\tan^{-1}\left(\frac{b}{a}\right)}\int_0^{\frac{a}{\cos\theta}} e^{-jkr}\,dr\,d\theta + \int_0^{\tan^{-1}\left(\frac{a}{b}\right)}\int_0^{\frac{3b+d}{2\cos\theta}} e^{-jkr}\,dr\,d\theta \qquad (2)$$

3. VIBRATION RESPONSE OF THE WOODEN HOUSE

Schematic representation of the wooden house and its vibration model are shown in Fig.2. Mass is sum of the mass of the foundation and the dwelling part. The foundation is treated as a lumped mass system. The vibration response of the first floor is assumed to be a vibration response of the beam which supports the first floor. The beam is a simply supported beam. The dynamic relation between the foundation and the beam is assumed to be a cascade connection.The basic equation of the vibration system of the foundation is given by equation (3).

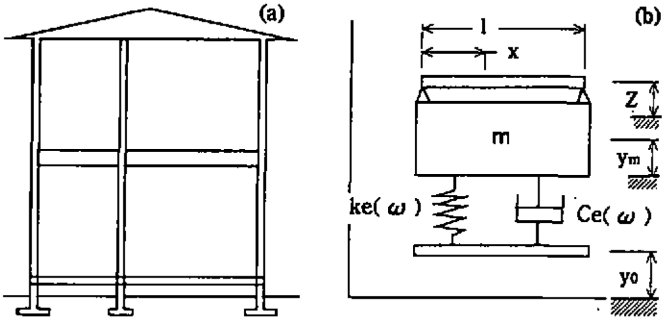

Fig.2 (a); Schematic representation of the wooden house. (b); Simplified vibration model.

$$m\ddot{r} + C_e(\omega)\,\dot{r} + k_e(\omega)\,r = -\,m\,E(t)\cdot\ddot{y}_0(t) \qquad (3)$$

$$C_e(\omega) = \frac{\beta}{(\alpha^2+\beta^2)\,\omega}\ , \quad K_e(\omega) = \frac{\alpha}{\alpha^2+\beta^2}$$

Where E(t) is an envelope function, $r = y_m - y_0$. In this case, E(t) will be given by u(t) (u(t) means unit step function) approximately if the train runs fast. Then, the vibration response of the foundation is given by equation (4).

$$P_{\ddot y_m \ddot y_m}(\omega,t)=|-2h_e\omega G_{\dot r}(j\omega,t)-\omega_n{}^2 G_r(j\omega,t)|^2\,|L(j\omega)|^2\,P_{\ddot y_0 \ddot y_0}(\omega) \qquad (4)$$

$$h_e=\frac{C_e(\omega)}{2\sqrt{mK_e(\omega)}} \qquad \omega_n=\sqrt{\frac{k_e(\omega)}{m}}$$

Where $G_r(j\omega,t)$ and $G_{\dot r}(j\omega,t)$ mean non−stationary transfer function of displacement and velocity, respectively. $P_{\ddot y_0 \ddot y_0}(\omega)$ means input PSD, $P_{\ddot y_m \ddot y_m}(\omega,t)$ means non−statinary PSD of the foundation and $L(j\omega)$ means a loss filter.

The basic equation of the simply supported beam is given by equation (5).

$$\rho A\frac{\partial^2 W}{\partial t^2}+EI\frac{\partial^4 W}{\partial X^4}+\xi I\frac{\partial}{\partial t}\left(\frac{\partial^4 W}{\partial^4 X}\right)=-\rho A\frac{\partial^2 y_m}{\partial t^2} \qquad (5)$$

Where W is a deflection from the neutral axis of the beam, $w=z-y_m$. The non−stationary vibration response of the beam is given by equation (6).

$$P_{\ddot z\ddot z}(x,\omega,t)=\left|\sum_{s=1,3,\ldots}^{N} Y_s(x)\{-1+2h_s\omega G_{\dot q}(j\omega,t)+\omega^2 G_q(j\omega,t)\}k_s+1\right|^2 P_{\ddot y_m \ddot y_m}(\omega) \qquad (6)$$

$$P_{\ddot y_m \ddot y_m}(\omega)=u(t)\,P_{\ddot y_m \ddot y_m}(\omega,\infty),\quad k_s=\frac{2\{1-(-1)^s\}}{s\pi},\quad h_s=\frac{\xi\omega_s}{2E},\quad \omega_s{}^2=\frac{EI}{\rho}\cdot\frac{s^4\pi^4}{l^4}$$

Where $Y_s(X)$ means characteristic function of the beam, $G_q(j\omega,t)$ and $G_{\dot q}(j\omega,t)$ are non−statinary transfer function of the beam.

4. CALCULATION RESULTS

Fig.3 shows the non−stationary vibration response (reference acceleration is 10^{-5} m/s^2) at the center of the beam excited by an envelope PSD obtained from the measured railway vibration. Fig.3 shows that the transient vibration response is greater than in stationary vibration response in instantaneous vibration response.

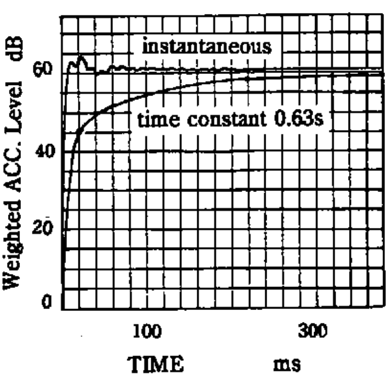

Fig.3 Response of the beam. Vs=160m/s, mass=45,000kg, span=3600mm, η_1 = 0.03, ρ_b =730kg/m^3, E=1.03*10^{10} N/m^2

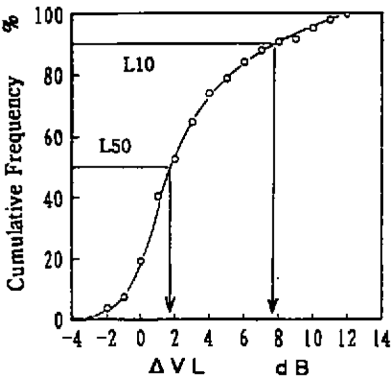

Fig.4 Cumulative frequency between the ground and the 1st floor. Vs=120, 160, 240m/s, Mass=30,000, 45,000, 60,000kg.

Fig.4 shows cumulative frequency of the gain of the statinary state (when t>>0) between the ground and the first floor. The calculation conditions are four type beams, three kinds of input PSD which were derived from measured railway vibration, three kinds of ground conditions and three kinds of mass.

Median is around 2dB and L10 (L10 means upper value of 80% range of the cumulative frequency.) is around 8dB at the center of the beam. These value well fit measured values [5]. Considering with this method and prediction method for railway vibration [6], it is possible to predict the ground vibration caused by railway trains and the exposure of dwellers to railway vibration.

5. CONCLUSION

The dynamic complex compliance of the ground beneath the foundation was calculated by impedance method and the vibration response of the foundation was calculated with the complex compliance of the ground.

The vibration response of the first floor was assumed to be a vibration response of the beam. The responses were treated as transient non-stationary vibration response, respectively. The results are as follows.

1. The vibration model of the wooden house is possible to treat as combined system of mass concentrated system and simply supported beam.
2. The ground vibration which acts on the foundation decreases at the foundation, but the vibration of the foundation is amplified at the first floor. After all, the vibration of the first floor becomes greater than the vibration of the ground.
3. In the stationary state, the exposure of dweller to vibration was 2dB greater than the ground vibration in L50 (median) and was 8dB greater than the ground vibration in L10. These values agreed approximately with measured values.
4. In the transient state, the vibration which the dwellers receive is greater than measured vibration .

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