HIGH FREQUENCY VIBRATION TRANSMISSION IN STEEL STRUCTURES

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1. Introduction

The problem of structural borne noise in steel bridges is of growing concern. The noise related vibration analysis usually involve low amplitude, high frequency vibration with a high modal density. Furthermore, in welded structures, the determination of vibrational energy transmission through joints is an important issue. Various power flow methods [1], which involve the concept of substructuring, are helpful in explaining the coupling behavior at joints between various parts of the structure. In this paper a mobility based energy transfer model for a welded plate girder, including the energy transfer in bending mode, is presented. A finite element based mobility power flow method (FEMPF) is suggested for the analysis and expression for mobility functions are derived for various substructures.

2. The Mobility Power Flow (MPF) Approach

In MPF [2], the general form of vibrational power equation is

$$P = | F(f) |^2 \ \psi(M) \tag{1}$$

where $| F(f) |^2$ is the spectrum of the forcing function and $\psi(M)$ is the mobility function which is to be defined for each joint in the structure. In general the mobility of a structure at the given point is defined as

$$M_{ij} = \frac{\dot{x}_i}{F_j} = \frac{\dot{\theta}_i}{\Pi_j} \tag{2}$$

where $\dot{\theta}$ and Π are rotational velocity and bending moment, respectively. If $i = j$ then M represents the point mobility. Otherwise it represents the transfer mobility.

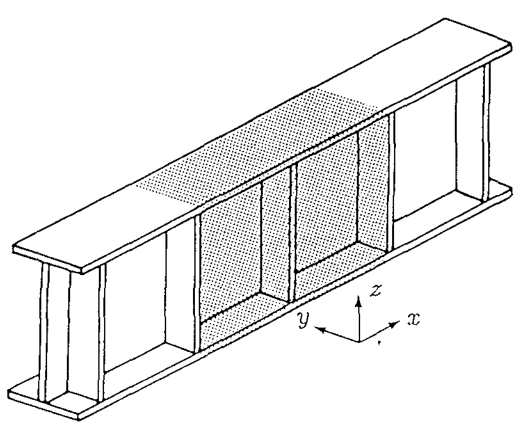

Fig.1 Welded Plate Girder

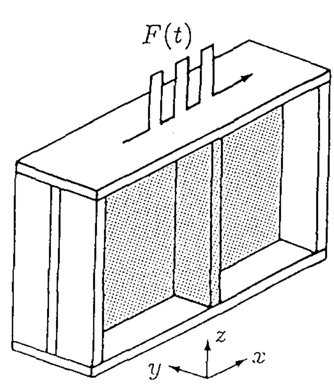

Fig.2 Substructuring of a Periodic Part of the Girder

3. Analysis of Plate Girder by FEMPF

In view of a kind of a periodicity, which exist in railway bridges, only a portion of girder including an intermediate stiffener is considered here as shown by shaded portion in Fig. 1. The substructuring model consist of upper flange, which is regarded as source substructure, the web with attached stiffeners as primary receiver substructure and the lower flange as secondary receiver substructure as shown in Fig. 2. To simulate the impact of train's wheel, the upper flange is subjected to delta function type spike of forces as shown in Fig. 2.

3.1 Determination of Mobility Functions

At this stage we have to define the mobility function for every substructure with respect to each decoupling location. The energy transfer path is assumed to be via upper flange to web and consequently to lower flange in transverse force and bending modes as shown in Fig. 3. We first consider the decoupling between upper flange and the lower part of the structure as shown in Fig. 4. From equilibrium condition of source substructure (upper flange)

$$\begin{bmatrix} M_{1F} & M_{12F} & 0 & 0 & 0 & 0 \\ M_{21F} & M_{2F} & 0 & 0 & 0 & 0 \\ 0 & 0 & M_{1\Pi x} & M_{12\Pi x} & 0 & 0 \\ 0 & 0 & M_{21\Pi x} & M_{2\Pi x} & 0 & 0 \\ 0 & 0 & 0 & 0 & M_{1\Pi y} & M_{12\Pi y} \\ 0 & 0 & 0 & 0 & M_{21\Pi y} & M_{2\Pi y} \end{bmatrix} \begin{Bmatrix} F_1 \\ F_2 \\ \Pi_{1x} \\ \Pi_{2x} \\ \Pi_{1y} \\ \Pi_{2y} \end{Bmatrix} = \begin{Bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{\theta}_{1x} \\ \dot{\theta}_{2x} \\ \dot{\theta}_{1y} \\ \dot{\theta}_{2y} \end{Bmatrix} \quad (3)$$

where M and Π are explained in Eq. 2. The subscripts F and Π are to explain the mobilities as either force or moment mobilities along with their location.
Similarly, from the equilibrium of receiver substructure (web)

$$\begin{bmatrix} M_{3F} & 0 & 0 \\ 0 & M_{3\Pi x} & 0 \\ 0 & 0 & M_{3\Pi y} \end{bmatrix} \begin{Bmatrix} F_3 \\ \Pi_{3x} \\ \Pi_{3y} \end{Bmatrix} = \begin{Bmatrix} \dot{x}_3 \\ \dot{\theta}_{3x} \\ \dot{\theta}_{3y} \end{Bmatrix} \quad (4)$$

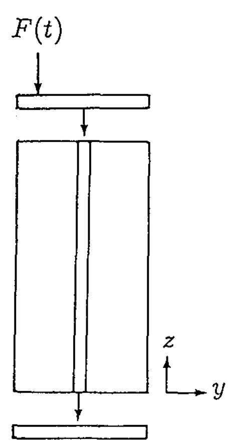

Fig.3 Energy Flow Model

Using the compatibility condition at the coupling location

$$\begin{Bmatrix} F_2 \\ \Pi_{2x} \\ \Pi_{2y} \end{Bmatrix} = \begin{Bmatrix} F_3 \\ \Pi_{3x} \\ \Pi_{3y} \end{Bmatrix} \; and \; \begin{Bmatrix} \dot{x}_2 \\ \dot{\theta}_{2x} \\ \dot{\theta}_{2y} \end{Bmatrix} = \begin{Bmatrix} \dot{x}_3 \\ \dot{\theta}_{3x} \\ \dot{\theta}_{3y} \end{Bmatrix} \quad (5)$$

The expressions for input and transferred power can be expressed as

$$P_{in} = \frac{1}{2} \mid F_1(f) \mid^2 Re\left\{ M_{1F} - \frac{M_{12F} M_{21F}}{M_{2F} + M_{3F}} \right\} \quad (6)$$

and

$$\begin{aligned} P_{tr} = \frac{1}{2} \Bigg[& \mid F_1(f) \mid^2 \mid \frac{M_{21F}}{M_{2F} + M_{3F}} \mid^2 Re(M_{3F}) \\ & + \mid \Pi_{1x}(f) \mid^2 \mid \frac{M_{21\Pi x}}{M_{2\Pi x} + M_{3\Pi x}} \mid^2 Re(M_{3\Pi x}) \\ & + \mid \Pi_{1y}(f) \mid^2 \mid \frac{M_{21\Pi y}}{M_{2\Pi y} + M_{3\Pi y}} \mid^2 Re(M_{3\Pi y}) \Bigg] \end{aligned} \quad (7)$$

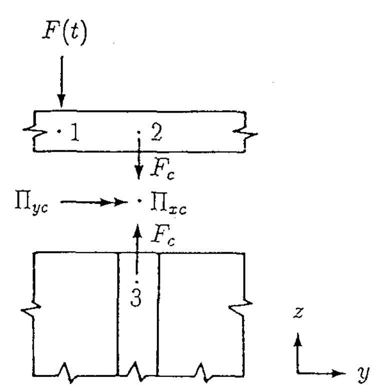

Fig.4 Decoupling of upper flange and web

3.2 Transient Analysis of Individual Substructures

To compute various mobilities appearing in Eq. 6 and Eq. 7 it is necessary to have transient analysis for each substructure. For this purpose a FEM code is being developed for high frequency vibration analysis. Results of the analysis will be shown at the time of presentation.

References

1. Wholever, J. C. and Bernhard, R.J., 'Mechanical Energy Flow Models of Rods and Beams', *Journal of Sound and Vibration.*, 1992, 153(1), pp. 1-19.

2. Cuschieri, J. M., 'Structural Power flow Analysis using a Mobility Approach of an L-Shaped Plate', *J. Acoust. Soc. Am.*, 87(3), March 1990, pp. 1159-1165.