Stabilization of vibrating bridges

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Objeobonable vibratioi cridge decks cause discomfert to pedestrians walking the bridge, reduce the strength of superstructure due to fatigue of materials and damage the wearing surface of the deck.The paper presents suitable means of controlling such vibrations.

It is common experience that many highway bridges after construction are found to generate objectionable vibrations during passage of vehicles over them. Objectionable, from the point of view of discomfort for pedestrians walking on the bridges as also of reduction in strength of the superstructures due to fatigue of materials in their construction. Besides. such vibrations damage finishing layers provided on the surface of deck, that consequently require constant and cosily maintenance. It. therefore, becomes necessary for those bridges that are already built without due precautions during design stage, to devise some suitable means for controlling objectionable vibrations occurring therein.

As an example, it has been found from earlier reports that the vibration occurring in the new Sone River Bridge is very severe during passage of heavy vehicular loads[1].

Philosophy

A simple device for controlling unwary vibrations in a bridge structure would be to provide a body of mass placed thereupon, or connected thereto loosely at midspan, with a view to induce pounding or rebounding effect at intermittent frequency. The minimum weight of the body of mass requires to be carefully assessed for achieving the desired results.

Figure 1 (a) shows a bridge deck under vibration wherein the point Pat midspan has the maximum effect of vibration. The deflections due to self-weight and vehicular loads are represented by δ_w and δ_{st}, respectively, and the amplitude by A.

Figure 1 (b) shows the vertical displacement of deck structure at midspan with respect to time. A mass M_2 placed at midspan and oriented at the position of zero amplitude of structure, is also shown to have its vertical displacement with time, when velocity of upward movement is maximum.

There is a time interval t_o when the deck structure and the mass M_2 come to face an impact at point Q, whereafter both the mass

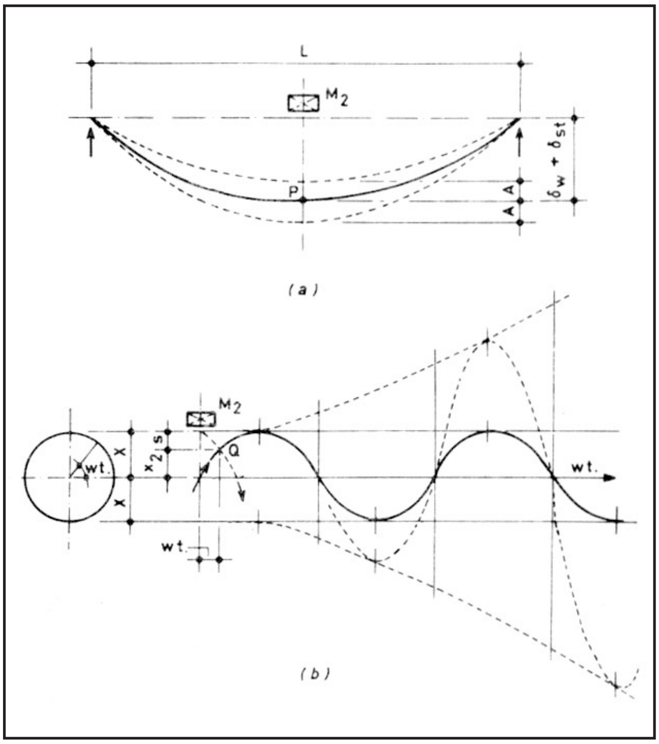

Figure 1. (a) Deflections and amplitude of a bridge deck under vibration (b) Vertical deflection of deck structure at midspan with respect to time

and the structure change their courses of displacement. The amplitude of the structure diminishes after impact with disruption of frequency.

Analysis

The development of process of evaluation for such a device is considered hereunder with reference to Sone River Bridge.

Data

From Ref. 1 and 2

1. Span, L = 108ft = 33m, simply supported
2. Weight of bridge deck, W_B = 380tons = 387tonnes
3. Weight of vehicle, W_V = 20tons = 20.4tonnnes
4. Amplitude of vibration, X = δ_{st} = 0.102″ = 0.259cm
5. Acceleration due to gravity, g = 386in/sec^2 = 981cm/sec^2
4. Natural frequency of bridge, f_B = 3.90cycles/sec
   (t) = 2π x f_B = 24.5red/sec

Vibration properties

1. Desk structure :
   Referring to Figure 1 (b)
   Displacement, $X_1 = X sin\ cot$
   Velocity $V_1 = x_1 = coX cos\ cot$
   Dynamic mass of dect structure.
   $$M_1 = \frac{1}{2}\frac{W_B}{g} = \frac{1}{2}\,x\,\frac{387{,}000}{981}$$
   = 197dynes.

2. Imposed mass, M_2,
   $$s = \frac{1}{2}gt^2 = \frac{981}{2}\,x\,t^2 = 490t^2$$
   Displacement, $x_2 = X - s = X - \frac{1}{2}gt^2$
   $$v_2^2 = (x_2)^2 = 2gs = \frac{2g\,x\,gt^2}{2} = g^2t^2$$
   Velocity, $v_2 = x_2 - gt$

Analysis

Equating vertical displacements,

$$x_1 = x_2$$
$$\text{or } X \sin (i)t = X - \frac{1}{2}gt^2$$
$$0.259 \text{ x } \sin 24.5t = 0.259 - 490\,t^2$$
$$T = 0.0175\text{sec} = t_o$$
$$\text{Co } t_o = 24.5 \text{ x } 0.0175 = 0.429\text{red}$$
$$\text{Thus, } v_1 = \text{coXcos coto}$$
$$= 24.5 \text{ x } 0.259 \text{ x } \cos 0.429$$
$$= 5.77\text{cm/sec.}$$

Also

$$V_2 = gt_o$$
$$= 981 \text{ x } 0.0175 = 17.17\text{cm/sec.}$$

Now, if it were for neutralizing the kinetic energy of the deck structure by that of the mass body at impact then

$$½ M_1 v_1^2 = ½ M_1 v_1^2$$
$$\text{or } M_2 = M_1 (v_1/v_2)^2$$
$$= 197 (5.77 / 17.17)^2 = 22.25 \text{ dynes}$$
$$\text{Required } W_2 = M_2 g$$
$$= 22.25 \text{ x } 981 / 1000$$
$$= 21.83 \text{ tonnes}$$

Practical considerations

Since the rebounds of imposed mass M_2 would continuously provide damping effect to the energy of the structure, full neutralization of the same at the very first impact would not be possible. The mass should be capable of damping the logarithmic increment value in its amplitude. The logarithmic increment is similar to logarithmic decrement value with opposite sign.

It is established from tests on more than 50 existing bridges of various types that the logarithmic decrement value in a structure could be related to its fundamental frequency by the following expression[3].

$$\delta = 0.06\,(l_n f_B)$$

In the present case, therefore.

$$\delta = 0.06\,(l_n 3.90) = 0.082\,;\ \text{i.e., 8.2 percent.}$$

Thus, for Sone River Bridge, the required minimum weight of imposed mass should be

Adjusted W_2 = 0.082 x 21.83 = 1.79 tonnes.

Field tests can, however, be carried out on the existing bridge to assess the exact value of logarithmic decrement, δ.

Practical details

The above load may be accommodated at midspan of the deck structure in various ways, symmetrically disposed on the two sides of the central girder. One of the methods would be to suspend 4 weights of 0.45 tonne each in pairs from the central diaphragm units under the deck slab. Figure 2 shows the arrangement wherein the weights are comprised of steel containers filled in with weak concrete. The clear length of the suspender chains between ends may be around 400mm.

Trial performance

Prior to undertaking the rectification work for the bridge structure,.as indicated in Figure 2, it may be in order to make a trial performance of the scheme. This may comprise of

1. positioning of a vehicle of consolidated minimum weight of 1.8 tonnes along one lane at midspan of bridge, by lifting and placing the same on timber sleeper cribs to eliminate sprung support

2. running a loaded truck of maximum weight (20t or so) over the bridge at maximum permissible speed

3. recording the maximum amplitude and frequency of vibration during such run of vehicle

4. recording similar amplitude and frequency when the truck is run over the empty bridge.

References

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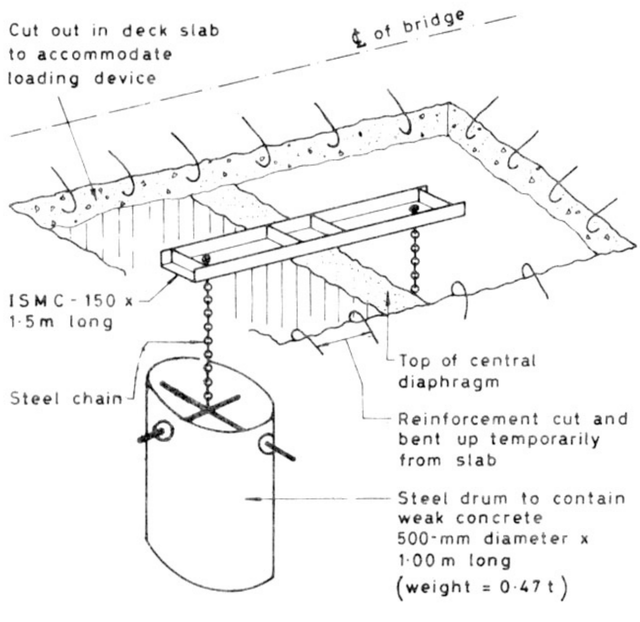

Figure 2. A typical arrangement for controlling vibration in a bridge deck