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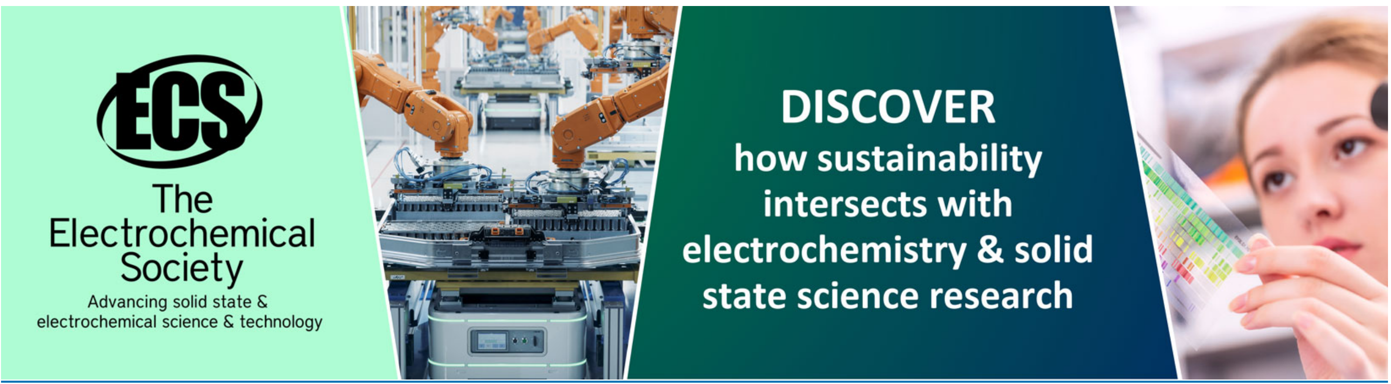

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Damage Identification of Simply-Supported Beam Bridge Based on Deflection Influence Line

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Abstract: In order to extend the service life of the bridge and reduce the occurrence of catastrophic accidents, it is necessary to monitor and identify the damaged parts of the bridge in time. In this paper, the author firstly proposes a basic theory of deflection influence line, then analyzes the calculation basis and proposes a method of deflection influence line of simple supported structure. Finally, according to displacement-time curve of simply-supported beam structure under different load-moving speed can be obtained by using MIDAS, the mid span, damage degree and load-moving speed of structure model can be set to carry out the simulation calculation. The results show that: when the load moving speed is 10km/h, 30km/h, 60km/h and 100km/h, the influence line of deflection difference has no obvious change pattern, and there are different peak values, which cannot be used for damage identification. Under the static load condition, the influence lines of deflection difference at 1/2L position, 3/4L position and end part at 10% and 25% damage degree basically show linear change, while the deflection difference value at 1/2L position appears peak value, and the maximum deflection difference value at different damage positions shows nonlinear change. It indicates that the damage degree can be judged according to the deflection differences at the damage positions identified above.

1. Introduction

As an important transportation infrastructure, bridge always boasts a long service life of over 50 years which is gradually increasing [1]. However, the function of bridge structures will be damaged, and even more serious, catastrophic accidents will occur, due to various factors such as environment, raw materials and fatigue effect[2].

The number of bridge engineering in China is huge. Generally, plenty of money and labor should be invested in the early stage. If the bridge is directly demolished as soon as it is damaged, it will not only cost a lot of money, but also countless property losses, which will bring an unbearable burden to our country's finance. According to the current economic development situation, the most feasible method is to detect the bridge damage and judge the degree in time so that the bridge can be repaired effectively. By doing so, the service life of the bridge can be extended to the greatest extent, and thus the huge loss of manpower and property can be avoided. At present, health monitoring equipment [3] for large bridges has appeared, and good results have been achieved in bridge safety early warning. However, due to the different size and number of bridges in China, the lack of structural internal force data [4], the cost of large bridge health monitoring system is very high, which makes it difficult and impractical to be popularized in China. Therefore, it is necessary to establish an appropriate damage identification method according to the specific characteristics of the bridge.

Based on the theory of deflection influence line and the calculation basis, this paper puts forward the calculation method of deflection influence line of simple support structure, discusses the influence line of various deflection difference under different load speed, and concludes that the damage of bridge beam can be judged by deflection influence line under static load condition.

2. Methods

2.1. Basic Theory of Deflection Influence Line

Therefore, it can be seen from the change of bridge structure's shape and deflection that the change of bridge structure's shape can be seen from the change of bridge's internal structure's shape. According to the deflection influence line theory [5], the number of sensors can be reduced to the greatest extent and the test cost can be reduced. However, because the interference degree of local damage to the overall deflection influence line is very low, a damage identification technology of simple supported beam bridge based on the value of deflection change before and after damage is proposed [6], and within the elastic range, the calculation method of deflection difference influence line can be obtained based on virtual displacement principle [7].

First, calculate the structural displacement under the load. It is stipulated that the structure is stable and the material has elastic properties. According to structural mechanics [8], the calculation method of structural section displacement based on load conditions is obtained, as shown in the following formula:

$$\Delta_P = \sum \int \left(\frac{\overline{F_N} F_{NP}}{EA} + \frac{\mathrm{k}\overline{F_Q} F_{QP}}{GA} + \frac{\overline{M} M_P}{EI} \right) \mathrm{d}s \tag{1}$$

Where "E" represents the elastic modulus, "G" represents the shear modulus, "A" represents the cross-sectional area, "I" represents the moment of inertia of the section, and "k" represents the shape coefficient of the section.

Formula (1) contains two kinds of internal forces: one is that the actual load causes the internal forces (FNP, FQP and MP), and the other is that the imaginary unit load causes the internal forces ($\overline{F_N}$, $\overline{FQ}$ and $\overline{M}$). According to structural mechanics, the positive and negative internal forces are: if the axial force (FQP and $\overline{FQ}$) is tensile force, then it is positive; if the shear force (MP and $\overline{M}$) causes the micro segment to rotate clockwise, it is positive; if the bending moment (FNP and $\overline{F_N}$) makes the fiber on the same side of the member subject to tension, the product is positive.

Secondly, under the action of quasi-static load, there are several calculation methods of structural displacement. The proportion of deformation in displacement varies with different structures. If it is a slight change to the structure, then the calculation method of displacement under different structures can be obtained without considering the calculation. Including: beam and rigid frame and arch structure. Among them, for beam and steel frame structure, the bending moment has a very weak influence on the displacement, axial force and shear force, which is not included in the calculation. For the arch structure, it belongs to the structure of mixed force. If the pressure line is close to the axis of the arch, the displacement distance of the arch is affected by two kinds of deformation. If the pressure line is not close to the arch axis, it is necessary to note the influence of deformation.

Thirdly, when calculating the average shear strain, a correction factor should be added because of the unbalanced distribution of shear stress in the section. According to formula (1), the coefficient is 6/5 if it is rectangular, 10/9 if it is circular, 2 if it is a thin-walled circular ring, and 2 if it is 工-shaped or box shaped.

2.2. Calculation Basis of Deflection Influence Line

The influence line of internal force is proposed based on the deflection influence line related to the structure, such as bending moment and shear force. Taking the load position along the beam length direction on the simple support structure as the abscissa and the vertical displacement of the measuring point as the ordinate, the curve formed by the two is the deflection influence line of a point of the simple support. In the process of simple support deformation, bending moment will cause structural deformation, and the deformation degree caused by shear force and axial force is very small, which is not included in the calculation scope. Only the bending deformation caused by bending moment and bending moment under concentrated moving load need to be calculated, and then the deflection here can be calculated. The location of moving load is shown in Figure 1 below.

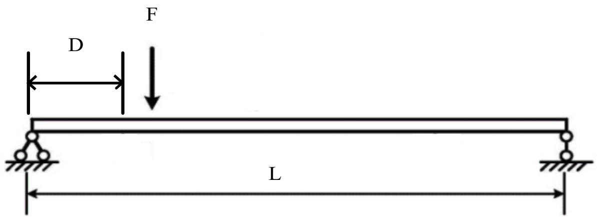

Fig. 1 location of moving load

The above figure shows the simply supported structure under moving load F, L is the structure span, and D is the distance from the moving load to the left end. Assuming that the position of the upper section of the simply supported structure is A, the bending moment H of any section can be calculated according to formula (1), as follows:

$$H=\begin{cases}\dfrac{L-D}{L}FA & 0 \le \mathrm{A} \le \mathrm{D} \\ -\dfrac{DF}{L}A+FD & \mathrm{D} \le \mathrm{A} \le \mathrm{L}\end{cases} \tag{2}$$

2.3. Calculation Method for Deflection Influence Line of Simple Support Structure

From formula (1), we can know that the action position of F will affect the bending moment of any section of simply supported structure under the action of moving load F. According to the relevant literature, the position of the displacement point to be calculated will affect the bending moment of the simple support structure under different load conditions [9]. Therefore, the influence factor of deflection influence line belongs to the damage part of simple support structure and the part of deflection test. If the deflection influence line is required, it is assumed that the local damage part of the bridge structure is B, and the compressive strength near the location will be reduced due to small damage. The stiffness of the structure before damage is G, and the reduction value of the stiffness in the damaged area is G', the distance between the desired point R and the left end is S, and the range of the area near the damage point is [C, E] According to the damage position of the simple support structure and the orientation of the deflection measuring point, combined with formula (2), the calculation method of the structure deflection influence curve is as follows:

$$k_R=\frac{1}{G}\int_0^D\frac{L-D}{L}FA\frac{L-S}{L}A\cdot r_A+\frac{1}{G}\int_D^S\left(-\frac{DF}{L}A+FD\right)\frac{L-S}{L}A\cdot r_A$$
$$+\frac{1}{G}\int_S^C\left(-\frac{DF}{L}A+FD\right)\left(-\frac{S}{L}+S\right)\cdot r_A+\frac{1}{G}\int_C^D\left(-\frac{DF}{L}A+FD\right)\left(-\frac{S}{L}+S\right)\cdot r_A \tag{3}$$
$$+\frac{1}{G}\int_D^L\left(-\frac{DF}{L}A+FD\right)\left(-\frac{S}{L}+S\right)\cdot r_A$$

If the damage occurs in some areas of the simple support structure, the bending resistance of the damaged area will be reduced, and the bending stiffness of the section without damage will not be affected. By changing the section bending stiffness G to G', the calculation method of the influence line of damage deflection in small range of simple support structure can be obtained.

Then, according to formula (3), the calculation formula of deflection difference V of simple support structure can be expressed as follows:

$$V=\left(\frac{1}{G'}-\frac{1}{G}\right)\int_C^D\left(-\frac{DF}{L}A+FD\right)\bullet\left(-\frac{S}{L}+S\right)\cdot r_A \tag{4}$$

2.4. Simulation Calculation

In practical bridge engineering, the influence line of bridge deflection can be calculated according to vehicle motion loading. The deflection influence line may be disturbed by the impact effect of loaded vehicles, which will eventually affect the damage identification effect of bridges. In order to solve the above problems, the displacement time history curves of simply-supported beam structure under different load moving speeds are obtained according to MIDAS [10]. Through the time of load acting on different nodes of the simple support structure, the mid span deflection is calculated, and the influence line of the difference between the mid span deflection and the deflection difference of the non-damaged simple support structure is subtracted to obtain the influence line of the mid span deflection under different load moving speed, so as to analyze the influence degree of the load moving speed on the damage identification effect. In this paper, the calculation model is simply supported T-shaped interface beam with a length of 20 meters. It is divided into 20 units by MIDAS, as shown in Figure 2.

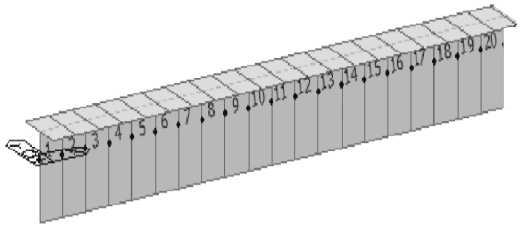

Fig. 2 Calculation Model

As shown in the figure above: (1) take three units in the area of 10m-11.5m in the middle of the span of the structural model, and set the damage degree as 25%, and take the quasi-static load, 10km/h, 30km/h, 60km/h and 100km/h respectively. (2) When the damage location is identified, the damage degree is set as 10% and 25% respectively in 1/2 of L and 15 at 3/4 and 20m at the end under quasi-static load.

3. Conclusion

3.1. Influence Line of Deflection Difference under Quasi-Static Condition

When the load speed is quasi static force, the influence line of deflection change value is shown in Figure 3.

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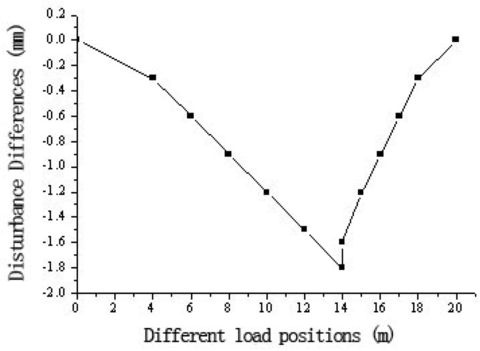

Fig. 3 influence line of deflection change value under quasi-static condition

It can be seen from the above figure that when under static load, the influence line of deflection change value is relatively stable, in a linear change state, and there is a single peak value in the middle of the span. Therefore, it can be judged that the damage location can be identified, which is the same as the damage location set by simulation.

3.2. Influence Line of Deflection Change Value under Different Load Rate Values

The influence line of deflection change value under the conditions of 10 km/h, 30 km/h, 60 km/h and 100 km/h is shown in Figure 4 below.

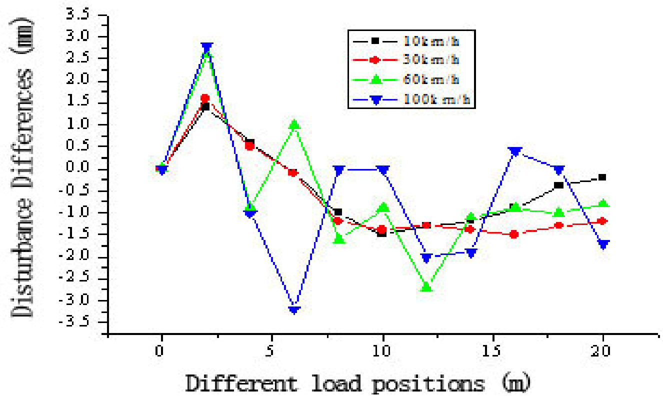

Fig. 4 influence line of degree difference under different load speeds

It can be seen from the above figure that when the change speed of load distance exceeds 60km/h, the change rule of deflection change value influence line cannot be seen, and damage identification cannot be carried out due to many peaks. When the load distance change speed is 30 km/h, the amplitude fluctuation of the influence line of deflection change value is significantly reduced, but there is fluctuation in the area of 0m-5m, and the structural damage cannot be identified. When the load moving speed is 10km/h, the influence line of deflection change value is relatively gentle, but there is also a peak value, which cannot be used for damage identification. That is to say, the influence of the speed of load distance change on the deflection change value influence line is relatively deep, which makes the deflection influence line fluctuate greatly. With the increase of load distance change speed, the deflection change value will also increase.

According to the relevant theory, the peak position of the curve is the location of damage identification. Compared with the damage location specified above, the damage location identification by deflection change value influence line moves backward, which may be due to the different load movement speed, which makes the identification change value. When the structure is stable, the influence line of deflection change value is relatively stable There is a linear change and a single peak in the middle of the span, which can identify the damaged parts.

3.3. Damage location identification

Under quasi-static load, the damage location map and the influence lines of deflection difference with 10% and 25% of the damage degree at 1 / 2L, 3 / 4L and end are shown in Fig. 5 and Fig. 6

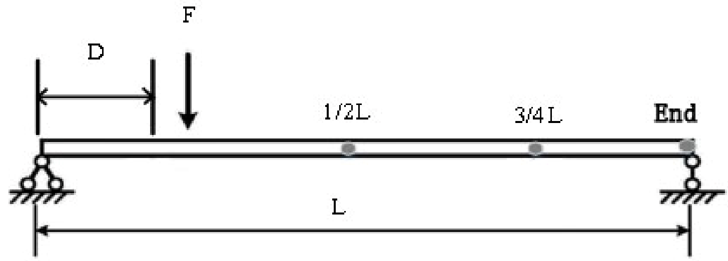

Fig. 5 damage position of simple support under quasi-static load

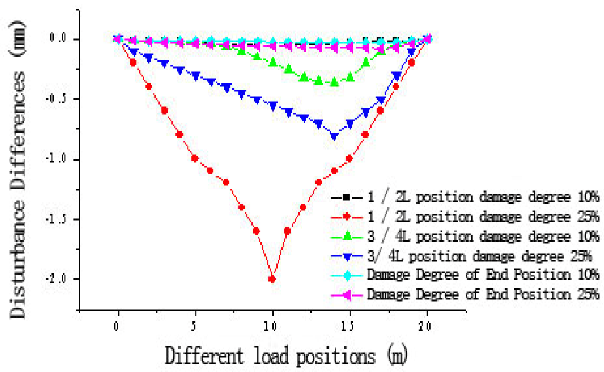

Fig. 6 influence lines of deflection difference under different positions and different damage degrees

Then the maximum deflection difference of 1/2L position, 3/4L position and end under different damage degree can be obtained, as shown in Figure 7.

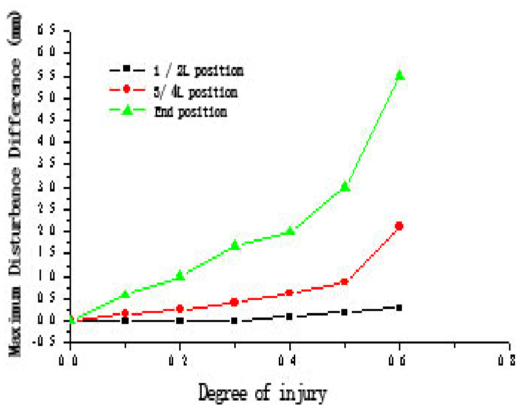

Fig. 7 curve of maximum deflection difference under non-stop position and different damage degree

It can be seen from Figure 6 above that the influence lines of deflection difference at 1/2L position, 3/4L position and end part show linear change when the damage degree is 10% and 25%, respectively. When the damage area is 1/2, the deflection difference value has a peak value, and the damage location can be identified here. It can be seen from Figure 7 that the maximum deflection difference of

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different damage locations does not change linearly when the damage degree increases, indicating that the damage degree can be judged according to the deflection difference at the damage location identified above.

4. Conclusion

In this study, numerical simulation is used to analyze the influence line of deflection difference of simple support structure under different load moving speed. The results show that when the load speed is relatively high, the range of deflection difference influence line is relatively large, which will produce a long time of free vibration, resulting in a lot of numerical peaks on the deflection difference influence line, which leads to no method for damage identification. When the load speed is small (less than 10km/h), the damage location can be identified according to the position of the numerical peak on the influence line caused by the deflection change value.

Due to time and personal reasons, there are still some deficiencies in this study. The lack of multiple identification or the identification of specified parts in the damage identification will affect the comprehensiveness of the research results, which is also the focus of the next research.

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