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A Review of Vibration Based Techniques for Bridges

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ABSTRACT

In order to examine how structures react to severe events such as natural or man-made disasters, structural health monitoring, or SHM, systems have been created and implemented. In addition, the ever-increasing number of people who use bridges and the ever-growing size of the vehicles that utilize them may rapidly cause the structures of bridges to become damaged or even collapse. Therefore, structural monitoring and dynamic characteristic studies of bridge structures are vital necessities for ensuring the safety of bridges. SHM has the capability of overcoming the shortcomings of visual examination procedures, such as a lack of resolution. On the other hand, considerable amounts of SHM data have been inadequately understood, mostly as a result of computing constraints as well as the absence of methodologies for data analysis. The so-called "health condition" of bridge structures is evaluated using SHM of bridges based on dynamic properties in this particular piece of research. A complete SHM system that makes use of vibration-based approaches and modal identification has been successfully established for bridge constructions. The techniques for evaluating bridge safety, including damage detection and load-carrying capability, are given a thorough examination here, along with some more advanced ideas and application areas. When it comes to the process of building a database for the management of bridges, the authority or structural owner now has an advantage since for the first time, the benefits and drawbacks of each vibration approach have been thoroughly examined. After that, this information may be put to use for continuous structural monitoring in order to evaluate and forecast the status of the bridge structure.

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INTRODUCTION

In recent years, because to significant advancements in sensor technology, numerical modeling methodologies, and technology for damage detection, structural health monitoring, often known as SHM, has been extensively employed in bridge infrastructures (Xu et al., 2014). SHM technology can continuously provide reliable state of bridge structure and response information, identify deterioration and damage during design and construction, assess the effect of this damage on the bearing capacity and reliability of the bridge structure, and provide overload and damage warning information for bridge structure operations and maintenance decisions. All of these benefits can be realized through the application of SHM technology. As a direct consequence of this, the use of SHM technology has developed into an increasingly effective method for determining the state of a bridge's structural integrity. Because of developments in sensor technology and electrical infrastructure, there has been a recent uptick in people's awareness of vibration-based SHM systems for highway bridges, as well as an increase in familiarity with these systems. FIG. 1 is an illustration of the use of vibration-based SHM in a range of fields, with the most prevalent application being in the field of civil engineering.

LITERATURE SURVEY

Vibrations on bridge structures may be induced by dynamic loads, such as those caused by human and vehicular activity, wind, and weather power, and other factors; as a result, the vibration analysis of a bridge's structure is an essential component of the study of a bridge's structure. It is essential to conduct a thorough inspection of the condition of a bridge in order to guarantee its ongoing dependability, durability, and operational usefulness. This demands an accurate examination of the operation of the bridge with the most recent diagnostic tools available. The applications of these approaches are able to detect the existence of damage, pinpoint its position, and quantify the damage levels, which together are referred to as damage detection and characterization for maintenance operations (Mousavi et al., 2021).

The absence of a baseline derived from type testing or the time-consuming and expensive qualification processes that are relevant to bridge building presents a significant challenge when it comes to the creation of a SHM method for civil infrastructure. The method and the gadgets that are used ought to be simple, not time-consuming or labor-intensive, cost-effective, and easy to employ in practical settings. As a consequence of this, one of the distinguishing characteristics of SHM for civil infrastructure is that a significant component of the system has to be centered on a long-term assessment of what constitutes "normal" structural performance or the "health state condition" (Aktan et al., 2001). An SHM method was developed by Magalhees et al. for the Infante D. Henrique Bridge in Portugal, which is a 280-meter concrete arch bridge, in order to evaluate the effcacy of modal parameter tracking for bridge SHM (Magalhees et al., 2012a). The objective of this study was to determine whether or not modal parameter tracking is effective for SHM. The SHM system is included in the Te Lupu Bridge, which is the world's second-longest arch bridge in length. It is constructed out of steel and is designed in the form of a half-trough tied-arch. In order to ascertain the condition of the bridge, the monitoring system took readings of acceleration, temperature, wind pressure, and strain (Sun et al., 2009).

It is vital to choose the key components that are to be analyzed, and these parameters need to be measured in the correct manner in order to give the findings that are sought. The dynamic characteristics of a high-speed railway arch bridge in China known as the Dashengguan Yangtse bridge were investigated by Ding et al. using data that was obtained by a SHM system (Sun et al., 2009).

If the dynamic properties of the bridge structure are understood, then it is possible to prevent failures from occurring. The natural frequencies, damping ratios, and mode shapes of a structure are the three parameters that may be used to categorize the dynamic properties of the structure. In order to correctly define the structure's dynamic behavior, it is necessary to determine certain modal features.

On the other hand, there is a paucity of published material on the subject of the large-scale use of an effective SHM strategy.

(Alamdari et al., 2016) Alamdari et al. suggested a significant SHM deployment for the 503-meter-long Sydney Harbour Bridge. Using data obtained from the SHM system, an evaluation was conducted to determine the level of performance and structural degradation of a sample of 800 jack arches that are placed under traffic lane 7. During the course of the last decade, SHM system implementations for large bridge building projects have been created in Japan, Hong Kong, and, subsequently, in the United States of America. This is as a result of the fact that SHM systems have a significant amount of potential in terms of acquiring insight into the state of the structures that make up bridges (Wong, 2004).

Recent research developments pertaining to the SHM of civil infrastructures are analyzed and discussed in this study. The benefits and limitations of the methodologies are brought to light by the periodic examination as well as the findings obtained by earlier researchers. As a consequence of this, there is potential for increased awareness of the methods. This work was intended to give a pretty extensive literature and background assessment of bridge dynamic features in vibration-based SHM. The goal of this review was to raise overall awareness of the subject matter. This contribution will provide individuals with varying levels of knowledge in the field with a helpful chance to assess bridges using a dynamic approach. The following are the primary focuses of this paper: (3) vibration-based SHM for detecting damage and structural capacity. (1) Determination of dynamic characteristics using dynamic testing methods, which include forced and ambient vibration tests. (2) Existing modal identifcation (MI) algorithms for identifying the dynamic properties of a structure based on measured data.

The Dynamic Examination

Testing structures at their full size with a dynamic load may offer significant information on the behavior and performance of structures in service. Because of the growing concern for the structural integrity of highway bridges, dynamic testing could become an option for determining the current operational status of bridges. From the field of mechanical engineering, which has traditionally been responsible for research into dynamic phenomena and experimental modal analysis, a variety of testing techniques and algorithms have been borrowed. It is possible to determine modal characteristics, such as natural frequencies and mode shapes, based on the observable dynamic response that is brought on by free, forced, or ambient stimulation (Fig. 2). It is recommended to do an analysis of the many methods that are accessible.

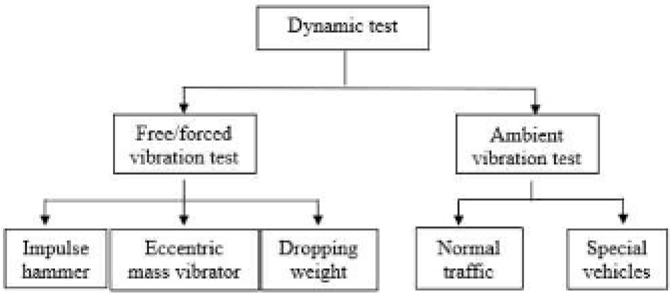

Fig 1 Illustration of the excitation instrument based on the characterisation of the dynamic test

MODELLING

The before choosing an acceptable testing technique in terms of its relevance to a bridge monitoring system. out before picking an appropriate testing method.

The approach used to excite the structure is the primary criteria for consideration in this comprehensive dynamic test of bridge monitoring.

The level of control that one has over the input excitement serves as the foundation for classifying the various types of stimulation. The dynamic testing approach known as forced vibration testing is characterized by the fact that the excitation is artificially created (FVT). The forced vibration test is a kind of test that is often referred to as a test with controlled input, however it is not quantified. The term "ambient vibration testing" refers to procedures in which the input stimulation is not under controlled conditions. The size of the structures that need to be examined will determine the kind of excitation devices and instruments that will be employed. In this section, the advantages and disadvantages of the selected testing techniques (Table 1), as well as the range of their application in bridge monitoring in terms of testing equipment, data processing, and analyzing dynamic parameters, are explained. Additionally, some examples of practical application are provided to demonstrate how these techniques can be put into practice.

The Vibrational Shock Wave Test

Several research have looked at the possibility of using FVT in conjunction with experimental modal analysis to detect damage in already-built civil structures. This approach employs input excitation with specified force values at predetermined frequency ranges. As a matter of fact, the experimentalist is in charge of the input. The benefit that forced vibration testing provide is the reduction of the effects of extraneous noise on the reported structural response. The input loading may be altered to meet the specifications of the test.

It is possible for an impulse hammer (Fig. 3a), eccentric rotating mass vibrators (Fig. 3b), or an impulsive shaker to stimulate the vibrations of the bridge (Fig. 3c). Te excitation technique is greatly impacted by the robustness of the bridge as well as the required level of intensity in the excitation.

Fig 1 Forced vibration test excitation technique

Excitations may be produced in buildings that are either tiny or medium-sized by using an impulse hammer, which is a tool that is currently employed in the field of mechanical engineering. This method is both the simplest and most effective way to excite the structure since it provides a wide-band input that may set off a variety of vibration patterns and because it does so in a single step.

In the study that was conducted by Maguire and Severn (1987), a 5.4-kilogram instrumented sledge hammer was used to evaluate four bridge beams that each weighed 40 tons. It was calculated that the hammer had a maximum impact force of 22 kilonewtons. According to the findings of this research, hammer testing is a method that may determine the as-built structural dynamic properties in a quick and accurate manner. The impact hammer's mass has to be increased in proportion to the growing size of the bridge. When high force levels are applied, however, the impact hammer presumably runs the danger of causing local damage at the location where it makes structural contact since it has a larger impact mass. An impact hammer was used to excite a steel footbridge with low-amplitude wide-band excitations during the FVT experiment that was conducted by Bayraktar (Bayraktar & ahin, 2014). The experiment was conducted on a steel footbridge. According to the findings of this research, the use of an impact hammer as the excitation for FVT produced the greatest results for short bridges with spans that were less than 30 meters.

An eccentric mass vibrator is one of the first contacting vibrators for FVT, and it has been employed for a number of years. This kind of vibrator is used as the source of excitation rather than an impact hammer (Jeary & Sparks, 1977). It is possible to adjust the input loading in order to fulfill the criteria of the test. One example of this is the loading that comes from an eccentric mass vibrator. Vibrator machines have the potential to be an effective solution for constructions ranging from slabs to footbridges that fall into the smaller to medium-sized category. These machines generate vibratory forces by using a spinning shaft that is coupled to a mass that has its center of mass displaced from where the shaft's center of rotation is located. Either a circular or rectilinear motion may result in the generation of the force known as Te. In actual laboratory application, eccentric mass shakers have only seldom been put to use to impart stresses in the vertical direction. By altering the speed at which the shaft rotates, it is possible to use the vibrator machine at a selection of different frequencies. It is necessary to have proper control over the speed of the shaft in order to get effective outcomes. In addition, Zwolski and Bien exploited the inverter powers of the rotating eccentric mass exciter to provide great control of the rotational speed as well as the excitation frequency (Zwolski & Bie, 2011). Depending on the kind of inverter that is used, the frequency of the rotating eccentric mass (REM) exciter may be regulated with a precision of

0.006 Hz. Other forced vibration tests that were performed at the Bosporus suspension bridge were only partially successful because the exciters were unable to produce sufficient force at frequencies lower than 1 Hz. This is the frequency range that is of interest for suspension bridges (1 Hz), so the inability of the exciters to produce sufficient force limited the success of the tests (Brownjohn et al., 2014). In a nutshell, eccentric mass shakers are not an appropriate choice for major bridge constructions like suspension and cable-stayed bridges since these types of bridges need hefty excitation equipment in order to be excited. Consequently, servo-hydraulic shakers are proposed as a solution due to the fact that they are capable of delivering wide-band stimulation throughout the majority of the preferred frequency ranges. A long wooden footbridge was stimulated by a servo- hydraulic vibrator with a peak pressure amplitude of +5 kN at frequencies>2.3 Hz. This was done with the intention of confirming the design assumptions that were made (Gentile & Saisi, 2011). In general, servo-hydraulic shakers are capable of producing bigger force levels, but they have difficulty producing excitations at frequencies that are higher than 100 Hz.

In spite of this, electrodynamic shakers have difficulty producing force at lower levels and are challenged by lower frequency excitations. A steel bridge in Virginia, United States of America, was subjected to a dynamic evaluation, which was carried out using an electrodynamic shaker (Chang et al., 2001). Because of this, only the first two modes of vibration were found, while higher modes remained undetected.

that have inherent frequencies greater than 7.5 Hz are unaffected by the excitations that are created by foot traffic because these frequencies are over the threshold. All variations of shakers need for considerable support structures, which may include cooling systems, control hardware, and power supplies. These components are often expensive and difficult to relocate. In addition to this, shakers are required to have a certain quantity of space.

As a consequence of this, a comparison and contrast of the advantages and disadvantages of FVT is shown in Table 1.

Ambient Vibration Test

Other methods for MI have been developed through the utilization of natural excitation from natural resources such as wind, waves, car or pedestrian activity, or any other service loading, in particular for large structural bridge applications. These other methods for MI have been successful in reducing the effects of service loading. These strategies have proven beneficial in decreasing bridge maintenance expenses. By using ambient excitation instead of mechanical excitation devices, it is possible to avoid the use of mechanical excitation devices. This is because the use of ambient excitation eliminates the need for the extremely cumbersome and pricey equipment that is required for the forced excitation of massive bridge structures. Gentile and Saisi employed a method that was based on ambient vibration in order to study the structural status of the medieval masonry bell tower that is located close to the Cathedral of Monza and determine the possibility for damage to the structure (a town about 20 kms from Milan, Italy).

The dynamically based evaluation takes into account both theoretical and experimental modal studies (Gentile & Saisi, 2007).

The efficacy of the ambient vibration measurements that may be acquired from the experimental testing setup is significantly impacted by the kind of equipment that is utilized in the setting as well as the characteristics of that equipment. When seen from this angle, making sure that the accelerometers and digitizers that you use are the right ones is of the highest significance. When selecting the kind of sensor to install, such as a strain gauge, accelerometer, thermometer, or data gathering system, it is important to take into mind the objective of the test. These tests include characterizing the physical and chemical parameters of the materials, such as temperature, cracks, humidity, pH value, and corrosion. They also include characterizing the mechanical parameters of the materials, such as ambient temperature, wind, load condition, and static and dynamic characteristics

(Pardi & Togersen, 2002). As can be seen in Table 2, the monitoring objective, the available budget, and the physical constraints all play a role in determining the kind of sensor that will be put in place.

Sensor kinds such as seismometers and accelerometers were used in the bulk of the previous research that were carried out on the complete scale of ambient vibration ways. These investigations were carried out earlier. The accelerometers need to be able to meet all of the following requirements:\sI frequency bandwidth between DC and 50 Hz (ii) very low peak-to-peak noise (if it is at all possible, less than 2 microg); (iii) high sensitivity (at least 1 V/g); and (iv) low fullscale range (+/0.5 g, lower or configurable). (Cunha et al., 2012). With the assistance of eighteen uniaxial piezoelectric accelerometers that had a sensitivity of 10 V/g and a peak acceleration of 0.5 g, the dynamic properties of the Paderno iron arch bridge, including its natural frequencies, mode shapes, and damping ratios, were analyzed. These properties include the bridge's natural frequencies, mode shapes, and damping ratios. The sensitivity of these accelerometers was ten volts per gram (Gentile & Saisi, 2011).

The most important mode forms, as well as the natural frequencies that go along with them, were successfully taken from the study after having their linked natural frequencies determined in the frequency range of 0–10 Hz. In a separate piece of research (Chang et al., 2001), ambient vibration testing (AVT) was conducted on a long-span cable bridge in Hong Kong in March 1997, after surface paving work had been completed on the bridge deck. This testing took place after the bridge deck had been subjected to surface paving work. As a component of the AVT, this was carried out. A total of twenty-one accelerometers, one anemometer, a twenty-four channel data gathering system, and triaxial signal cables were used in the conducting of the experiments.

This shows that the following components are commonly included in a basic ambient or free vibration bridge testing system: I a collection of sensors, most frequently accelerometers and seismometers; (ii) a data collecting system (an analogue to digital converter) that is able to digitize the analogue signal; and (iii) a single computer that is responsible for organizing the data, as shown in Fig. 4. I a collection of sensors, most often accelerometers and seismometers; (ii) a data collecting system (an analogue to digital converter) that

These tests involve measuring the structural response under ambient excitation by placing one or more stationary reference sensors along with a collection of roaming sensors at various measurement sites along the structure in a variety of different configurations. This is done in order to determine how the structure reacts when subjected to the excitation. The location of the fixed reference sensors along the construction is completely up to the user. The number of points that are used is determined by the spatial resolution that is required to accurately characterize the form of the most significant modes of vibration (based on preliminary FE modeling), while the reference points must be sufficiently far away from the corresponding nodal points in order to be accurate. The spatial resolution that must be met in order to adequately identify the shape of the most important modes of vibration is what determines the number of points that are employed in the analysis. As can be seen in Figure 5, the deck of the 750-meter-long long-span cable bridge in Hong Kong has been split into seven measurement parts at intervals of 53 meters. In order to get accurate results from each measurement, two places on the upper bridge deck, one on each side of the cross-section, were placed in direct opposition to one another. For each and every one of the measurements, a sampling frequency of 50 Hz was used. The configuration of the measurement locations was confirmed by utilizing the mode shape acquired from the prior FE investigation in order to retrieve the frst 30 natural frequencies at the bulk of the measurement sites (Chang et al., 2001). Bayraktar et al. collected data on the structural responses in the vertical, lateral, and horizontal directions at adequate locations on the steel footbridge deck.

CONCLUSION

Over the course of the last several decades, there have been a significant number of investigations on vibration-based technologies. This state-of-the-art review study has concentrated on dynamic testing procedures, MI algorithms to analyze the observed data, damage detection, and an assessment of the load-carrying capacity based on vibration SHM. These topics were chosen because they are at the forefront of the field. After looking at the work that has been done in the past, we have come to the following conclusions:..

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