Int. j. adv. multidisc. res. stud. 2022; 2(5):748-754

Received: 06-09-2022
Accepted: 16-10-2022

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Application of ambient vibration experimental analysis on large structures

Kamalaldin Fadhil Hasan
Northern Technical University, Kirkuk, Iraq

Corresponding Author: **Kamalaldin Fadhil Hasan**

Abstract
The ambient vibration measurement is a kind of output data-only dynamic testing that employs natural environmental stimulation sources like traffic and wind. Since input data cannot be used, an output-only modal analysis approach must be used for testing in an ambient vibration environment. When doing modal analysis using output-only data, it is necessary to use a specialized modal identification approach that can handle extremely tiny magnitudes polluted by noise. There are two modal analysis techniques used, and they are complimentary. In the frequency domain, we have the relatively straightforward peak picking (PP) approach, while in the time domain, we have the more complex stochastic subspace identification (SSI) method. This article discusses the use of experimental modal analysis and ambient vibration testing on major civil engineering constructions. These two examples are a 15-story reinforced concrete shear core building and a concrete-filled steel tubular arch bridge. The findings demonstrate that both methods are capable of accurately pinpointing the frequencies. In most circumstances, the stochastic subspace identification methodology provides more realistic mode shapes and can discover frequencies that would otherwise be overlooked by the peak selecting method.

Keywords: Engineering structures, Stochastic subspace identification, Ambient vibration, Modal analysis

1. Introduction
In more sophisticated fields of mechanical and aeronautical engineering, parameter identification by dynamic measurements was first created. There is evident value in attempting to use this technique in civil engineering contexts, where we are dealing with challenges that are vastly different in size, logistics, and reasoning from their mechanical and aeronautical engineering equivalents. Buildings and bridges are only two examples of the enormous and intricate structures that civil engineers work with. Therefore, the created parameter identification methodology has to be suitable for usage in such massive buildings and more efficient than previous methods. When testing a brand-new, sizable piece of infrastructure, there is always something novel, unexpected, or otherwise interesting to learn and share [1].

Civil engineering constructions may have their modal properties (such as their frequencies, damping ratios, and mode shapes) determined experimentally by means of dynamic measurements.

These modal parameters will be used as input or foundation for finite element model updates, damage detection and localization, structural health monitoring over time, and risk assessment in the face of extreme conditions like earthquakes and wind. There are primarily three categories of structural dynamic testing, and they are as follows involves the use of mechanical excitation, such as shakers or drop weights, to cause the structure to vibrate. Creating a state of free vibration in a structure requires nothing more than an abrupt reduction in the applied load. Artificial stimulation techniques have the drawback of requiring lengthy traffic shutdowns. This might cause significant issues for heavily used infrastructures. However, traffic and wind-induced disturbances are used in ambient vibration testing as natural or environmental excitation, therefore this method is unaffected by the disturbances on the buildings. This method may be used without disrupting the service in any way. It's meant to mimic how the building really functions while it's in regular usage [2, 3].

Frequency response functions (FRFs) in the frequency domain and impulse response functions (IRFs) in the time domain are used for modal which is dynamic responses (outputs) of civil engineering constructions are the direct recordings of sensors placed at various places. However, it is more difficult to estimate under operating conditions. Input excitation forces operating on a real big structure are notoriously hard to quantify. In certain circumstances, associated however technique, structural complexity possible limit the use of such systems. Real-world operating conditions for complicated structures may vary greatly from idealized laboratory settings. This is why it is important to be able to recognize modal models in the context of actual operational settings [4, 5].

Since no machinery is required to stimulate the structure, dynamic testing based on output-only data has the benefit of being low-cost. The ambient vibration test is an example of a dynamic test with no input data required. In the field of civil engineering, the identification of modal parameters by measurements of ambient vibration has recently emerged as a hot issue. Numerous large-scale bridges, including the Golden Gate Bridge, the Faith Sultan Mehmet Suspension Bridge, the Tsing Ma Suspension Bridge Bridges, the Vasco da Gama Cable-Stayed Bridge, the Kap Shui Mun Cable-Stayed Bridge, the Roebling Suspension Bridge, the steel girder arch bridge (Ren *et al.*). Only response data is collected during ambient vibration testing, but the real loading circumstances remain a mystery. Therefore, an output-only approach is required for a modal parameter identification technique [6, 7].

Offers difficulty necessitates the use of unique methods that handle tiny polluted information about input forces. Advanced rapidly during the last several decades. Several methods for identifying modal parameters using only output data have been developed by various researchers for various purposes. These methods include peak picking from power spectral densities, an ARMA model for discrete-time data, the natural excitation technique (NExT), and stochastic subspace identification. In order to evaluate the dynamic features of an actual building under operational settings using ambient vibration data, a conducted methodology [8, 9].

Mathematical foundation of these output-only modal parameter identification approaches is generally rather similar. Implementation details like data reduction, equation solvers, matrix operation order, etc. are often to blame for the discrepancy. That being the case, the issue of how these various methods of structural analysis stack up against one another when applied to actual buildings emerges. In order to assess the dynamic properties of an actual building or bridge under operational circumstances, modal parameter identification algorithms are compared in this research using ambient vibration data. Two system identification strategies employed include method. No attempt made choose victor amongst the several approaches to system identification that may be made using ambient vibration data. The objective emphasize reality some strategies may actual use. Nature of the intended use is the only determinant of the best approach [10, 11].

2. Identification of Modal Parameters Based Solely on Output

Because input forces are not recorded during ambient excitation testing, FRFs and IRFs cannot be directly calculated from the results. Two modal parameter identification strategies suitable for use with measurements of environmental vibration presented in the study. The first is a straightforward technique called "peak picking" (PP). Approach perhaps due to, despite certain theoretical disadvantages. The supplementary nature of the alternative strategy is apparent. Stochastic subspace identification (SSI) is a cutting-edge technique that takes longer than peak selection but produces more reliable outcomes. Two experimental modal parameter identification methods and their underlying theory are briefly discussed.

Achieving Success through Careful Selection of Peaks (PP)

When it comes to determining characteristics that exposed peak pick technique simplest approach. Beginning with the observation that the FRF reaches its maximum and minimum values around the natural frequencies, the approach founded. As a rough measure of the system's frequency, we may look at how often this extreme number happens. It is the auto spectra of the ambient outputs that take the role of the FRF while taking vibration measurements in their natural environments. in provide a straightforward method for identifying the natural frequencies (ANPSDs). In order to acquire the ANPSDs, we first discretize the acceleration measurements using the Fourier transform. This shifts the accelerations into the frequency domain (DFT).

This issue is often worked around in ambient vibration testing by using in which signal from the treated the. Additionally, it provides operational forms that are not the mode shapes but typically correlate to them, which helps in the discovery of resonances. High signal-to-noise ratios at resonance frequencies cause the coherence function estimated for two concurrently recorded output signals to have values close to one. As a result, the coherence function may be inspected to help choose the frequencies.

The present peak-picking approach relies on the values of the to calculate the mode shape components. It's important to keep in mind that in refers to recorded mobile. Consequently, the output of any with respect presumed there is a single dominant mode in the dynamic response near resonance. This assumption becomes more correct as mode separation improves and structural damping decreases.

As a method based on the frequency domain, peak picking has its uses. The frequency domain algorithms are the most widely used because of their efficiency and ease of implementation. However, these algorithms often average out time series data, losing a great deal of nuance in the process. Some theoretical problems exist with the peak-picking method:

- Peak selection is an inherently subjective process;
- Rather of obtaining mode forms, operational deflection shapes are obtained;
- The approach can only be used to infer genuine modes or proportionately damped structures;
- Predictions of damping effectiveness are quite questionable.

Despite its disadvantages, the peak-picking method has found widespread use in many civil engineering contexts. The ease with which the approach may be put into practice and its speedy results have contributed to its widespread adoption.

Indicator of Stochastic Subspaces (SSI)

Explaining the stochastic subspace identification approach in great depth is beyond the scope of this work. Inquisitive readers may learn more by perusing relevant texts. All except the most essential details are glossed over in this work.

It is generally known that a may represent a structural model:

$$KU(t) + M\ddot{U}(t) + C\dot{U}(t) = F(t) \tag{1}$$

where M, C, and K are mass, damping, and stiffness matrices that do not change with time and are specific to the structure connected to that make up vector U(t). The input forces, denoted as F(t), are a vector that changes in shape over time. There are several methods to rewrite Eq. (1) as a set of differential equations of the first order. In a state-space model, one popular recasting is as follows:

$$\dot{x}(t) = A_c x(t) + B_c u(t) \quad (2)$$

If $x(t) = [U(t), \dot{U}(t)]^T$ is a state vector, A_c is a state matrix, and B_c is a matrix defining the impact of the controller

$$A_c = \begin{bmatrix} I & 0 \\ -M^{-1}C & -M^{-1}K \end{bmatrix} B_c = \begin{bmatrix} 0 \\ M^{-1}B_2 \end{bmatrix} F(t) = B_2 u(t) \quad (3)$$

In addition, the state vectors of the system may be linearly combined, and component any of these linear combinations.

$$y(t) = Cx(t) + Du(t) \quad (4)$$

matrix of real influence coefficients for the output, and D is a matrix for the control output. The state-space model of a dynamic system formed by Eqs. (2) and (4) may be thought of as being in continuous time. Expressions may be evaluated at any point in time in a continuous-time system. Since experimental data are often discrete, this is obviously not possible. The results of any measurements are subject to the effects of sampling time and noise. Here we see what a model of the state space in continuous time looks like after sampling.

$$X_{k+1} = Ax_k + Bu_k \quad (5a)$$

$$y_k = Cx_k + Du_k \quad (5b)$$

State vector $x_k = x(k\Delta t)$, state matrix, $A = \exp\,(A_c\Delta t)$ and input matrix $B = [A - I]A_c^{-1}B_c$ are all discrete quantities. The dynamical system modeled by Eq. (5) is a state-space model with discrete time steps.

Whenever a system is put into action, it is subject to noise from factors including the processes involved and the measurements taken. Disturbances and incorrect modeling account for the process noise, whereas errors in the sensors themselves are to blame for the measurement noise. Eq. (5) may be modified to account for process noise w_k and measurement noise v_k using a continuous-time stochastic state-space model if stochastic components (noise) are included.

$$x_{k+1} = w_k + Ax_k + Bu_k \quad (6a)$$

$$y_k = v_k + Cx_k + Du_k \quad (6b)$$

There must be certain assumptions made since it is difficult to precisely establish the unique features of process and measurement noise. Here, it is assumed that the process noise w_k and the measurement noise v_k are both white, have a zero mean, and have covariance matrices.

$$E\left[\begin{pmatrix} v_p \\ w_p \end{pmatrix} \begin{pmatrix} v_q^T w_q^T \end{pmatrix}\right] = \begin{pmatrix} S & Q \\ R & S^T \end{pmatrix} \delta_{pq} \quad (7)$$

To which the Kronecker delta δ_{pq} is added, where E is the expected value operator. We suppose that the w_k and v_k sequences are statistically unrelated to one another.

As a matter of fact, while dealing with the actual issue of civil engineering structures, only the reactions of a structure are measured, while the input sequence u_k is left unmeasured. Because of this, it is not feasible to separate the input term u_k from the noise terms w_k, v_k in Eq (6). If we replace the input term u_k with the noise terms w_k, v_k, we get a completely random system:

$$x_{k+1} = w_k + Ax_k \quad (8a)$$

$$y_k = v_k + Cx_k \quad (8b)$$

The noise terms w_k and v_k are now implicitly modeling the input. On the other hand, the white noise assumptions of these noise terms are required. Therefore, if the white noise assumption is broken, for example if the input has any dominating frequency components in addition to white noise, then emerge.

Measurements of background vibrations provide the foundation of a time-domain approach to system identification, as shown in Eq. (8). In order to implement system identification algorithms based on Eq., a number of methods have been developed (8). In order to identify a system that measures environmental vibrations, currently cutting-edge technique available. Using the data and reliable numerical methods like state space matrices are determined using the subspace approach. Data reduction is achieved by the QR, while noise rejection is accomplished using the SVD is located, the modal parameters (natural frequencies, damping ratios, and mode shapes) may be easily determined (by an eigenvalue decomposition).

The core idea of SSI is to use the row space of future outputs as a projection onto the row space of previous outputs. It is evident that the stochastic subspace identification is a time domain approach that directly works with time data, without the need to transform them to correlations or spectra; this is the primary difference between the subspace algorithm and the preceding methods. Because the input is unknown, there is no system identification technique for measuring ambient vibration that can guarantee an absolute scale recognized.

3. Extensive Case Analysis

Constructed using reinforced concrete

In Fig 1 we see the Heritage Court Tower, a 15-story structure in downtown Vancouver, British Columbia, Canada, made of reinforced concrete with a shear core. In the spring of 1998, the University of British Columbia's (UBC) Department of Civil Engineering established a new group called the Dynamic Testing Group. Viewed from above, the building's layout is mostly rectangular, with a few minor projections and setbacks. Most of the building's lateral resistance to stresses comes from central core, where elevator and stairwell are located. When the structure was put through its paces, it was in its latter stages of construction. Anticipated to be activated vibration produced. To ensure that all of the relevant modes are suitably aroused, the measured accelerations are collected over a considerable time period. The degrees of freedom of the structures are captured by taking measurements in certain spots. For the ambient vibration measurements, eight horizontal accelerometers were employed, with two serving permanently installed fourteenth level. employed (moveable stations). different configurations were used get a good read on the mode shapes and natural frequencies. Two measurements were collected at different spots on every other level, starting on the ceiling top ground level. Three spots on the ground were used for the final measurements. A typical accelerometer installation in a building's floor is seen in Fig 2.

Fig 1: Heritage Court's Skyscraper

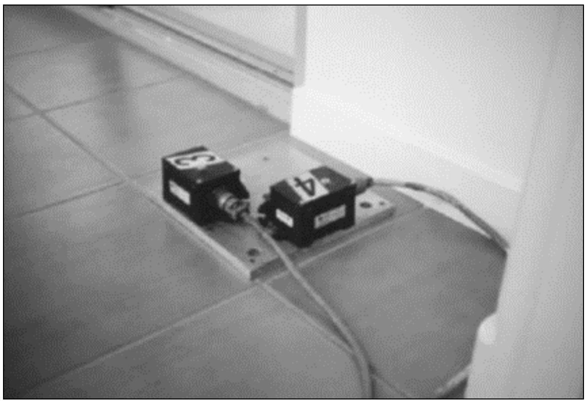

Fig 2: Picture of several accelerometers placed on the ground

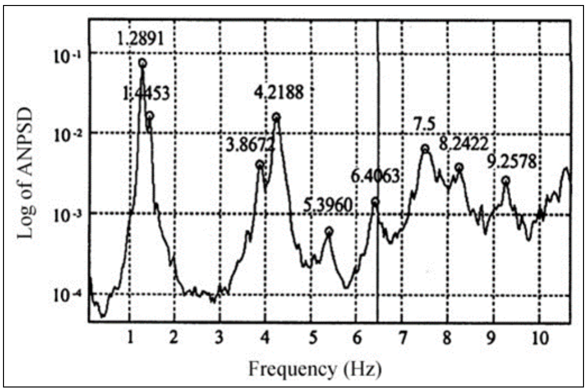

Fig 3: The power spectral density adjusted to an average value (ANPSD)

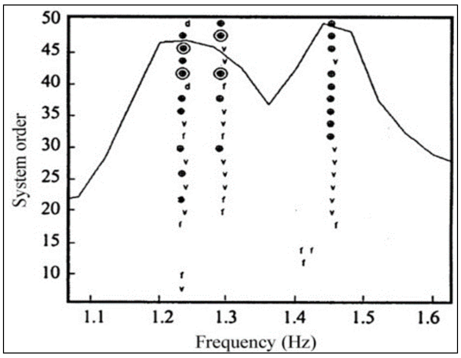

Fig 4: This is a zoomed-in version of the SSI stabilization diagram: (Setup1)

A sensor (a forced-balanced accelerometer) is used to transform the physical excitation into an electrical output. go the through cables. An amplifier and filter in one, a signal conditioner device is used to boost and clean up a signal's signal quality. With the help of boosted and filtered analog signals are transformed into digital information. The data acquisition computer's hard drive is where the digitalized signals are kept. The data for the background vibration test were collected at 200 Hz, and the anti-aliasing filter had a 50 Hz cutoff frequency. Each setup included acquiring 65536 samples (327.68 s) from each channel. Dyck and Ventura provide more information on the structure and measurement techniques (1998).

Peak picking and stochastic subspace identification were used in conjunction with MACEC for the experimental modal identification. Fig 3 depicts the average choosing method, and Fig 4 shows the magnified created using in accordance with the data of setup 1. There is no mistaking that the peak-picking technique does not capture the closed-frequency region around 1.2 Hz that was discovered using the stochastic subspace approach. Bending modes along either of the two principal axes and/or torsion modes are likely to have closely-spaced frequencies, making the peak choosing approach difficult to apply to nearly symmetric structures. It seems to be less of an issue for beam-type constructions like bridges. Two approaches are compared in Table 1 for their ability to identify frequencies up to 10 Hz.

Measuring was normally done at the northwestern and northeastern corners of the structure. movements converted corresponding in order display complete assuming that the floor slabs are moving as a rigid body. Stochastic subspace analysis yielded a visual representation of the two mode forms in Fig 5. It is shown that 9 modes below 10 Hz may be identified using just. In addition, the findings reveal that higher modes consistently couple the torsional and transverse modes.

Table 1: Determined frequency ranges (Hz)

Mode	Subspace of Probability Distributions		Picking at its Highest Point
	F(Hz)	ξ(%)	F(Hz)
1	1.132	1.3	NA
2	1.189	1.4	1.178
3	1.346	1.4	1.334
4	2.757	1.5	2.756
5	3.304	2.3	3.108
6	4.275	1.4	4.289
7	5.334	4.6	5.395
8	6.639	1.7	6.499
9	7.802	1.4	8.147

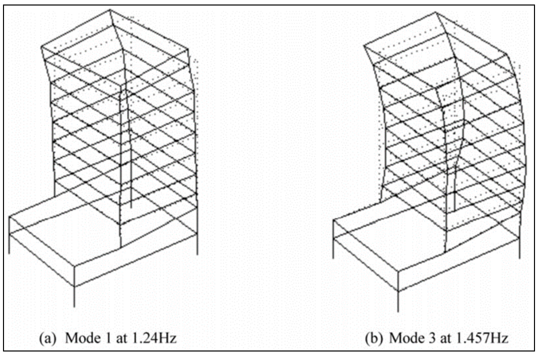

Fig 5: Mode forms of the Heritage Court Tower, as determined by SSI

Tubular arch bridge made of concrete and steel

It A 90-meter-long, half-through arch bridge is the subject of the second case study. Located in Xining, Qinghai Province, China, across the Beichuan River is a bridge with the same name. The arch of this bridge is created out of a concrete-filled steel tube, which is a unique aspect of this structure. The bridge has a 1:5 rise to span ratio. Catenary defines the axial line of the rib, and its coefficient is 1.167. The primary ribs are a truss construction comprised of four steel tubes measuring 650 mm in diameter. The bridge deck is supported by a total of sixteen suspenders.

The bridge's ambient vibration testing was conducted on the field the weekend of June 17-18, 2002, shortly before the grand opening. The goal of the tests is to provide a set of reference dynamic characteristics against which the finite element model may be validated. Locations for taking measurements were chosen on the deck close to the

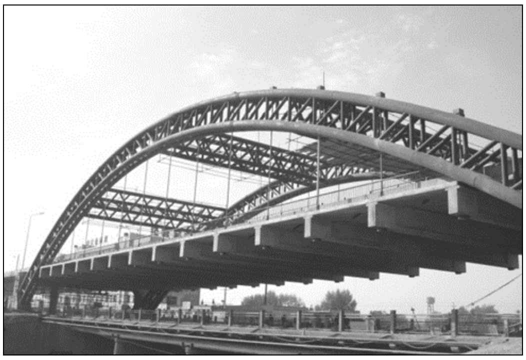

Fig 6: Steel tubular arch bridge at Beichuan, China, filled with concrete

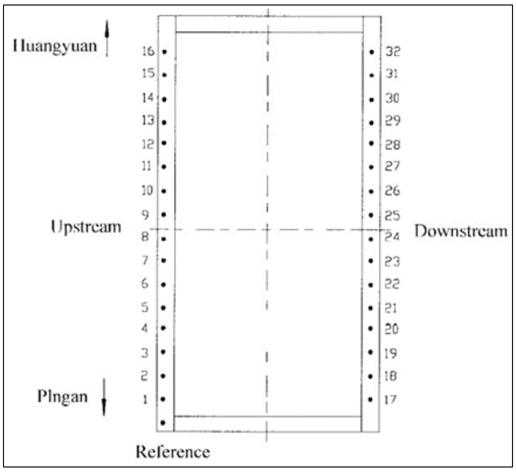

Fig 7: Instrumentation for measuring acceleration

the point where the suspenders attach to the deck. The total number of measured sites was 32. In Fig 7, we see the accelerometer set up. Only in the vertical plane were the accelerometers set up. Fig 8 depicts the measuring equipment installed on the bridge deck. To ensure that the whole arch span of the bridge could be tested, four different test configurations were designed. All configurations shared a arrangement had one fixed accelerometer and eight movable ones. In Table 2 we can see how many points were measured for each configuration.

Fig 8: Picture showing vertical accelerometers mounted on the bridge deck

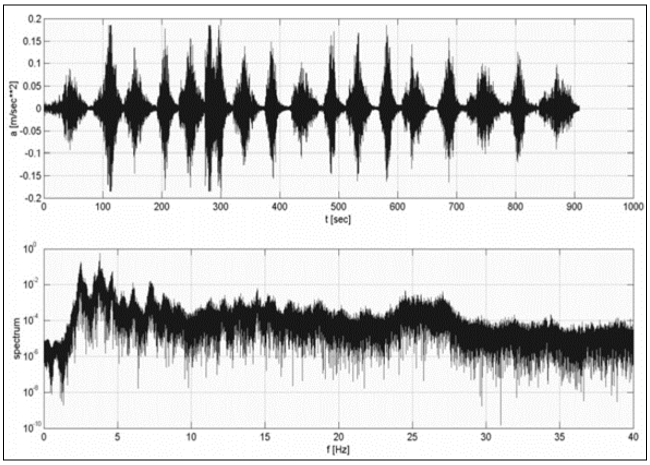

Fig 9: Point 8 raw measurement data

There is an 80 Hz sample rate with a 40 Hz cutoff frequency in place. At 15 minutes in length, the recording provides. In Fig 9, we can see from measurements represented in both. The power spectral of the recorded environmental vibrations reveals a wide variety. However, relevance is, and includes. Therefore, the original measurement data must be resampled.

The measurement data via before the identification. As a result of this procedure, fewer data points are needed to accurately identify signals in the range of 0-10 Hz. When raw data is divided by 4, we get 18 176 data points per channel satisfactory, even after resampling. By tweaking the PSD values, a significantly less choppy spectrum may be achieved. Thereafter, a window size is decided upon. An outstanding, created by repeating this process for subsequent blocks of 1024 data points. Fig 10 displays the time domain visualization and frequency visualization of the updated point spread function for Point 8. Modal parameters may be extracted from the data using the modal identification process. Table 3 displays the identified frequencies from the two supplementary approaches. It is standard practice to use a stabilization diagram to determine the values of the modal parameters. The frequencies determined by the peak picking and stochastic subspace identification approaches are found to accord rather well. Stochastic subspace identification has so far revealed the following three vertical bending mode shapes

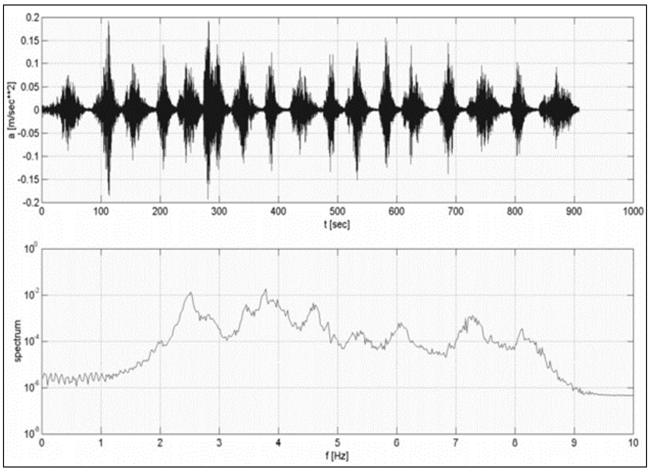

Fig 10: Point 8's power spectral density has been recalculated using resampled data

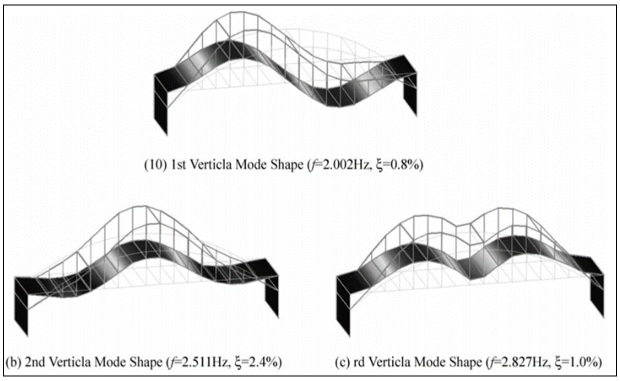

Fig 11: The Beichuan Arch Bridge's Mode Shapes Have Been Identified

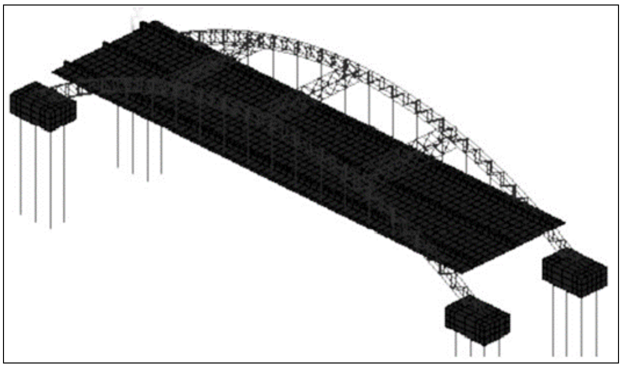

Fig 12: The Beichuan Arch Bridge Modeled in Three Dimensions Using Finite Element Analysis

As seen in Fig 11. Evidence is presented showing that high-quality mode shapes may be obtained using the stochastic subspace identification. In comparison to lower modes, higher modes suffer from worse resolution as a result of a lack of measurement locations. It has been determined that eight modes below 10 Hz may be isolated using just ambient vibration data.

As can be seen in Fig 12, the Beichuan arch bridge's finite element (FE) model was set up in the environment of the widely used FE program ANSYS. Data from ambient vibration testing in the field supplemented the findings of the analytical modal analysis. Table 3 compares the computed frequencies. Shapes of the modes as computed. We show that the FE calculation and accord quite well approved may be used as a starting point for further FE simulations.

Table 2: Found and tallied up the numbers

Model	Method of finite elements (Hz)	Peak-picking (Hz)	Identification of stochastic subspaces	
			Frequency (Hz)	The ratio of damping (%)
1st vertical	1.855	1.901	1.991	0.7
2nd vertical	1.527	1.408	1.400	1.3
3rd vertical	1.673	1.701	1.716	0.9
4th vertical	2.490	2.346	2.362	1.1
5th vertical	3.095	2.815	2.753	1.8
6th vertical	3.401	3.517	3.513	1.2
7th vertical	5.096	4.289	4.308	1.4
8th vertical	5.554	5.963	5.942	1

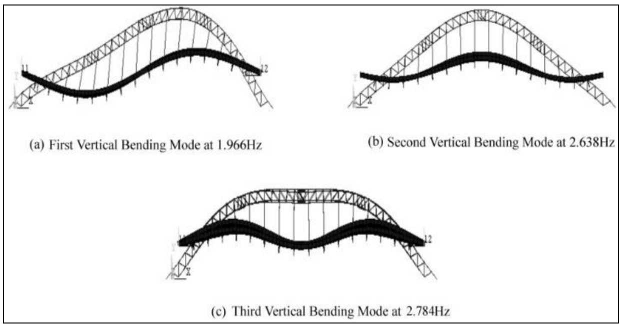

Fig 13: Beichuan Arch Bridge Vertical Bending Mode Shape Calculations

4. Conclusion

This research presents a major based on their measured outputs alone. Both of these numerical methods were used to isolate the most crucial frequencies and mode shapes while simultaneously filtering out background noise derived data approach and the methodology is shown. Frequencies have been detected using two different approaches, and they have been shown to accord with one another rather well. But known approach gives selecting.

ANPSD peaks that best represent the natural frequencies are chosen using the peak-picking approach. If the peaks are not easily discernible, this becomes a very subjective undertaking. The stabilization diagrams let the engineer choose the real modes while using the SSI technique. The stabilization diagram may be created efficiently, which is one of the many benefits of using the SSI approach. Time-consuming computational procedures (such as QR and SVD) need only be run once. Next, by excluding fewer singular values, higher-order models are produced.

Because no modal model is applied to the data in the PP technique, operational deflection shapes are produced rather than mode shapes. This is not a huge issue, however, since the form of an operational deflection is quite close to a mode shape, so long as the modes are kept wide apart. Despite this flaw, PP remains a powerful and helpful strategy because of how quickly identification may be made. When it comes to identifying modal parameters from measurements of ambient vibration in the field, the SSI methodology is currently the most cutting-edge technology available. This approach, which makes use of a stabilization diagram, may pick up on frequencies that the PP method could miss. The SSI approach has a much larger computing burden, but identification much.

Field ambient vibration measurements may be used to identify a structure's modal parameters; however, this is a time-consuming and laborious process for real-world civil engineering projects. Validation of recognized findings through other independent identification methods is crucial. When supplemental methods are used, found information is more likely to be accurate. The peak selecting method is proposed for usage in the field to verify the accuracy of collected data and evaluate the dynamic properties of civil engineering structures. workplace, method might use for further inspection and quality control.

5. References

1. Hou, Rongrong, and Yong Xia. Review on the new development of vibration-based damage identification for civil engineering structures: 2010-2019. Journal of Sound and Vibration. 2021; 491:115741.
2. Guéguen, Philippe, Ariana Astorga. The torsional response of civil engineering structures during earthquake from an observational point of view. Sensors. 2021; 21(2):342.
3. Maljaars, Johan, Mathias Euler. Fatigue SN curves of bolts and bolted connections for application in civil engineering structures. International Journal of Fatigue. 2021; 151:106355.
4. Ye, Yu-Yi, *et al*. Recyclable LRS FRP composites for engineering structures: Current status and future opportunities. Composites Part B: Engineering. 2021; 212:108689.
5. Pan, Xiao, Zhizhao Wen, Yang TY. Dynamic Analysis of Nonlinear Civil Engineering Structures using Artificial Neural Network with Adaptive Training. arXiv preprint arXiv. 2021; 2111:13759.
6. Kamal, Ayoub Esam, Zuhiar Shakor Mahmood, and Ali Najdet Nasret. A new methods of mobile object measurement by using radio frequency identification. Periodicals of Engineering and Natural Sciences (PEN). 2022; 10(1):295-308.
7. Mahmood, Zuhair Shakor, Imad Burhan Kadhim, and Ali Najdet Nasret. Design of rotary inverted pendulum swinging-up and stabilizing. Periodicals of Engineering and Natural Sciences (PEN). 2021; 9(4):913-920.
8. Huang, Yu, Xiaoyan Jin, and Junji Ji. Effects of barrier stiffness on debris flow dynamic Impact-II. Numerical simulation. Water. 2022; 14(2):182.
9. Kucharska W, Wildowicz-Giegiel A. Company Culture, Knowledge Sharing and Organizational Performance: The Employee’s Perspective, In Proceedings of the 18th European Conference on Knowledge Management. 2017; 1:524-531.
10. Zhang, Bei, Yu Huang. Numerical and analytical analyses of the impact of monodisperse and bidisperse granular flows on a baffle structure. Landslides, 2022, 1-23.
11. Zhang, Bei, Yu Huang. Seismic shaking-enhanced impact effect of granular flow challenges the barrier design strategy. Soil Dynamics and Earthquake Engineering. 2021;143:106655.