APPLICATIONS OF AMBIENT VIBRATION TESTING: AN OVERVIEW

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Abstract - ***A large number of applications of Ambient Vibration Testing have been reported. Wide Variety of full-scale structures has been tested by the method and the method has turn out to be both a cost-effective and practical way of determining the dynamic properties of these structures. These publications deal into about three fourth experiments in buildings, dams, chimneys and silos, and about one fourth to bridges. An overview on the application of Ambient Vibration Testing for different structures is presented in this paper.***

Key Words: *Ambient vibration tests, Finite Element method, Dynamic Parameters, Structural health monitoring, Bridges, Multi-storey buildings, Dams etc…*

1. INTRODUCTION

The ambient vibration testing procedure consists of real time recording of the vibrations and processing of the records. This method of structural testing is based on measuring the small structural vibrations caused by the ambient forces. Ambient forces may be caused by the wind, the traffic noise or some other micro-tremor [24]. An advantage of the ambient vibration over the forced vibration surveys is that usually light equipments are required. Further it requires only relatively short and simple field measurements, and the measuring instruments can be installed and operated by a smaller number of operators [22]. The method is very fast and relatively simple procedure and can be performed on a structure in use without disturbing its normal functioning [23]. Since the amplitudes of structural vibrations are small, the ambient vibration tests describe the linear behavior of the structures. However, earlier studies found that testing based on ambient vibrations gives essentially the same results as would be obtained from the forced vibration experiments, in the linear range of excitation [24]. One of the most frequent uses of the method involves identification of dynamic characteristics of various full scale structures. Some of the other applications of Ambient vibration testing are calibration of analytical models of structures; structural health monitoring; to identify and to monitor changes of natural frequencies of damaged, and repaired structures; to predict difference in response due to different soil conditions and type of excitation etc. [10]. The ambient vibration tests are "complete" full-scale experiments. Even wisely devised laboratory experiments will characterize only those aspects of the problem that the experiment designer had selected to study and integrated into the model. The best and most complete laboratory tests can validate and quantify only those aspects of the problem that the investigators know. Except when fortunate accidents occur, we do not know how to model what we are not aware of and what we do not understand. The full-scale ambient vibration tests give away an entirely different situation that cannot be commanded effortlessly. The as-built environment holds all the belongings of reality. We only have to find nifty ways to discover record and interpret this reality [10].

2. INSTRUMENTATION

As described, the ambient vibration testing (AVT) process involves sensing the structural vibrations caused by ambient forces, recording the vibration responses and then analyzing the data to arrive at dynamic characteristics of the structure. Thus the instrumentation for AVT may be categorized into three main units viz. (i) Data Acquisition System (ii) Power System and (iii) Sensing System.

2.1 Data Acquisition System

Data acquisition is a procedure in which the analog data from the sensing device is converted into digital data and stored permanently. The data need to be checked for errors related to the quantization, aliasing, filtering and leakage and need to be processed for error mitigation and parameter estimation [18]. Parameter estimation involves identification of the magnitude and phase of different signals obtained [8]. For this purpose data logger and computer are used.

A data logger is electronic device which changes an analog input into a digital time series representation. At the time of setting up and programming a data logger, following precautions should be taken [26].

- Set up in safe place free from moisture.
- Supplied with consistent and adequate power.
- Programmed with the right recording parameters.
- Allied properly to the sensor for receiving accurate timing (from GPS).
- Recording data on site to non-volatile memory.

In practice there are three types of data logger namely (i) 1-channel data logger, (ii) 3-channel data logger and (iii) Multi-channel data logger

2.2 Power System

In case of non-availability of electronic power, the most common power source is a battery [11]. Batteries are of two main types: primary and secondary. Primary batteries are used once then discarded and secondary batteries are rechargeable. Mostly deep cycle lead-acid batteries are used to specific data acquisition system. The capacity and size of the lead-acid battery will depend on the type of data logger, type of sensor, size of solar panel, telemetry and geographic location [26].

Now a days, a system which is a combination of enclosure, solar charge controller and connectors is being used frequently which ensure that batteries are charged and data loggers and sensors are received power simultaneously. It has power output, solar panel input and battery input. This system is specifically named as power system having load capacity of 12-15 amp and a low voltage disconnect (LVD) to safeguard battery from damage and operated with nominal 12 volt solar panel and deep cycle gel-cell lead acid battery. The power box should have features like water resistance, smaller size, maximum power point tracking, lower self-consumption and regulated and unregulated output [26].

2.3 Sensing System

The sensing system is targeted to measure the structural responses and the equipment that actually detects and quantifies motion is called sensor. Sensors send this information to the data logger through cable [18]. Details of different sensors used for measurement have been provided in text books [6, 7, and 27]. Sensors have been developed for measurement of different parameters such as strain, temperature, pressure, wind speed, velocity, displacement, and acceleration, etc. and depending upon the desired parameters work on different operating principle [6]. Sensors which are commonly used in AVT are Forced Balanced Accelerometers (FBA) and Ranger Seismometers. Acceleration is a common parameter for short and long term monitoring of prototype structures and model testing purposes. Many types of accelerometers are available, such as capacitive accelerometers, piezoelectric accelerometers, strain gauge accelerometers, fibre grating accelerometers, micro-electro-mechanical systems (MEMS) accelerometers and servo accelerometers [27]. At a specific point of the structure, accelerometer measures accelerations and typically generates electric signals in the form of voltage which is read by a data acquisition system. If signals are weak, conditioning amplifiers are used to amplify the signals [18]. Different types of sensors are described below:

Broadband sensors are 3-component seismometers competent of sensing ground waves having frequency in the range of .01 Hz to 10 Hz [11]. These sensors are very frequently exercised in passive experiments and regional earthquake. With enough signal, however, 120 sec. and 240 sec. velocity transducers can resolve signals with periods much longer than the corners period [26]. Corner period is defined as the period at which magnification drops by 3db of peak value [3].

Intermediate sensors are three component seismometers with corner periods in the 30 to 40 seconds range. These sensors are capable of sensing ground motions of much longer periods than their corner periods, if the long-period amplitudes are sufficient [26].

Short-periods sensors are three component seismometers that cover higher frequency bands usually 1Hz to 100+Hz [11]. These sensors are used in both passive and active source experiments. They have a flat response to ground velocity for frequencies greater than this corner frequency [26].

High-Frequency Sensors are very rugged seismometers that cover even higher frequency bands of range 4.5 Hz to 100+ Hz. These sensors are most-often used in active-source experiments and often referred to as geophones [26].

Accelerometers also known as strong motion sensors are devised to assess the large amplitude, high frequency seismic waves typical of large local earthquakes, and operate in the frequency band 0 Hz to 100+ Hz [27].

3. APPLICATIONS OF AVT

AVT has been used for various types of structures namely Bridges, Dams, Multi-storey buildings etc. Large number of papers has been published till date on the AVT of structures. Researchers documented issues of the technique and used the method for achieving their objectives. Applications of AVT for different category of structures are discussed in the following sections.

3.1 Bridges Structures

Bridge is one of the oldest instruments of our civilization. It is difficult to understand the dynamic response of bridges to effects of traffic movement, strong wind or earthquake. Evaluation of the dynamic properties like modal frequencies, mode shapes and damping values is very important for earthquake resistant design of bridges. Ambient vibration method is simpler method of determination of these dynamic characteristics. The uses of ambient vibration testing of bridges started in 1970 and have become frequent since 1985[10].

Mclamor et. al. (1971) conducted experiments on two American suspension bridges to determine natural frequencies, mode shapes and damping experimentally. The objective of this study was to find out vertical and torsional mode in the frequency range 0Hz to 1Hz from recorded vertical motions. They identified two torsional modes but these results were not compared with the computed results.

Ghaffar and Housner (1977) conducted a study on Vincent-Thomas suspension bridge having 1500 ft. suspended center span and two suspended side span of 506.5 ft. situated in Los Angeles Harbour. The structure got excited simultaneously in vertical and lateral direction by vehicular traffic. The measurements identified sixteen, eleven and ten modes in vertical, torsional and lateral directions respectively in the frequency range of 0Hz to 3Hz. Owing to small amplitude excitations, the structural behaviour indicates in the range of linear response. Though measurement shows an interaction among side and center span in some higher as well as lower modes, which signify non-linear behaviour. Good modal identification was attained by specific arrangement and orientation of sensing instrument and by adding and subtracting records to boost vertical as well as torsional motions. Long-time intervals were recorded for improved determination of the densely spaced modes of vibration. From recorded lateral motion the properties of torsional modes were well determined. Torsional motion's vertical component was not precisely obtained. Only six out of eleven torsional modes were recovered from the recorded vertical motion and the other five modes were very near to vertical modes which conquered the vertical motion.

Kato and Shimada (1986) performed vibration measurement on an existing pre-stressed concrete bridge (π-shaped of span 116ft.) to obtain change in vibration due to deterioration of bridge at the time of its failure when the bridge had been removed for the new bridge construction. The vertical and horizontal vibrations were measured by ambient vibration test during static loading test. Numerical analysis was done to simulate deterioration effect on vibrational characteristics. It was seen that when load applied at the centre of span, first vertical mode's frequency reduced promptly as load advanced to ultimate load. Because of ambient vibration test slight modification in damping constant was also observed. Numerical analysis showed that frequencies computed were in close agreement with measured value in the situation of inserting a hinge at the centre of span after the pre-stressed steel wires yielded.It was observed that the decrease in natural frequency was small even if cracks occurred while the pre-stressed reinforcement was in elastic state. This may be due to the cracks of concrete closing together by effective pre-stressing force. When reinforcement crossed the elastic limit abrupt decrement of natural frequency was observed. This observation indicates that vibration measurement may be to find out weak reinforcement of a pre-stressed concrete bridge.

Ventura et. al. (1996) presented the results of ambient vibration studies in 1993 on three bridges having two short spans each viz (i) Painter Street Overpass (44.51m and 36.28m.) (ii) 7th Street Overpass (39.63m and 33.54m.) (iii) 11th Street Overpass (33.54m and 48.78m) situated in the Cape Mendocino area of Northern California. Painter Street Overpass had permanent instrumentation that had been recorded the motions from significant earthquakes in the area since 1980. Decks of three bridges skewed at about 39^o, 19^o and 6^o respectively. The identified frequencies of vertical mode and transverse mode of bridges had been in the ranges of 3.4Hz -3.6Hz and 4.1Hz – 4.6Hz respectively. During this investigation the main source of dynamic excitation was vehicle traffic for these structures. Results of the ambient vibration testing from Painter Street Overpass were matched with those obtained from a series of ambient vibration tests conducted more than 13 year before. This comparison displayed that the frequencies of fundamental modes of earlier test were on higher side than the later tests. This confirms some degree of structural degradation over the years due to the significant seismic activity in the area.

Bayraktar et. al. (2010) studied masonry arch bridge consisting two spans of length 28.4m and 23.3m situated in Rize, Turkey is taken and its finite-element modelling, model testing and element model updating is done. ANSYS software is used to create 3D finite-element (FE) model and dynamic parameters are determined analytically. Further ambient vibration testing is performed on the bridge. Peak picking (PP) and stochastic subspace identification (SSI) are used to extract dynamic properties experimentally. FE model is updated by changing boundary conditions to minimize the deviation between analytical experimental values. The frequencies of first five mode shapes (bending, vertical and torsional) obtained from FE model are between 3 to 15 Hz while from ambient vibration test range between 4 to 16 Hz. After FE model updating maximum difference in the natural frequencies are averagely reduced from 18% to 7%. By comparing analytical and experimental results, we come to know that mode shapes shows good agreement but some difference in the natural frequencies and experimental frequencies are bigger than analytical frequencies. In this study, it is seen that to understand the complex dynamic behaviour of historical bridges, which have sophisticated geometric features and material type's operational model analysis can be applied.

Costa et. al. (2014) carried out a study on centenary double-deck steel-arch bridge having total span of 565.25 m regarding the model identification, which endured rehabilitation and strengthening work to incorporate its upper deck (UD) into the light metro infrastructure network of Porto. To collect data from the pre-rehabilitation and post-rehabilitation conditions, two ambient vibration tests were performed. First test's data were used to assist the viability study of the project and subsequently its design, whereas the measurements from the second test aided to identify the change produced in the behaviour of bridge for the new service condition and also gave a sound baseline for Structural Health Monitoring (SHM). The 3D FE models were made to support the modal analysis. Experimental data helped to validate or update the numerical models. The measured natural frequencies for the same vibration modes have underwent minor modifications, presenting a slight tendency to increase after bridge rehabilitations. The deformed configuration of the UD became less smooth near the steel piers for the transverse vibration modes, with regard to the mode shapes, particularly as order increased. The modal parameters identified from ambient vibration tests matched very well with the estimates provided by the numerical models developed for this work. The new model that imitates the pre-rehabilitation condition of the bridge has provided appraisals of improved quality in relation to those that had been calculated in the viability work. The variation of frequencies shows that the transverse bending stiffness of the UD was reduced by 58% while the vertical one attained a decrease of 18%. The values were very near to static estimates either numerical or experimental. Constraints of the longitudinal translation of both decks decisively contribute to dictate the natural frequencies of the specific vibration modes, which has permitted a simple and dependable calibration practice to quantify the stiffness constants taken in the longitudinal springs of the model supports.

3.2 Multi-storey Building

These structures are generally treated as equivalent discrete multi-degree of freedom system. At the floor level, the various masses of the floor system together with half the supporting systems (columns and walls) located both above and below the floor level are assumed to be concentrated [12]. With increase in number of storey, the fundamental period of the structure increases. Multi-storey buildings are usually tested for safety due to wind forces but some regions of a building would be more critical for earthquake forces as compared to wind and vice versa. Hence, there is a need to check the design parameters for both types of forces [12]. Ambient Vibration testing is a pretty good tool to find the dynamic parameters of multi-storey building experimentally without disturbing the normal functioning of the building [24]. The U.S. Coast and Geodetic Survey started measuring the fundamental periods of building by ambient vibration tests in early 1930's [10].

Trifunac (1970) conducted his experiment on the Union Bank building in the city of Los Angeles. In this study, the Union Bank building having rectangular plan and 39 stories rises for 496 feet is subjected to ambient vibration testing. The dynamic behavior of the building was also examined by analytically computing the response for the EL Centro earthquake, May 18, 1940 N-S component of ground. Firstly all four seismometers oriented in the same direction and placed on the 39th floor in order to calibrate dynamically four simultaneous outputs. After this calibration run as, two seismometers (number 3 & 4) were left on the 39th floor in direction NS and EW and other two (number 1 & 2) were moved to 36th floor with orientation NS and EW, five minute recording was made and was referred to as Run 2 and similarly Runs 3, 4, ……., 15, was made and seismometers number 1 and 2 were successively moved to lower floors with each run having 5 minutes recording of vibration. Runs 16 and 17 were performed to determine torsional vibrations. At the time of Run 16 all the seismometers were in the SE corner, two on 39th and two on 21st floor and during run 17 all four seismometers were on the 39th floor in the NE and SW corners of the tower. The recorded quantity was relative velocity of the seismometer mass which has a natural frequency near to 1 cps. The Fourier amplitude spectrum was computed by with the help of Cooley-Tukey algorithm. The first seven frequencies and first five mode shapes of the translational and torsional vibrations were determined. These frequencies and mode shapes are based on small amplitude vibrations and hence indicate the structural behavior in range of linear response.

Ivanovic et. al. (2000) bestowed a literature review on the topic of ambient vibration testing and a review of study conducted on seven storey reinforced concrete building situated in Van Nuys, California to illustrate the state-of-the -art in application of the ambient vibration method. During the review, they found that around 1970 reports on testing of full-scale structures by ambient vibration testing started to appear consistently with about three fourth of all contributions dedicated to the study on dams, buildings, silos and chimneys and about one fourth to bridges. World-wide, only 3 papers are published per annum dealing with this subject since 1985.Two ambient vibration surveys were conducted on the seven story building ,following the Northridge earthquake of 17th January 94(M= 6.4) and its early aftershocks that damaged the building severely. Approximately after two and half week of earthquake experiment-1 was conducted and after three month of earthquake (M = 6.4) and one month after 20th March aftershock (M = 5.2) experiment-2 was performed. The building was restrained in the meantime by wooden braces between the duration of two experiments. Due to the differences in the state of the structure and underlying soil, change in the modal frequencies was expected. It was observed that three out of four spotted frequencies for longitudinal vibrations increased (the 1st, 2nd, and 4th increased by 10%, 6% and 5% respectively) but third longitudinal mode's frequency was not changed. Also frequencies of 1st torsional mode and 1st transverse mode remained same but second purely transverse mode's frequency increased by 10%. The transfer function of the recorded vertical motion had peaks at the frequencies of the longitudinal and transverse modes. At these frequencies the vertical responses analyzed alone or combined with the corresponding horizontal responses, may be useful for detection of the damage of the columns. Near one of the damaged columns where ambient noise was measured, have change in the amplitude of the vertical responses. The detection of the damaged structural members would have been more complete if the vertical motions been recorded at more points through-out the structure. The motive of the test was to check whether highly localized damage in structural member could be identified by ambient vibration surveys. So far results show that this cannot be done with the common process. Analyses of complex building behavior need much higher spatial resolution of recordings. Ambient noise should be recorded at comparable separation distances to detect severe and localized column damage. In most of the practical cases conducting such detailed experiments may not be feasible. Although loss of axial capacity could be seen in the vertical response of the damaged columns, moderate or weak damage of this kind may not be noticed in most ambient response survey. When the loss of strength is moderate and when the damage is less obvious, more detailed survey of ambient vibration should be carried out for damage identification.

Baptista et. al. (2004) did experimental and analytical studies on a 16-storeyed office building having 12 floors above the ground and 4 basement levels situated in alluvium soil, near Tagus River, Lisbon. To obtain dynamic parameters ambient vibration testing was conducted. Artemis software was used to download experimental data. For analytical study FEM model of the building was developed using SAP2000 software. Two techniques, peak picking (pp) method based on frequency domain decomposition (FDD) and stochastic subspace identification (SSI) based on time domain method (TDM) were used to extract dynamic properties. The natural frequencies identified by PP and SSI showed good agreement. The first five modes obtained experimentally are in the same sequence of that obtained in the analytical study. Second mode had maximum difference of 6.87% between experimental and numerical results and for rest of the modes difference was less than 1%.

Singh et.al., (2006) performed an ambient vibration testing on the G+9 story residential building in Ahmedabad, Gujarat after 2001 Bhuj earthquake to determine the modal parameters. Ahmedabad city comes in zone ш and assigned a zone factor *(Z)* of 0.16 by IS code 1893 (part 1):2002. Modal parameters were determined using frequency domain decomposition technique, which is an output-only modal identification technique. Frequency and mode shapes for first five modes of the building were extracted from the records and compared with the finite element modal analysis. The finite element model included the effects of infill, staircase & floor slabs in the modelling of building. It was observed that first translational mode had the maximum difference equal to 16.26% in modal frequencies while the second torsional mode had minimum difference of 0.01%. It was noticed that the patterns for first five modes obtained from the ambient vibration testing and finite element model were same.

Zhou and Yi (2008) performed ambient vibration testing of RUIHUA situated in Shenzhen, building of height 86 meter having two towers linked by air passages & enlarged base. Both linear and torsional modes were assessed. For numerical modal analysis and structural seismic analysis SATWE module in PKPM software and Newmark-β method were used respectively. Each mode of the building had the component of torsional vibration because of eccentricity of the air passages. The measured and analytical fundamental frequencies were 0.684Hz and 0.402Hz respectively. By comparing measured response with the response obtained by empirical equation given in the codes of other nations, it was observed that experimental fundamental time period is little less in comparison of fundamental time period obtained by codes of other nations.

3.3 Dam Structures

Dams are important civil engineering structures due to their high replacement cost and their potential of the vast extent of property damage and loss of life which would result from their failure and it is a good practice to conduct in-situ dynamic tests on important dams in areas susceptible to strong earthquake events to estimate dynamic characteristics at the low level of excitation [26]. For dynamic analysis of Dam forced and ambient vibration tests were frequently employed in the past but with time ambient vibration testing due to its simplicity have become an excellent tool to conduct vibration analysis of dams.

Mivechi et. al. (2003) applied ambient vibration testing on two Iranian dams namely Shahid Rajaee dam(height = 138m) located on Tajan river and Saves dam(height = 128m) located on Qura-Chai river. A new combination of different technique was employed to achieve highest possible precision using the minimum available hardware. The cross power and auto power spectrum had been calculated by Fourier transformation and the original frequencies had thus been detected. Fourier spectra were taken in use to obtain mode shapes and phase and half power method is used for damping determination. Total 4 modes were detected for each dam having frequencies and damping in the ranges of Hz1 to 3.6Hz and 1.3% to 0.95% for Shahid-Rajaee dam and 3.9Hz to 7.61Hz and 1.74% to 0.905% for Saves dam. Experimental results were than compared with the result obtained by mathematical model. It was observed that 1st and 2nd mode have large deviation between frequencies of experimental and mathematical in comparisons of 3rd and 4th modes.

Sevim et .al. (2013) performed ambient vibration testing on Berke Arch Dam of 201 meter height situated in Turkey. The study was carried out for structural identification of dam under the natural excitation of wind and water effects. Three ambient vibrations tests were conducted at different locations of the dam. To extract the modal parameters Enhanced Frequency Domain Decomposition technique was taken in use for mathematical model of dam and Operational Modal Analysis (OMA 2006) was used to estimate parameters from ambient vibration tests. The frequencies of first 8-10 modes of dam from finite element analysis were in the range of 0-12 Hz and total eight frequencies in the range of 0-12 Hz were also obtained experimentally from test-1, test-2 and test-3 setup. It was observed that the computed and experimental fundamental frequencies were different. Since sensors were mot placed in vertical direction, vertical modes were not attained from AVT. The modal parameters attained from all three test setup were almost same. Average damping ratio of dam was 0.6% of critical damping.

3.4 Other Applications

Apart from Bridges, Multi-storey building and Dams ambient vibration technique can also be used for dynamic identification of structures like water tanks, chimneys, stadiums and many more structure. This can also be used for Structural health monitoring and modal updating.

Lotfalipour et. al. (2008) conducted ambient vibration testing on the rural houses of Iran made of mud and adobe. They selected three types of eleven single storey adobe rural houses including adobe wall with wooden flat roofs, vaulted roofs, and arched roofs for dynamic parameters investigation with the help of three SS-1 seismogram SSR-1 signal conditioner systems. Fourier amplitude spectrum was used to find frequency in both horizontal and vertical. Rough estimate of damping ratio by the half power method presented due to close peaks of amplitude spectrum. Fundamental frequencies of translation and vertical vibration were in the range of 4.8-16.2 Hz and 9.0-18.7 Hz. Due to the lack of confinement in wooden flat roofs; torsional frequencies were found to be different in both the directions. Even though some building had same dimension they had different frequencies, because of different percentage of wall covering area.

Giraldo et. al. (2009) worked on the identification of modal properties of civil engineering structures as they vibrate in their natural environment. The main aim of the paper was to statistically assess and equate three of the most standard time-domain modal identification techniques in a totally automated environment. The outcome showed that stochastic subspace identification (SSI) algorithm is both extremely robust to sensor noise and user friendly. Satisfactory results were also obtained with prediction error method through least square (PEM/LS) with better performance at low noise levels. However as the noise in sensors increased, its accuracy seemed to be negatively affected. The other objective of this work was to investigate the performance of the most useful approach by comparing it to more traditional ways of testing. With the use of experimental data comparison between modal properties obtained from real ambient vibrations and those obtained from hammer tests was done. Although SSI gives very acceptable results, however due to nonlinearities present at low levels of vibrations some mode shapes have consistent error. Here the purpose was not to discuss the stationary of the load working on civil structures and their ability to stimulate an acceptable amount of vibrational modes. These considerations are unique for each case and should be estimated in the field.

Tashkov et. al. (2011) conducted the dynamic in-situ testing of primary school Dimitrije Tucovic in Karljevo zone by applying the ambient vibration testing method after the earthquake in Karljevo zone in 2010 to obtain the dynamic characteristics of marred structure. In two orthogonal directions measurements have been performed. The dominating frequencies are: 3.71Hz, 4.49Hz, 6.74Hz and 8.3Hz. 3.71Hz is the most expressed frequency in transversal direction and 4.49Hz is the 1st frequency in longitudinal direction with significant torsional effects. Due to the high length/width ratio, the building had well expressed higher modes in transversal direction (6.74Hz) and in torsion (8.3 Hz). The values of the equivalent damping coefficient are in the range 2.0-2.9%. Based on the observation of mode shapes in horizontal plane it was concluded that the stiffness of the floor slabs is not adequate. This should be taken into account at the time of strengthening process.

Rhimi et. al. (2012) published their work on energy harvesting from ambient vibrations in civil structure. Energy harvesting from ambient vibrations in civil buildings offers a potential constant power supply meant for sensor linkages used in structural health monitoring. These structures display a confine natural frequency response range, which are usually one to two orders of magnitude lesser than the working frequency spectrum of most piezoelectric –scavenging devices. It is significantly bounds the levels of harvestable power and therefore stymies the effectuation of advanced sensing functionalities. They studied the progress of the energy harvesting properties of bimorph cantilever lead zirconate titanate piezoelectric beam. The application of an erratic pre-stress-loading condition was exercised as a solution to revise the system's properties. With the help of Hamiltonian principle a global model was developed to describe the consequence of the pre-stress parameters on the reapable energy levels. An analysis of changes of the frequency response, damping ratio, amplitude and efficiency of the preload was bestowed and model's experimental verification was also performed. Measured frequency domain response and time of the piezoelectric bimporh were compared with the theoretical results. To indicate the variations of the reaped power with respect to different pre-stress conditions acceleration measured from a concrete bridge deck under ambient excitation and recording from the event (earthquake) were used.

Nunez et. al. (2013) presented an article dealing with quality control during construction process by means of a structural health monitoring network. A structural health monitoring (SHM) network was established on a 56-floor frame-wall concrete building with height of 196 m during the construction. The SHM network recorded the vibrations created by earthquake, construction and ambient turmoil. The vibrations were employed to categorize the natural periods, mode shapes, and damping ratio of the structure every 10 min for 6 successive months and at five specific phases of the construction process over two year period. The recognized modal parameters were employed to ratify the construction process and computer design model by matching different adaptive computer models that gibe to the progress in construction. There were uttermost differences of 14% between assessed and analytical model's natural period and correlation to model shapes were near to 95%, which shows an appropriate approximation of the foretelling design computer model. For the direct measurement of the energy dissipation properties of the building experimental technique also permitted. For the low amplitude vibrations, the modal damping ratio ranges from 0.7 to 1.6% for the biggest natural periods. For the comparison of the dynamic properties before and after an intense loading event Central-South Chile earthquake (magnitude = 8.8) of 2010 was used to compare dynamic properties before and after intense loading event. The nonstop observing of the dynamic properties of this permanently erratic building proves to be an outstanding tool for the confirmation of design models and quality surety in construction control.

4. CONCLUSIONS

Estimation of dynamic characteristics is an important step in analysis and design of Earthquake Resistant structures. Further measurement of frequencies of an existing structure indicates the health of structure during its design life. Ambient vibration survey is one of the methods for evaluation of dynamic characteristics of a structure. Following are some conclusion of the review presented in this paper-

1. The method has got number of applications for variety of structures.
2. The method requires light and handy equipment viz. (i) Data acquisition system, (ii) Power system and (iii) Sensing system and can be used by small number of operators.
3. Developing energy harvesting from ambient vibration may eliminate need of power system.
4. Tests carried out near or at failure helped in validating analytical models at plastic state also.
5. Judicious use of the sensors may provide dynamic characteristics for desired number of modes.
6. Various techniques like Fourier Amplitude Spectrum, Operation Modal Analysis, Prediction Error Method through Least Square, Stochastic Subspace Identification, Peak Picking etc. may be used to extract useful information viz. natural frequencies, damping etc. from the recorded data.
7. The method has been used to refine and validate the analytical models developed for bridges, buildings, dams etc.
8. It helped in estimating the expected earthquake load for complex geometry or historical structures.
9. The method got application in diagnosing the reduction in strength of structures thereby planning strategy for retrofitting /replacement.
10. The technique has been used as one of the measure for quality control during construction process of multi-storey building.
11. Application of ambient vibration survey is lacking for elevated water tanks and need to be explored.

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