A Critical Evaluation of Structural Health Monitoring for Damage Detection in Bridges

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Abstract:

The point of the examination is for the assessment of Structural Health Monitoring. SHM techniques in Bridges and Highways have assessed by researchers and specialists worldwide. They have presented various strategies in different conditions. By keeping all, system procedures and preferences of SHM have examined in this paper. The main focus of this paper is a broad writing assessment done on basic SHM structures used to explore the capacity of tollway connections. The focal point of this evaluation is on making sense of the SHM considers endeavors that comprise damage identification, fundamental capacity estimation, and reliability analysis of life tollways. These endeavors have spread over an enormous scope of certainties handling procedures focused on observing changes in necessary qualities for damage location, classified systems permitting essential ability assessing, and dependability investigation to anticipate shutting presence. Discover that a significant wide assortment of concentrates over damage identification by utilizing actualities preparing techniques while a shockingly modest number of studies had been committed to the estimation of auxiliary limits and a definitive transporter presence of scaffolds. We conclude that the critical identifying gaps, including the approved SHM that used to circulating the data to examine the design code-based structural integrity and life of the tollway bridges.

INTRODUCTION

In structural building, the pertinent order for harm acknowledgment is generally called Structural Health Monitoring (SHM). Parkway spans exposed to dead and live loads close by outrageous masses alongside specific and man-made risks are showing up as the most significant primary segments in transportation foundation frameworks. Unexpected crumples of extensions can bring about sizable human and financial misfortunes; in like manner, precisely keeping up their necessary respectability over their life expectancies is expected to make

particular open wellbeing. To assess the auxiliary trustworthiness of extensions and to settle on educated choices concerning their fix procedures, most scaffolds crosswise over areas inside the US are reviewed, and appraised if required by methods for the Department of state Transportation (DOT's) in any event once in an annum, as per AASHTO's Manual for Bridge Evaluation [1]. Even though the DOT's have situated noteworthy endeavors to examine the fundamental harm and burden bringing limit of toll street connects through the arranged methodologies, it found from past calamitous occasions [2] that few extensions in the

administration have endured basic disintegrate because of remaining hundreds identified with decay as the years progressed.

Structural Health Monitoring (SHM) frameworks that go past the arranged techniques had utilized to identify damage on connect structures. SHM regularly alluded to as the way of affecting harm location calculations with auxiliary capacities for spans [3]. This framework incorporates the observation of extensions throughout the years utilizing ongoing or intermittently found estimations of stress, vertical, and vibration development from sensors through SHM structures [4]. Nearby and common attributes separated from the estimates and afterward damage discovery calculations with those qualities can encourage the recognizing unharmed

and harmed circumstances in a scaffold exposed to typical supplier powers. The destruction detection mainly depends on the methodology that adopted. In first, the methodology has created. The methodology is works on the VB and SB SHM. The other influences of the structure damages can be identified.

PROCEDURE OF EVALUATION

The internal damages of the structures identified through the changes in the frequencies of the structure. Those frequencies identified through a damage detection algorithm. The table below described the process of the algorithm through various steps.
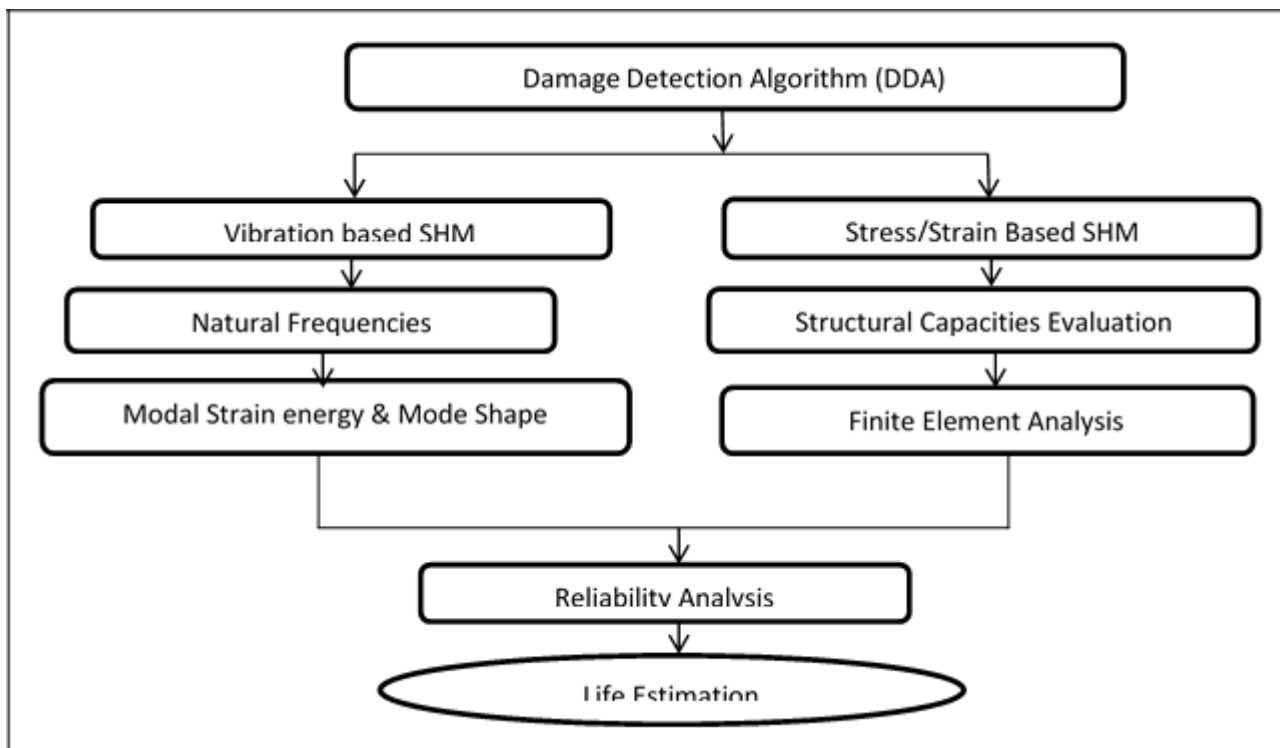

FIGURE.1: STEP BY STEP PROCESSING OF EVALUATION OF STUDY

ALGORITHMS BASED DAMAGE DETECTION:

Harm might be portrayed as alterations in connect characteristics brought into an auxiliary gadget that influences its basic respectability [5]. The essential statute of harm discovery calculations is that the parameters of the fundamental attribute are elements of the physical parameters of similar shape, comprising of mass, damping, and firmness.

Subsequently, damage during one's physical parameter will cause changes inside the auxiliary parameters. In light of that statute, it accepted that harm could modify essential solidness and mass, which adjustments the auxiliary reactions estimated from a variety of sensors related to an SHM device. Broad works of art with harm identification calculations for double carriageway connections

finished the utilization of vibration-based and strain-based SHM frameworks.

3.1 Vibration Essentially Based SHM

An SHM framework, this is primarily founded on vibration estimations taken from spans, is fit for identifying modifications in unique attributes parameters comprising regular recurrence, modular strain control, mode structure ebb and flow, dynamic adaptability, and others [6], [7] & [8]. A significant writing audit for harm discovery calculations with a regular recurrence found from some other spot [9]. Modular weight quality and mode shape arch have extra extensively used to discover and limit damage on necessary parts than on spans [10] & [11]. Subtleties on other location calculations through the vibration-fundamentally based SHM framework resolved in past research [8 - 12].

3.2 Natural Frequencies:

The dynamic capacity, regular densities were perceived as one of the best extreme splendid signs while identifying damage in shape through the vibration-essentially based SHM device [8 -11]. These pointers might be estimated more without trouble utilizing the SHM machine than various unique capacity parameters have used to analyze fundamental worldwide harm legitimately. Over quite a while, numerous specialists have attempted to utilize changes [13-14] in standard frequencies to examine auxiliary mischief in entangled designing structures, particularly connects [15-17].

An earthquake harm discovery calculation to assess the auxiliary execution of strengthened solid Column Bridge glorified as single degree opportunity framework [8]. The calculation utilized a sensor cluster that ready to recognize changes in the regular terms of the section through quick Fourier change of the quickening response recorded on the highest point of the segment all through a tremor, as reenacted in the lab. It transformed into found that the regular length became lengthened due to the seismic damage and that the charge of the average span will increment as the response relocation increments.

Vibration primarily based the SHM machine on doing a modular operational assessment for a double carriageway connects [11]. The modular attributes of the scaffold underneath operational circumstances tentatively caught through a network of accelerometers connected to the SHM gadget. Additionally, evaluated changes in unique modular parameters estimated from bidirectional increasing velocities of the misleadingly realized mischief of an extension, the utilization of factual instruments using the SHM contraption [18].

3.3 Modal Strain Energy:

MSE is the more delicate parameter to structural harm than natural frequency, appeared as a vital parameter for identifying damage in structural additives [19] & [20]. The methodology is dependent on strain control combined with the FEM to choose a subset of analyzed auxiliary vibration modes for basic mischief location [21]. FEM procedures have been founded absolutely on changing the FEM firmness, mass, and damping lattices to limit a couple of proportions of mistakes as a component of the FEM grids and estimated modular parameters. This methodology has furthermore received 3-mode decision strategies [14] & [21] related with the base modular recurrence or the absolute best degree of weight power. It became indicated that the mode decision approach dependent on the most noteworthy modular strain power delivers more right supplant results than method dependent on the base modular recurrence. The modular strain quality change-based absolutely strategy to restrict harm, and it also respected to be dominant in finding the basic damage [22]. The modular strain control change utilized now not most straightforward to limit the damage but rather furthermore to choose its worth.

3.4 Mode Shape Curvature:

Mode structure shape, viewed as a stunning section for harm recognition in primary segments or genuine scaffolds, can result from part of the modular examination. Truth told relevant harm discovery strategies had been affirmed with the expectation to find confined harm of genuine scaffolds [23] & [24]. The execution of a particular

extensive timespan vibration-based SHM contraption. The SHM gadget did on the scaffold got used to doing the modular investigation of encompassing vibrations with a reason to separate mode structure ebbs and flows. These ebbs and streams had discovered to have the option to distinguishing restricted mischief of the scaffold. Notwithstanding neighborhood harm recognizable proof, limited component rendition refreshing transformed into played out the utilization of tentatively estimated frequencies to higher speak to the primary direction of the extension while exposed to surrounding vibrations.

In light of the general assessment of the scaffold, persevered through nearby deck disappointment may realize a conclusion on account of severe decay related to the absence of ability. Subsequently, CFRP becomes settled on for the restoration of fundamental segments of the extension. The mode states of the solid deck have removed from encompassing vibration evaluations performed past to the repair and, at rare occasions, over a length of pretty much two years after recovery. Firmness alterations of the CFRP restored connect had been restricted and measured the use of the mode shape arches of the deck. Harm lists and fragmentary firmness changes determined dependent on the bends utilized to select and find alterations in the solidness of the solid deck.

3.5 Health Monitoring through Strain-Based:

The inclinations of VB SHM, there were some ongoing task by the utilization of the time-space system, fusing pressure measures to recognize the mischief in double carriageway spans. The time-space strategy might depict because of the examination of numerical highlights or physical flags as a component of time [25].

The critical rule of weight-based auxiliary wellbeing following is the physical changes of a shape will intention modifications inside the wavelength of stress estimations. One incredible addition to this methodology is that it can recognize and confine damage by methods for examining time-

area pressure estimations from spans. Additionally, the SB SHM of damage identification grants for simplicity of data arrangement and flexibility in the data examination while an encompassing site guest crosses a scaffold. The focal point of this stage is to abridge the discoveries on stress-based, absolutely SHM frameworks used to an endless supply of double carriageway spans.

Although an enormous number of researches for the vibration-based SHM gadget has led to harm identification of extensions, the minimal amount of late examinations has endeavored to find damage on genuine scaffolds through the SB SHM framework. One of the most extreme intensive real scaffold damage recognition examines propelled a weight-based SHM contraption that estimates pressure amounts [26].

3.6 STRUCTURAL CAPACITY EVALUATION:

For double carriageway connect upkeep, connect needs to evaluate the advanced essential potential. It is generally referred to that a heap rating as a proportion of the capacity of extensions crosswise over areas inside the United States has been comprehensively utilized. The AASHTO Manual for circumstance appraisal of scaffolds [1] offers proposals while in transit to assess ability through the loads. Demonstrative truck appraisals along the edge of limited detail are much of the time executed to assess load scores [27] & [28]. These scientists have discovered that the heap scores are preservationists on numerous occasions and that an extension has an extra auxiliary limit than that foreseen by method for the checks.

To appraise more noteworthy properly the heaps speaking to the contemporary limits of scaffolds, best in class limited detail designs should be aligned with surrounding traffic data estimated from either VB absolutely or stress-principal SHM structures. This portion is devoted to a writing evaluation on the heap rating figuring utilizing either limited component styles adjusted with discipline

measurements or unwavering quality examination the utilization of observing insights.

3.7 Finite Element Model:

The stacking rating estimation has ordinarily completed during the limited component styles aligned with territory actualities got from a pressure put together SHM contraption concerning an extension stacked with vans wearing their most approved masses with recognized attributes. When the limited component rendition for the extension gets approved with estimations from the field, giving it a shot, the variant transformed into used to build up a benchmark load rating for the scaffold. Anticipated burden evaluations of a 3-length constant metallic brace wearing paths of Interstate in Delaware of the US after which ventured forward them through the utilization of analytic burden testing with the SB SHM framework [29]. As indicated by the AASHTO Standard [1], stock and working burden evaluations have resolved with the dissemination components (DFs) decided through the AASHTO particulars-over rule as an element of support dividing and connected characteristics that turned out to previously presented in the Nineteen Thirties. The heap evaluations had then refreshed with the symptomatic test outcomes. The SHM gadget for persistently following encompassing traffic strains inside the extension to refreshing burden rankings utilizing surrounding observing information. The artworks concentrated on a general portrayal of the system convention that may use for load scores.

The weight rating of an extension through analytic burden testing dependent on a pressure based SHM framework. The scaffold became outfitted with a few weight sensors and tried with vehicles with respected hundreds [30]. Results from the aligned model have utilized to decide the weight rating and have then contrasted, and the ones got from customary score computation as per the AASHTO Standard [1]. It became discovered that the scores yielded from the adjusted model had been enormous than those gained from the traditional

system. The discoveries obtained from work by methods had well [31]. In San Ysidro bridge in US Highway region live load giving a shot on the pre-focused on concrete [31]. A limited component rendition transformed into moreover made and adjusted using assessing flexural minutes got from the model and discipline looking. The territory giving a shot alongside the modified limited detail variant changed into used to decide the heap appraisals, which were in correlation with the weight rating from the AASHTO well known and AASHTO LRFD determination [32].

Notwithstanding the weight score commitment, a couple of studies have performed to gauge auxiliary firmness identified with basic limit utilizing limited subtleties combined with a vibration-essentially based SHM following machine. A period space separating method dependent on vibration estimations because of a seismic tremor event to right presently see basic solidness estimations of an extension. A limited detail rendition of the extension turned out to be moreover produced in MAT Lab programming, utilizing more than one edge factor with knot masses. The solidness esteems state-of-the-art the utilization of the deliberate reactions sooner than and after mischief. It demonstrated that the firmness corruption and areas concurred appropriately with the scaffold harm saw through the previous visual examination and stress estimations. To understand basic firmness estimations of a real extension, stretched out their work to a three-range nonstop pre-focused on confine brace connect put Irvine, California inside the United States. The examination utilized the equivalent SHM method. The extension's essential solidness accurately refreshed in light of on vibration estimations taken on the scaffold over a length of five years. Different techniques, remembering a stochastic model of surrounding traffic excitation for an extension, have moreover been incorporated directly into a vibration-based SHM device to evaluate a present scaffold's auxiliary limit, enveloping fundamental firmness [33].

3.8 Accuracy Analysis:

Treat vulnerability in live loads related to truck weight data, dynamic impact, and brace dissemination components; load rankings had likewise refreshed the utilization of various dependability systems consolidating either encompassing or zone load testing realities estimated from a weight-based SHM gadget [68]. A dependability based structure for the assurance of burden appraisals utilizing website page specific in-supplier strain measurements in an LRFR group [70]. It became found that this system transformed into a way to decrease the vulnerability in live hundreds with the guide of the utilization of in-supplier stress realities, and changed into fit for making sense of burden appraisals for vary return spans and target dependability files, which outfitted preferable confidence arranges overdid the AASHTO rankings.

A few types of research for time-organized methods like rankings pressure methods established to overcome the utilization of unwavering quality methods [67] & [68] For example, propelled an unwavering quality based structure to break down subordinate time connections between loads and dependability records for falling apart scaffolds and alongside 14 sorts of highways are connected in the transportation network. The time-setup rankings and records processed by methods for consolidating probabilistic crumbling designs for concrete and metallic failure after some time by the utilization of Monte Carlo reproduction. Examinations of rankings and records had made over the presence of time extensions inside the network. The procedure for computation of time- subordinate pressure evaluations considered for establishing the extensions utilizes for the supplier's data in an enhanced LRFR design.

3.9 REMAINING LIFE ESTIMATION:

Assessing the last existence of double carriageway scaffolds will turn into a significant component in long haul connect execution control? Interstate scaffolds experience developing encompassing traffic loads, bringing about collective

weariness pushes and crumbling span added substances because of maturing results identified with ecological conditions. As examined, at last, some of the extensions have surpassed their design ways of life because of the surrounding site guests and factor crumbling.

Comparative with harm recognition or potential basic research, just a few examinations to break down the anticipated last ways of life of scaffolds had been done, coordinating observing records got from spans using an SHM contraption. These examinations had been, for the most part, practiced dependent on a probabilistic system or armada the executives. The accompanying writing assesses each topic provided in the component.

STUDY OF EVALUATION

There are several research of SHM are concentrating on the advancement of destruction identification algorithms in bridge. Algorithm based destruction identification evolved on vibration and stress measurements implemented to damaged bridges [34].

Notwithstanding the SHM harm location calculations, SHM structures nearby the classified technique outfitted inside the AASHTO manuals utilized to appraise the weight donning limits of double carriageway connects progressively. The basic limit has the use of a heap idea ordinarily. Most investigations [29] & [34] did the heap counts at specific, discrete, and unpredictable occasions chose with the guide of adjustments in stacking and capacity of the scaffold. Field and research center burden checks related to aligned limited detail designs had additionally used to decide the weight appraisals at pivotal occasions in light of the AASHTO determinations [1].

Remaining ways of life have furthermore generally related to potential calculations in the mix with strain amounts acquired from SHM structures [5]. The auxiliary execution of existing extensions dependent on the primary reaction checked from a weight fundamentally based observing contraption and a circumstance appraisal of basic parts [35]. A

strain-based following machine into the auxiliary in general execution appraisal of a metal support scaffold and utilize the resulting data to conduct a basic dependability assessment of its crucial areas [5].

Observations:

The below table describes the more relevant reviews on structural health monitoring of bridges by various method

TABLE.1: RELEVANT REVIEWS ON STRUCTURAL HEALTH MONITORING

Author	Objective	Overcomes
Chajes et al. 2000 [29]; Chen et al. 2009 [33]	Time- Based Specifications	Describes the changes in bridge by the performance of the load at certain, discrete and irregular specifications.
Liu et al. (2009a) [35]	Stress/Strain-Based Monitoring	The response of the existing structure and identifies the condition of bridge by strain-based monitoring.
Farrer and Worden (2007) [5]	Damage Detection Algorithm	Stiffness, Damping, and Mass are the physical properties of the structure which may unfavorable to the structure can be identify the damage detection algorithm.
Fox 1992 [10]	Mode Shape and Mode Shape Curvature	Model strain energy and Mode shape is more widely used to detect the localized damages in bridges.
Cawley and Adams (1979) [13]	Damage Identification Algorithm	DDA (DIA) techniques can be able to identify, limit and damage extension by using the changes in Frequencies of the structures.
Sakai et al. (2007) [8]	Seismic Damage Identification	The Seismic Damage identification Techniques are used to evaluate the performance of the steel & concrete Bridges.
Doebling et al. 1997 [19]; Shi et al. 2000 [20];	Strain Energy	A natural frequency is more effective than the strain energy and is considered for the major factor in structure.

SUMMARY AND CONCLUSIONS

There has a significant scope of investigations of VB and SB SHM structures in the course of the last a few numerous years. The studies that have outlined in this stylish assess paper have concentrated on damage identification, assessment of burden conveying limits, and estimation of the rest of the ways of life of scaffolds. From the evaluation of this previous work, the accompanying could make, and the accompanying limits can be called attention to, with a view to the corresponding betterment of the SHM framework for helping long term remodel and essential recovery leadership inside the tally of street spans.

1. Damage detections are depends on the vibration, and strain estimation of the model that consider for the explanatory models. It considers the actual scaffolds exposed to the damage area. Standard

frequencies are most likely helpful pointers of mischief markers, the usage of the vibration-based SHM framework. Past investigations developed that mode shape ebbs and stream coming around because of particular appraisal computations had the decision to find ordinary restricted sizeable mischief to ranges. Despite the vibration-fundamentally basically based SHM structure, the pressure based absolutely SHM framework joined with harm notoriety set of arrangements changed into ready to do numerically get aware of the spots of damage to a metallic help interface. Through the result of the device to the genuine twofold carriageway interface with propitiatory hurt models, the structure feasibility got delineated. In light of the composing evaluation, every vibration-based absolutely and stress-based definitely prosperity checking systems had quick quickened to go over fiendishness to ranges. The basic opening inside the present composing that has gotten kept an eye on is an automated and re-dependable prosperity gazing at the contraption that can fittingly save onto a dynamic and enveloping limits sooner or later of the years, the utilization of either vibration or strain estimations to see naughtiness to ranges revealed to encompassing site guests.

2. The significant capacity has commonly assessed through methodology for the utilization of weight evaluations. Most examinations did the load rating estimation at specific, discrete, and flighty timespans chose through changes in stacking and limitation of the framework. The issue and studies office load tests, together with adjusted limited viewpoint plans, widely used to pick the heap investigates at basic physical exercises, essentially dependent on the AASHTO particulars and manuals. A couple of examinations had been fused with a normal quality assessment to check time-delicate scores and a constancy record with discipline measurements. The impressive hole found from the review is turning into an individual from the abilities to electronic controlled detail clean structures for assessing draining side helper capability of existing

expansions following the framework arrangement codes.

3. Remaining assistance methods for presence has anticipated together with constancy computations, and with the SB SHM techniques. The strain-in a general sense based absolutely the accompanying machine has introduced directly into a straightforward in favored execution evaluation of a contemporary framework.

REFERENCES

1. AASHTO. (2000), (2003), (2008), (2011), Manual for Condition Evaluation of Bridges, Washington, DC.
2. La Corte, R. (2014). "Review: Multiple errors led to I-5 Skagit River bridge collapse." Komonews.
3. Radzienski, M., Dolinski, Ł., Krawczuk, M., and Palacz, M. (2013). "Dam- age localization in a stiffened plate structure using a propagating wave." Mech. Syst. Sig. Process., 39(1–2), 388–395.
4. Dawson, B. (1976). "Vibration condition monitoring techniques for rotating machinery." Shock Vibr. Dig., 8(12), 3–8.
5. Farrar, C. R., and Worden, K. (2007). "An introduction to structural health monitoring." Philos. Trans. R. Soc. London, Ser. A, 365(1851), 303–315.
6. Farrar, C., (1994). "Dynamic characterization and damage detection in the I-40 bridge over the Rio Grande." Los Alamos National Laboratory, Los Alamos, NM.
7. Liu, M., and Frangopol, D., and Kim, S. (2009b). "Bridge safety evaluation based on monitored live load effects." J. Bridge Eng., 10.1061/(ASCE) 1084-0702(2009)14:4(257), 257–269.
8. Sakai, J., Kobayashi, H., and Unjoh, S. (2007). "Real-time earthquake damage detection system for bridge structures." Proc., 23rd US-Japan Bridge Engineering Workshop, Public Works Research Institute.
9. Salawu, O. S. (1997). "Detection of structural damage through changes in frequency: A review." Eng. Struct., 19(9), 718–723.
10. Fox, C. (1992). "The location of defects in structures: A comparison of the use of natural

frequency and mode shape data." Proc., 10th Int. Modal Analysis Conf., Society for Experimental Mechanics, Vol. 1, San Diego, CA, 522–528.

11. Whelan, M. J., Gangone, M. V., Janoyan, K. D., and Jha, R. (2009). "Real- time wireless vibration monitoring for operational modal analysis of an integral abutment highway bridge." Eng. Struct., 31(10), 2224–2235.

12. Fugate, M., Shon, H., and Farrar, C. (2001). "Vibration-based damage detection using statistical process control." Mech. Syst. Sig. Process., 15(4), 707–721.

13. Cawley, P., and Adams, R. D. (1979). "The location of defects in structures from measurements of natural frequencies." J. Strain Anal. Eng. Des., 14(2), 49–57.

14. Kato, M., and Shimada, S. (1986). "Vibration of PC bridge during failure process." J. Struct. Eng., 10.1061/(ASCE)0733-9445(1986) 112:7(1692), 1692–1703.

15. Kim, J. T., Ryu, Y. S., Cho, H. M., and Stubbs, N. (2003a). "Damage identification in beam-type structures: Frequency-based method vs mode-shape-based method." Eng. Struct., 25(1), 57–67.

16. Kim, J.-T., Yun, C.-B., and Yi, J.-H. (2003b). "Temperature effects on frequency-based damage detection in plate-girder bridges." KSCE J. Civ. Eng., 7(6), 725–733

17. Kim, J. T., and Stubbs, N. (2003). "Nondestructive crack detection algorithms for full-scale bridges." J. Struct. Eng., 10.1061/(ASCE) 0733-9445(2003)129:10(1358), 1358–1366.

18. Whelan, M., and Janoyan, K. (2010). "In-service diagnostics of a highway bridge from a progressive damage case study." J. Bridge Eng., 10.1061/ (ASCE)BE.1943-5592.0000088, 597–607.

19. Doebling, S., Hemez, F., Peterson, L., and Farhat, C. (1997). "Improved damage location accuracy using strain energy-based on mode selection criteria." AIAA J., 35(4), 693–699.

20. Shi, Z. Y., Law, S. S., and Zhang, L. M. (2000). "Structural damage detection from modal strain energy change." J. Eng. Mech., 10.1061/ (ASCE)0733-9399(2000)126:12(1216), 1216–1223.

21. Choy, F., Liang, R., and Xu, P. (1995). "Fault identification of beams on elastic foundation." Comput. Geotech., 17(2), 157–176.

22. Sampaio, R., Maia, N., and Silva, J. (1999). "Damage estimation using the frequency-response- function curvature method." J. Sound Vib., 226(5), 1029–1042.

23. Guan, H., Karbhari, V., and Sikorsky, C. (2006). "Web-based structural health monitoring of an FRP composite bridge." Comput.-Aided Civ. Infrastruct. Eng., 21(1), 39–56.

24. Guan, H., Karbhari, V., and Sikorsky, C. (2007). "Long-term structural health monitoring system for a FRP composite highway bridge structure." J. Intell. Mater. Syst. Struct., 18(8), 809–823.

25. Pandey, G., Thostenson, E. T., and Heider, D. (2013). "Electric time domain reflectometry sensors for non-invasive structural health monitoring of glass fiber composites." Progr. Electromagn. Res., 137, 551–564.

26. Wipf, T., Phares, B., and Doornink, J. (2007). "Evaluation of steel bridges- volume I, monitoring the structural condition of fracture-critical bridges using fiber optic technology." Iowa DOT TR-493, Center for Transportation Research and Education, Iowa State Univ., Ames, IA.

27. Faber, M. H., Val, D. V., and Stewart, M. G. (2000). "Proof load testing for bridge assessment and upgrading." Eng. Struct., 22(12), 1677–1689.

28. Moses, F., Lebet, J. P., and Bez, R. (1994). "Applications of field testing to bridge evaluation." J. Struct. Eng., 10.1061/(ASCE)0733-9445(1994) 120:6(1745), 1745–1762.

29. Chajes, M., Shenton, H., III, and O'Shea, D. (2000). "Bridge-condition assessment and load rating using nondestructive evaluation methods." Transportation Research Record 1696, 83–91.

30. Phares, B., Wipf, T., Klaiber, F., and Abu-Hawash, A. (2003). "Bridge load rating using physical testing." Proc., Mid-Continent Transportation Research Symp., Iowa State Univ., Ames, IA.

31. Barr, P., Woodward, C., and Najera, B. (2003). "Long-term structural health monitoring of the San Ysidro Bridge." Research Project No. NM02STR- 02, Bridge Research Center, New Mexico State Univ.

32. AASHTO. (1998). LRFD bridge design specifications, 2nd Ed., Washington, DC.

33. Chen, Y., Feng, M., and Tan, C. (2009). "Bridge structural condition assessment based on vibration and traffic monitoring." J. Eng. Mech., 10.1061/(ASCE)0733-9399(2009)135:8(747), 747–758.

34. Magalhães, F., Cunha, A., and Caetano, E. (2010). "Continuous dynamic monitoring of an arch bridge: strategy to eliminate the environmental and operational effects and detect damages." Proc., ISMA2010 Int. Conf. on Noise and Vibration Engineering, 1419–1434.

35. Liu, C., DeWolf, J., and Kim, J. (2009a). "Development of a baseline for structural health monitoring for a curved post-tensioned concrete box-girder bridge." Eng. Struct., 31(12), 3107–3115.