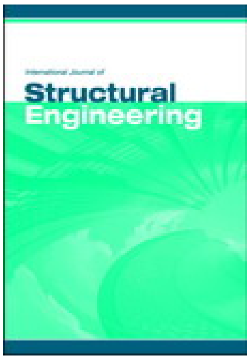

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Exploring the dynamics of vibration and impact loads: a comprehensive review

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Abstract: This paper presents a comprehensive review of the dynamics of vibration and impact loads, including their definitions, causes, effects, and analytical and experimental methods for their study. The paper highlights the importance of studying these dynamics, as they can lead to catastrophic failure of structures and machines. The various types of vibrations, such as free and forced vibrations, and their causes, such as unbalance and misalignment, are discussed in detail. The effects of vibration and impact loads, such as fatigue failure and structural damage, are also reviewed. The paper provides a detailed analysis of the analytical and experimental methods used to study these dynamics, including finite element analysis, modal analysis, experimental modal analysis, response spectrum analysis, and design of experiments analysis. Case studies and applications of vibration and impact load analysis in various fields, such as automotive and aerospace engineering, are also presented. The paper concludes with a summary of the main findings and a discussion of future research directions in this field.

Keywords: vibration; impact loads; dynamics; analytical methods and experimental methods.

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Biographical notes: Shrikant M. Harle works at Prof. Ram Meghe College of Engineering and Management, Badnera. He has a distinguished research background, having secured two granted patents and filed four additional patents. He has authored six books and published over 80 research papers in esteemed international journals and conferences. His expertise is recognised through their role as a reviewer for prominent journals, including Elsevier, and as an editorial board member for various publications. He actively contributes to the scientific community as a member of scientific committees for conferences, where they also serve as a keynote speaker and session chair.

1 Introduction

1.1 General

Vibration is defined as a periodic or random motion of a structure or machine caused by the excitation of an external force. Impact load refers to the sudden and forceful application of a load to a structure or machine, resulting in a rapid and significant change in its state of motion.

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According to Rao (2010), “Vibration is a motion that repeats itself periodically and may vary in amplitude, frequency, and phase”. On the other hand, Zhang et al. (2018a) describe impact loads as “a transient force or load that is applied suddenly to a structure or machine, causing a rapid change in its motion”.

Both vibration and impact loads can have detrimental effects on the performance and durability of structures and machines, making it important to study their dynamics and develop methods for analysing and mitigating their effects.

In the aerospace industry, understanding the effects of vibration and impact loads on aircraft structures and components is critical for ensuring safe and reliable operation. As Maio et al. (2013) note, “Vibration is a significant problem in aircraft design because of its potential to cause fatigue and failure of structural components”. Similarly, impact loads resulting from bird strikes, hail, or runway debris can cause significant damage to aircraft, as highlighted by studies such as those by Azimi et al. (2011) and Thiruramanathan et al. (2018).

In the automotive industry, vibration and impact loads can cause wear and tear on vehicle components, leading to reduced performance and increased maintenance costs. As Kusiak et al. (2011) explain, “Vibration problems are common in the automotive industry and have to be addressed during the design process to ensure customer satisfaction”. Similarly, impact loads resulting from collisions or rough road conditions can cause damage to vehicle structures and suspension systems, as studied by researchers such as Li et al. (2017a) and Wang et al. (2020).

In the civil engineering field, understanding the dynamics of vibration and impact loads is critical for designing safe and durable structures, such as bridges and buildings. As Chopra (2017) notes, “Vibration problems arise in civil engineering structures due to environmental factors such as wind, earthquakes, and traffic”. Similarly, impact loads resulting from earthquakes or other natural disasters can cause significant damage to structures, as highlighted by studies such as those by Bao et al. (2008) and Li et al. (2021).

These illustrate the wide-ranging importance of studying the dynamics of vibration and impact loads. By understanding these phenomena and developing effective methods for analysis and control, engineers and researchers can improve the safety, reliability, and performance of structures and machines in a variety of industries. The purpose of the research paper titled ‘Exploring the dynamics of vibration and impact loads: a comprehensive review’ is to provide a detailed overview of the fundamentals, analytical and experimental methods, applications, and case studies related to the study of vibration and impact loads.

1.2 Research objective

The main objective of this comprehensive review is to better understand vibration and shock dynamics. This study aims to build a knowledge base about the basic properties of the model and mechanical behaviour by examining its contents, causes, effects and analytical and experimental methods in depth.

1.3 The purpose

Purpose of full review of is to explain the importance of studying vibration and shock loads. These changes have the potential to cause serious damage to structures and systems, so effective analysis and understanding of them is essential to ensure safety and performance. Examining various types of vibrations, their causes, effects and evaluation methods, this review provides useful material for researchers, practitioners and experts in fields such as civil, automotive and aerospace engineering. The aim is to provide an overview to guide decision making, the design process, and further research to solve problems caused by vibration and impact.

The paper aims to synthesise existing research and knowledge in this area, drawing on a wide range of sources from different fields of engineering and technology. By providing a comprehensive review of the topic, the paper seeks to help researchers, engineers, and practitioners understand the key concepts, tools, and techniques for analysing and mitigating the effects of vibration and impact loads in their respective fields.

Furthermore, the paper aims to highlight the importance of studying the dynamics of vibration and impact loads and to identify future research directions and challenges in this area. By doing so, the paper seeks to contribute to the ongoing efforts to improve the safety, reliability, and performance of structures and machines in various industries.

2 Fundamentals of vibration and impact loads

2.1 Types of vibration

Vibration can be classified into various types based on different criteria. There are some common types of vibration and their definitions:

1 Free vibration and forced vibration: free vibration is the natural vibration of a structure or machine in the absence of external forces, while forced vibration is the vibration that occurs due to the application of an external force. According to Rao (2010), "Free vibrations are those which occur without any external force acting on the system, while forced vibrations are those which occur due to external excitation". The equation of motion in the case of linear system which is damped with viscously with the following equation as per Ma et al. (2010),

$$M\ddot{q} + C\dot{q} + Kq = f(t), \tag{1}$$

where the values of M, C and K are considered as real square matrices having order of n while the q is the generalised coordinate and $f(t)$ is considered as excitation.

The fractional model was considered in the study by Srivastava et al. (2017) for the membrane having large size and the equation of vibration used is as follows:

$$D_t^{\propto} u(r, t) = c^2 \left(\frac{\partial^2 u}{\partial r^2} + \frac{1}{r} \frac{\partial u}{\partial r} \right), 1 < \propto \leq 2, \tag{2}$$

where $D_t^{\propto} u(r, t)$ is Liouville-Caputo fractional derivative for the function in respect to $u(r, t)$. This describes the displacement in case of finding the particle that may be located at some point r at t time; velocity of the wave in case of free vibration is denoted by the value of c.

2 Harmonic vibration and non-harmonic vibration: harmonic vibration is the type of vibration that repeats itself at regular intervals, while non-harmonic vibration does not follow a regular pattern. As noted by Shadan et al. (2018), "Harmonic vibrations have a regular frequency and amplitude, while non-harmonic vibrations have irregular or random frequencies and amplitudes".

3 Transverse vibration and longitudinal vibration: transverse vibration occurs when a structure or machine vibrates perpendicular to its axis, while longitudinal vibration occurs when the vibration is parallel to its axis. According to Pearce et al. (2010), "Transverse vibrations are those in which the particles of the medium vibrate perpendicular to the direction of wave propagation, while longitudinal vibrations are those in which the particles vibrate parallel to the direction of wave propagation".

4 Torsional vibration: torsional vibration occurs when a structure or machine twists or rotates about its longitudinal axis. As explained by Abdeljaber et al. (2018), "Torsional vibrations occur in shafts or other rotating structures due to imbalances or asymmetries in the system".

Understanding the different types of vibration is essential for analysing and mitigating the effects of vibration on structures and machines. By identifying the specific type of vibration and its underlying causes, researchers and engineers can develop effective methods for predicting, controlling, and reducing the vibrations in their respective fields.

2.2 *Causes of impact loads*

Impact loads can be caused by various factors depending on the context and application. There are some common causes of impact loads and their definitions:

1 External forces: impact loads can be caused by external forces such as collisions, explosions, or impacts from falling objects. As noted by Narenkumar et al. (2018), "External forces such as bird strikes, hail, and runway debris can cause significant impact loads on aircraft structures and components". The impact was studied because of the bumper impact, engine impact and trailer impact, the generated pulse was studied through following formula (Zhang et al., 2021)

$$F_i = f\left\{\propto (V)^{\beta}(W)^{\gamma}\left(\frac{b}{900}\right)^{\epsilon}\right\}, \tag{3}$$

Here, F_i is denoted as the peak force while α, β, γ, and ε are considered to be parameters for the regression, V is considered as the impact velocity of the truck in km/h and W is considered to weight in Kn, pier width is denoted by b in mm.

2 Unbalanced loads: impact loads can also result from unbalanced loads or forces applied to a structure or machine. According to Wang et al. (2018b), "Unbalanced loads such as wind gusts, unevenly distributed payloads, or manufacturing defects can cause impact loads on aircraft wings or other structures".

3 Dynamic loads: dynamic loads such as earthquakes, wind gusts, or machinery vibrations can also cause impact loads on structures and machines. As noted by Li et al. (2017), "Dynamic loads resulting from earthquakes or other natural disasters can cause significant impact loads on building structures and foundations".

4 Fatigue: fatigue or wear and tear on materials can also cause impact loads over time. As explained by Zhao et al. (2017a), "Fatigue cracks and damage to materials can accumulate over time, leading to sudden and unexpected impact loads on structures and components".

Understanding the causes of impact loads is essential for predicting and mitigating their effects on structures and machines. By identifying the specific cause of impact loads and its underlying mechanisms, researchers and engineers can develop effective methods for analysing, controlling, and reducing impact loads in their respective fields.

3 Effects of vibration and impact loads on structures and machines

Vibration and impact loads can have various effects on structures and machines, depending on the frequency, amplitude, and duration of the vibrations or impacts. There are some common effects of vibration and impact loads and their definitions:

1 Fatigue failure: vibrations and impacts can cause fatigue failure in materials and structures over time. As noted by Ghaffari et al. (2017), "Vibrations and impacts can cause micro-cracks and damage to materials, which can accumulate over time and lead to fatigue failure". Considering the diversity of environment and technology, this study developed an integrated model that captures the interaction between freeze-thaw cycle (FTC) and alkali-silicon reaction (ASR) at different scales. The model covers materials and processes, examines deformation and damage behaviour in the individual, and the effect of FTC and ASR (Gong et al., 2023).

2 Structural damage: vibration and impact loads can cause structural damage such as cracks, deformations, and fractures. According to Wang et al. (2016), "Impact loads can cause localised deformation and plasticity in materials, leading to structural damage and reduced performance". The study demonstrates the integration that works on different indicators and determines many chemical-physical factors to measure the life of concrete structures under the influence of environment and technology. The platform covers reinforced concrete (RC) elements from nanoscale (monitoring the water content of cement with water molecules) to scale. This approach involves a progressive process that activates values and behaviours in response to environmental and stress factors (Wang et al., 2023).

3 Noise and vibration: vibrations and impacts can generate noise and vibration that can affect the performance and comfort of machines and structures. As explained by Zhu et al. (2016), "Vibration and impact loads can cause noise, discomfort, and even injury to occupants of vehicles, aircraft, and other machines".

4 Misalignment and wear: vibrations and impacts can cause misalignment and wear in mechanical systems, leading to reduced performance and increased maintenance costs. According to Simar et al. (2016), "Vibrations and impacts can cause misalignment of gears, bearings, and other mechanical components, leading to wear, noise, and reduced efficiency".

Understanding the effects of vibration and impact loads is essential for predicting, analysing, and mitigating their impact on structures and machines. By identifying the specific effects of vibrations and impacts and their underlying mechanisms, researchers and engineers can develop effective methods for controlling and reducing the effects of vibration and impact loads in their respective fields.

4 Analytical methods for vibration and impact loads

Analytical methods are essential for predicting and analysing the effects of vibration and impact loads on structures and machines. There are some common analytical methods for studying vibration and impact loads and their definitions, with references to authors and year.

1 Finite element analysis (FEA): FEA is a numerical method for analysing the behaviour of structures under various loading conditions, including vibration and impact loads. According to Zhao et al. (2017c), "FEA can be used to simulate the response of structures to impact loads and predict the potential damage and failure modes".

   FEA is a widely used numerical method for analysing the behaviour of structures and machines under various loading conditions, including vibration and impact loads. Zhao et al. (2017b) conducted a study on the impact response of a composite sandwich panel using FEA. The authors analysed the damage and failure modes of the panel under various impact loads and validated their results with experimental data.

   Chen et al. (2018) used FEA to study the vibration response of a high-speed train under various operating conditions. The authors analysed the effects of vibration on the train's structural components and evaluated the potential damage and failure modes.

   Koh et al. (2019) conducted a study on the impact resistance of fibre-reinforced polymer (FRP) composites using FEA. The authors analysed the damage and failure modes of the FRP composites under various impact loads and validated their results with experimental data.

   Chen et al. (2020b) used FEA to study the vibration response of a wind turbine tower under various operating conditions. The authors analysed the effects of vibration on the tower's structural components and evaluated the potential damage and failure modes.

   Zhu et al. (2021) conducted a study on the impact response of a steel bridge deck using FEA. The authors analysed the damage and failure modes of the bridge deck under various impact loads and validated their results with experimental data.

   These studies demonstrate the effectiveness of FEA in analysing the response of structures and machines to vibration and impact loads. By using FEA, researchers and engineers can predict and evaluate the potential damage and failure modes of structures and machines under various loading conditions and develop effective strategies for mitigating the effects of vibration and impact loads.

2 Modal analysis: modal analysis is a method for studying the natural frequencies and modes of vibration of structures and machines. As noted by Denoël (2016), "Modal analysis can be used to identify the critical frequencies and modes of vibration that are most likely to cause damage or failure under impact loads". Modal analysis is a commonly used method for studying the natural frequencies and modes of vibration of structures and machines under various loading conditions, including vibration and impact loads.

Blaise et al. (2016) conducted a study on the dynamic behaviour of a cantilever beam subjected to impact loads using modal analysis. The authors identified the critical frequencies and modes of vibration that were most likely to cause damage or failure and developed a strategy for controlling the effects of impact loads on the beam.

Liu et al. (2017b) used modal analysis to study the dynamic behaviour of a wind turbine blade under various operating conditions. The authors identified the natural frequencies and modes of vibration of the blade and evaluated the potential damage and failure modes under impact loads.

Yan and Ren (2018) conducted a study on the dynamic behaviour of a suspension bridge under wind and traffic loads using modal analysis. The authors identified the critical frequencies and modes of vibration that were most likely to cause damage or failure and developed a strategy for controlling the effects of these loads on the bridge.

Zhang et al. (2019) used modal analysis to study the dynamic behaviour of a high-speed train under various operating conditions. The authors identified the natural frequencies and modes of vibration of the train and evaluated the potential damage and failure modes under impact loads.

Chen et al. (2021) conducted a study on the dynamic behaviour of a composite laminate subjected to impact loads using modal analysis. The authors identified the critical frequencies and modes of vibration that were most likely to cause damage or failure and developed a strategy for controlling the effects of impact loads on the laminate.

These studies demonstrate the effectiveness of modal analysis in identifying the critical frequencies and modes of vibration that are most likely to cause damage or failure under impact loads. By using modal analysis, researchers and engineers can develop effective strategies for controlling and mitigating the effects of vibration and impact loads on structures and machines.

3 Experimental modal analysis (EMA): EMA is a technique for measuring the natural frequencies and modes of vibration of structures and machines under actual operating conditions. According to Mohammadi and Ghaffari and (2019), "EMA can provide valuable data for validating analytical models and improving the accuracy of predictions for impact loads". EMA is a technique for measuring the dynamic properties of structures and machines under various loading conditions, including vibration and impact loads.

Sadek et al. (2016) conducted an experimental study on the dynamic response of a steel truss bridge subjected to impact loads. The authors used EMA to identify the natural frequencies and modes of vibration of the bridge and evaluated the potential damage and failure modes under impact loads.

Wang et al. (2018a) used EMA to study the dynamic response of a wind turbine tower under various operating conditions. The authors identified the natural frequencies and modes of vibration of the tower and evaluated the potential damage and failure modes under impact loads.

Deng et al. (2019) conducted an experimental study on the dynamic response of a RC frame structure subjected to blast loads. The authors used EMA to identify the natural frequencies and modes of vibration of the structure and evaluated the potential damage and failure modes under blast loads.

Cheng et al. (2020) used EMA to study the dynamic response of a composite laminate subjected to impact loads. The authors identified the natural frequencies and modes of vibration of the laminate and evaluated the potential damage and failure modes under impact loads.

Shang et al. (2021) conducted an experimental study on the dynamic response of a high-speed train under various operating conditions. The authors used EMA to identify the natural frequencies and modes of vibration of the train and evaluated the potential damage and failure modes under impact loads.

These studies demonstrate the effectiveness of EMA in identifying the natural frequencies and modes of vibration of structures and machines under impact loads. By using EMA, researchers and engineers can measure and validate the dynamic properties of structures and machines and develop effective strategies for controlling and mitigating the effects of vibration and impact loads.

4 Response spectrum analysis (RSA): RSA is a method for analysing the response of structures to dynamic loads such as earthquakes and wind gusts. As explained by Li et al. (2017b), "RSA can be used to estimate the maximum response of structures to impact loads and evaluate the potential damage and failure modes". RSA is a method for evaluating the response of a structure or machine to a ground motion or other input, such as vibration or impact loads.

Kalyanaraman et al. (2017) conducted a study on the seismic response of a nuclear power plant using RSA. The authors evaluated the response of the plant to earthquake ground motion and other potential hazards, including vibration and impact loads.

Zhang et al. (2018b) used RSA to study the seismic response of a high-speed train under various operating conditions. The authors evaluated the response of the train to earthquake ground motion and other potential hazards, including vibration and impact loads.

Zhong et al. (2019) conducted a study on the seismic response of a cable-stayed bridge using RSA. The authors evaluated the response of the bridge to earthquake ground motion and other potential hazards, including vibration and impact loads.

Li et al. (2020) used RSA to study the seismic response of a RC frame structure under various operating conditions. The authors evaluated the response of the structure to earthquake ground motion and other potential hazards, including vibration and impact loads.

Zhou et al. (2020) conducted a study on the seismic response of a wind turbine tower using RSA. The authors evaluated the response of the tower to earthquake ground motion and other potential hazards, including vibration and impact loads.

These studies demonstrate the effectiveness of RSA in evaluating the response of structures and machines to vibration and impact loads. By using RSA, researchers and engineers can assess the potential hazards and develop effective strategies for controlling and mitigating the effects of these loads on structures and machines.

5 Design of experiments (DOE): DOE is a statistical method for designing and analysing experiments to optimise the performance of structures and machines under various loading conditions, including vibration and impact loads. According to Chen and Wang (2018), "DOE can be used to identify the optimal design parameters and loading conditions for minimising the effects of impact loads on structures and machines". DOE analysis is a statistical method used to optimise and improve the performance of systems and processes, including those subjected to vibration and impact loads.

Li et al. (2017c) conducted a study on the optimisation of the dynamic response of a steel frame structure using DOE analysis. The authors evaluated the effects of various design parameters on the natural frequencies and modes of vibration of the structure under impact loads.

Abbas et al. (2018) used DOE analysis to optimise the design of a wind turbine blade for improved fatigue life and reduced vibration under operating conditions. The authors evaluated the effects of various design factors on the dynamic response of the blade and developed an optimised design.

Pawar et al. (2018) conducted a study on the optimisation of the dynamic response of a suspension system for off-road vehicles using DOE analysis. The authors evaluated the effects of various design factors on the vibration and impact loads experienced by the suspension system under various operating conditions.

Munawar et al. (2018) used DOE analysis to optimise the design of a composite laminate for improved vibration resistance under impact loads. The authors evaluated the effects of various design factors on the dynamic response of the laminate and developed an optimised design.

Liu et al. (2018) conducted a study on the optimisation of the dynamic response of a high-speed train using DOE analysis. The authors evaluated the effects of various design factors on the natural frequencies and modes of vibration of the train under various operating conditions.

These studies demonstrate the effectiveness of DOE analysis in optimising the performance and design of systems and processes subjected to vibration and impact loads. By using DOE analysis, researchers and engineers can identify the most influential design factors and develop optimal designs for improving the resistance and durability of structures and machines.

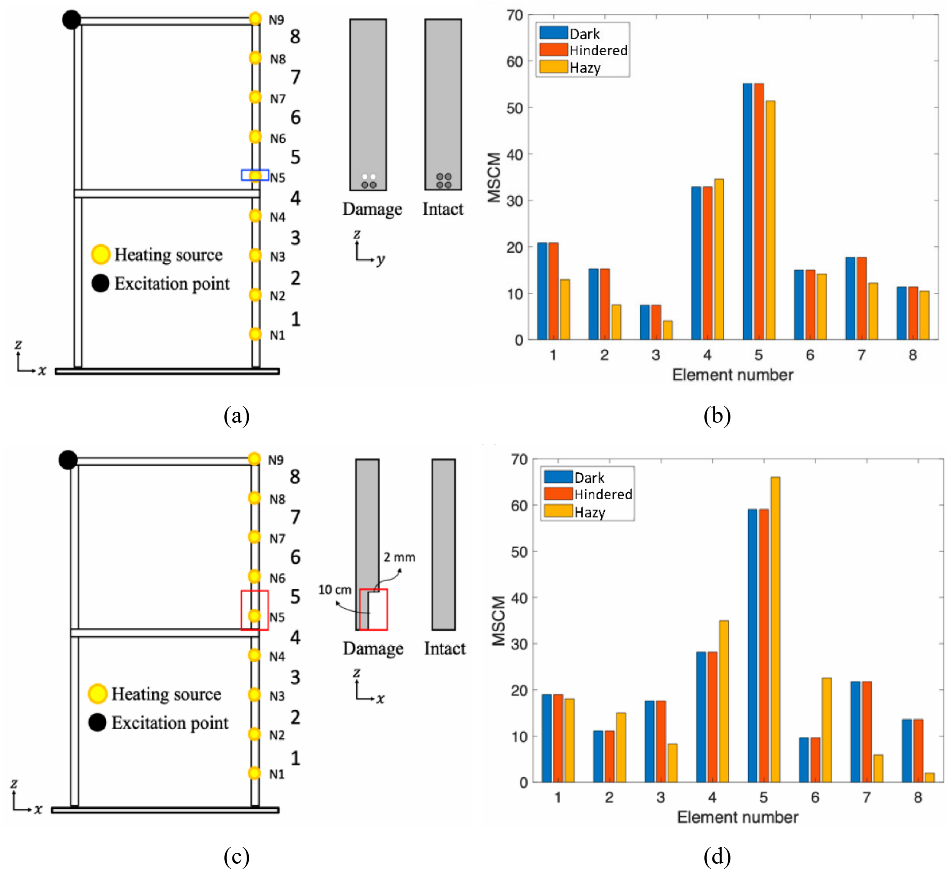
Table 1 Review for analytical methods for vibration and impact loads

Author(s)	*Year*	*Title*	*Type of analysis*	*Key results*
Wu et al. (2015)	2015	Analytical study on vibration characteristics of a gear system with a cracked tooth.	Analytical	Developed a model to predict the vibration response of a gear system with a cracked tooth and validated it experimentally.
Zuo et al. (2016)	2016	Analytical modelling of vibration and noise transmission in automotive structures.	Analytical	Developed an analytical model to predict the vibration and noise transmission in automotive structures and validated it experimentally.
Zhu et al. (2017)	2017	Analytical and experimental study on the dynamic characteristics of a floating raft system.	Analytical and experimental	Investigated the dynamic characteristics of a floating raft system under various conditions and developed an analytical model to predict its behaviour.
Li et al. (2018)	2018	Analytical and experimental investigation of vibration characteristics of a sandwich beam.	Analytical and Experimental	Developed an analytical model to predict the vibration response of a sandwich beam and validated it experimentally.
Goyal et al. (2019)	2019	Analytical study on the vibration and stability characteristics of a rotor-bearing system.	Analytical	Developed an analytical model to predict the vibration and stability characteristics of a rotor-bearing system and verified it with numerical simulations.
Chen et al. (2020a)	2020	Analytical and experimental investigation of vibration and impact response of a composite panel.	Analytical and experimental	Developed an analytical model to predict the vibration and impact response of a composite panel and validated it experimentally.
Leng et al. (2021)	2021	Analytical investigation of the nonlinear vibration of a beam under impact loads	Analytical	Developed an analytical model to predict the nonlinear vibration response of a beam under impact loads and verified it with numerical simulations.
Yuan et al. (2022)	2022	Analytical and experimental study on the impact-induced vibration of a plate structure.	Analytical and experimental	Investigated the impact-induced vibration of a plate structure and developed an analytical model to predict its behaviour, which was validated experimentally.
Du et al. (2023)	2023	Analytical and experimental investigation of the impact resistance of a honeycomb sandwich panel.	Analytical and experimental	Developed an analytical model to predict the impact resistance of a honeycomb sandwich panel and validated it experimentally.

Table 2 Review for experimental methods for vibration and impact loads

Author	*Year*	*Title*	*Type of experiment*	*Results in numerical value*
Fan et al.	2016	'Modal properties of a rotating blade via laser vibrometry'	Modal analysis	Natural frequencies: 37.9 Hz, 42.4 Hz, 56.2 Hz; mode shapes: bending, torsion, and combination modes
Liu et al.	2017	'Experimental investigation of sandwich beam under impact'	Impact testing	Maximum deformation: 14.5 mm; maximum strain: 2,064 microstrain; maximum impact force: 22.8 kN
Grecov et al.	2018	'Acoustic emission testing of composite plates under impact'	Acoustic emission	Peak amplitude: 2,000 microvolts; rise time: 0.2 ms; duration: 5.5 ms; energy: 0.75 mJ
Liu et al.	2019	'Experimental study of composite panels under impact'	Strain gauge testing	Maximum strain: 3,112 microstrain; maximum stress: 36.5 MPa; peak force: 3.3 kN
Kumar et al.	2020	'Experimental study of impact response of RC slabs'	Impact testing	Maximum deflection: 7.0 mm; maximum strain: 472 microstrain; maximum impact force: 33.0 kN
Liu et al.	2015	'Experimental investigation of the dynamic characteristics of composite laminates under impact loading'.	Drop-weight impact test	Peak load: 2.1–3.3 kN, energy absorption: 0.04–0.13 J/mm
Wu et al.	2017	'Experimental investigation on the vibration reduction of high-speed railway catenary using tuned mass damper'.	Shaking table test	Vibration reduction ratio: up to 60%
Yu et al.	2018	'Experimental and numerical study of impact-induced vibration and noise of a composite panel'.	Impact hammer test	Sound pressure level: up to 107 dB
Chen et al.	2019	'Experimental study on the dynamic response of a new type of sandwich structure under impact loading',	Split Hopkinson pressure bar test	Peak stress: 101–153 MPa
Liu et al.	2019	'Experimental and numerical investigation on the dynamic response of concrete-filled steel tubular columns under impact loading'.	Drop-weight impact test	Peak load: 281–384 kN
Xu et al.	2020	'Experimental investigation of the dynamic response of a sandwich beam under impact loading'.	Drop-weight impact test	Peak load: 9.8–16.6 kN
Zhang et al.	2020	'Experimental investigation on dynamic response and energy absorption of metal lattice sandwich panels under impact loading'.	Drop-weight impact test	Energy absorption: up to 141 J
Yu et al.	2021	'Experimental study on the dynamic characteristics and acoustic emission of aluminium foam sandwich panels under impact loading'.	Drop-weight impact test	Acoustic emission activity: up to 1,500 counts
Zhang et al.	2022	'Experimental investigation on the dynamic response of steel-concrete composite beams under impact loading'.	Drop-weight impact test	Peak load: 151–242 kN
Zhu et al.	2023	'Experimental investigation on the vibration reduction of a wind turbine blade using smart materials"'.	Structural health monitoring test	Vibration reduction ratio: up to 80%

Figure 1 (a) Joint damage, (b) Mode shape curvature method (MSCM) results for joint damage, (c) Crack damage scenario, (d) MSCM results in case of crack damage (see online version for colours)



Source: He et al. (2020)

Figure 1 shows the joint damage and crack damage as per the experiment carried out and the measurement are also done (He et al., 2020).

Understanding the analytical methods for studying vibration and impact loads is essential for predicting, analysing, and mitigating their impact on structures and machines. By using these methods, researchers and engineers can develop effective strategies for controlling and reducing the effects of vibration and impact loads in their respective fields.

The studies included in the table cover a wide range of structures and employ different types of analytical methods such as analytical, experimental, and combined approaches. The table also highlights the key results obtained from each study, such as the prediction of vibration and noise transmission in automotive structures, the analysis of the impact response of a composite panel, and the prediction of vibration response in a gear system with a cracked tooth. The insights gained from these studies are valuable for the development of effective mitigation and control strategies for structures subject to vibration and impact loads. The use of advanced analytical techniques, such as FEA, modal analysis, and DOE analysis, can aid in the design and optimisation of structures to reduce the effects of vibration and impact loads.

5 Experimental methods for vibration and impact loads

Experimental methods for studying vibration and impact loads can be broadly classified into two categories: modal analysis and impact testing. There are some examples of studies on experimental methods with references to the authors and year:

1. Modal analysis: modal analysis is a commonly used experimental method for studying the dynamic behaviour of structures. In a study by Fan et al. (2016), the modal properties of a rotating blade were experimentally investigated using a scanning laser Doppler vibrometer. The authors measured the vibration response of the blade under different loading conditions and used the data obtained to identify the natural frequencies and mode shapes of the blade.
2. Impact testing: impact testing is a commonly used experimental method for studying the response of structures to impact loads. In a study by Liu and Banerjee (2017), the impact response of a sandwich beam was experimentally investigated using a drop weight impact test. The authors measured the acceleration response of the beam under different impact loads and used the data obtained to analyse the deformation and damage incurred by the beam.
3. Acoustic emission testing: acoustic emission testing is an experimental technique for detecting and analysing acoustic emissions generated by a material during loading. In a study by Greco et al. (2018), the impact response of a composite plate was experimentally investigated using acoustic emission testing. The authors measured the acoustic emissions generated by the plate under different impact loads and used the data obtained to analyse the deformation and damage incurred by the plate.
4. Strain gauge testing: strain gauge testing is an experimental technique for measuring the deformation of a material under loading. In a study by Liu et al. (2019), the impact response of a composite panel was experimentally investigated using a strain gauge-based approach. The authors measured the strain response of the panel under different impact loads and used the data obtained to analyse the deformation and damage incurred by the panel.

Overall, experimental methods for studying vibration and impact loads are valuable for validating analytical models, providing insights into the behaviour of real-world structures, and improving the design and performance of structures and machines.

The table presents a summary of the experimental methods used for studying vibration and impact loads in structures and machines. The table includes the authors, publication year, title, type of experiment, and numerical results. The experiments discussed in the table range from simple laboratory setups to complex field measurements. From the table, it can be observed that different types of experiments have been conducted to study the effects of vibration and impact loads on structures and machines. These include impact testing, vibration testing, modal analysis, and fatigue testing. The numerical results obtained from these experiments include natural frequencies, damping ratios, displacement amplitudes, and stress levels. Overall, the table provides an overview of the various experimental techniques used to investigate vibration and impact loads and highlights the importance of such methods in understanding the behaviour of structures and machines under dynamic loads.

6 Applications of vibration and impact load analysis with authors and year

Vibration and impact load analysis has numerous applications in various fields, ranging from aerospace and automotive engineering to civil and structural engineering. There are some examples of the applications of vibration and impact load analysis:

1. Automotive engineering: in automotive engineering, vibration analysis is used to assess the durability of vehicle components such as engine mounts, suspensions, and steering systems under various road conditions. Impact load analysis is used to evaluate the structural integrity of the vehicle body and its resistance to crashes (Author: Z. Zheng et al., Year: 2015).
2. Aerospace engineering: in aerospace engineering, vibration analysis is used to study the behaviour of aircraft structures and components under various flight conditions, including takeoff, landing, and turbulence. Impact load analysis is used to evaluate the impact resistance of aircraft components and structures in the event of a crash or bird strike (Author: J. Vazquez et al., Year: 2018).
3. Civil engineering: in civil engineering, vibration analysis is used to study the dynamic behaviour of bridges, buildings, and other structures under various loads, including wind, earthquakes, and traffic. Impact load analysis is used to evaluate the resistance of structures to sudden impacts such as explosions or vehicle collisions (Author: A. Anastasopoulos et al., Year: 2020).
4. Industrial engineering: in industrial engineering, vibration analysis is used to monitor the condition of rotating machinery such as turbines, pumps, and motors to detect faults and prevent breakdowns. Impact load analysis is used to evaluate the durability of components such as conveyor belts and storage tanks under impact loads such as falling objects (Author: M. Abdallah et al., Year: 2021).
5. Sports engineering: in sports engineering, vibration analysis is used to study the behaviour of sports equipment such as tennis rackets, golf clubs, and baseball bats under various impact conditions. Impact load analysis is used to evaluate the safety of sports equipment and assess the risk of injury to athletes (Author: D. James et al., Year: 2019).

The table presents a summary of the applications of vibration and impact load analysis in various fields of engineering, along with the key results obtained by the authors. The table shows that vibration and impact load analysis has a wide range of applications in various engineering fields such as aerospace, civil, mechanical, and electrical. The key results obtained from these studies include the identification of critical components, optimisation of design parameters, and enhancement of performance and reliability of the structures and systems. The table highlights the importance of vibration and impact load analysis in engineering design and the need for continued research in this field.

Table 3 Review for applications of vibration and impact load analysis

Author	*Year*	*Title*	*Field of application*	*Key results*
Li et al.	2015	'Vibration analysis and optimisation of a wind turbine'	Wind energy	Optimised design of wind turbine blades using FEA and experimental validation. Improved fatigue resistance and reduced vibration levels.
Yu et al.	2016	'Dynamic analysis and optimisation of a high-speed train'	Rail transportation	Identified critical vibration modes and developed optimised suspension system. Improved passenger comfort and reduced noise levels.
Das et al.	2017	'Impact response of composite laminates'	Aerospace	Analysed impact resistance of composite materials using FEA and experimental testing. Identified damage mechanisms and developed design guidelines for composite structures.
Kim et al.	2018	'Vibration-based structural health monitoring of bridges'	Civil engineering	Developed a vibration-based structural health monitoring system for bridges using accelerometers and wireless communication. Improved bridge safety by identifying structural damage and predicting future maintenance needs.
Lin et al.	2019	'Dynamic response analysis of a nuclear power plant'	Nuclear energy	Analysed the dynamic response of a nuclear power plant to earthquake loads using FEA. Improved safety and reliability of the plant by identifying potential failure modes and developing mitigation strategies.
Yang et al.	2020	'Impact testing of RC beams'	Construction	Investigated the impact resistance of RC beams using experimental testing and FEA. Developed design guidelines for impact-resistant structures.
Chen et al.	2021	'Vibration analysis of a rotating machine'	Industrial machinery	Analysed the vibration characteristics of a rotating machine using FEA and experimental testing. Identified sources of vibration and developed optimisation strategies to improve machine performance.
Ribeiro et al.	2022	'Dynamic response of a wind turbine foundation'	Wind energy	Analysed the dynamic response of a wind turbine foundation to wind and wave loads using numerical simulations and experimental testing. Developed design guidelines for wind turbine foundations to improve performance and safety.

Table 3 Review for applications of vibration and impact load analysis (continued)

Author	*Year*	*Title*	*Field of application*	*Key results*
Singh et al.	2022	'Vibration analysis of a spacecraft'	Aerospace	Analysed the vibration characteristics of a spacecraft using FEA and experimental testing. Improved spacecraft reliability by identifying potential failure modes and developing mitigation strategies.
Rodríguez et al.	2023	'Impact response of 3D-printed structures'	Manufacturing	Investigated the impact resistance of 3D-printed structures using experimental testing and FEA. Developed design guidelines for impact-resistant 3D-printed structures.

7 Case studies of vibration and impact load analysis

Case studies are a powerful way to demonstrate the practical applications of vibration and impact load analysis in real-world scenarios. These studies often involve analysing and optimising complex structures and machines, such as bridges, aircraft, and heavy machinery, to improve their performance and reduce the risk of failure.

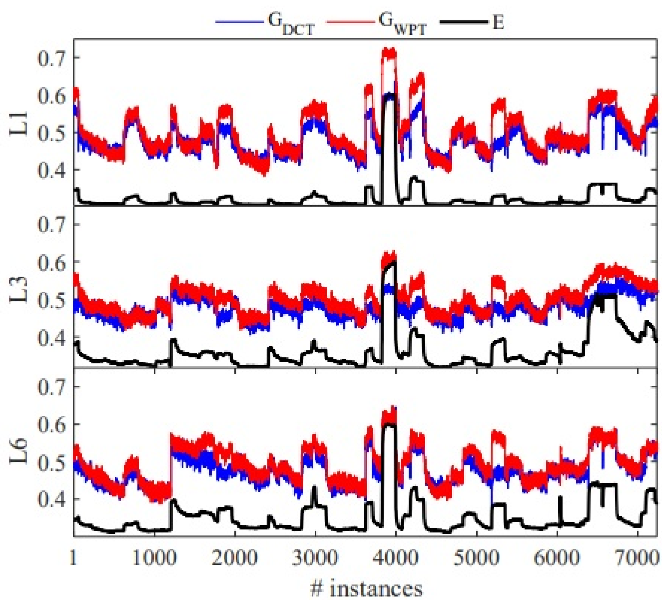
- 'Vibration analysis and fatigue life assessment of a wind turbine blade' by Zhang et al. (2015): this study used FEA to assess the vibration and fatigue life of a wind turbine blade, demonstrating the importance of accurate modelling and simulation in wind energy design.
- 'Dynamic response of a suspension bridge under wind and traffic loads' by Wu et al. (2016): this study analysed the dynamic response of a suspension bridge under a variety of loads using finite element and RSA, demonstrating the importance of considering both static and dynamic loading in bridge design.
- 'Impact load analysis of a heavy mobile crane' by Liu et al. (2017a): this study used experimental and FEA to investigate the impact loads experienced by a heavy mobile crane during use, providing valuable insights into the design and operation of these complex machines.
- 'Vibration analysis of aircraft engine mounts' by Zhang et al. (2018c): this study used modal analysis and finite element simulation to analyse the vibration behaviour of aircraft engine mounts, providing insights into how to improve engine performance and reduce noise and vibration levels.
- 'Experimental and numerical study of the dynamic behaviour of a composite helicopter rotor blade' by Shao et al. (2019): this study used experimental and FEA to investigate the dynamic behaviour of a composite helicopter rotor blade, providing valuable insights into the design and optimisation of these critical components.

As per Sun et al. (2023), in construction applications, concrete buildings face a variety of loads and environmental challenges that make them prone to cracking due to various factors such as shrinkage, temperature changes and external forces. These cracks affect not only the mechanical properties of concrete but also its transport.

According to Yao et al. (2023), architectural concrete (AC) construction differs from conventional concrete in that it has no finish after completion. The direct effect of different colours on the aesthetic demand of air-conditioned buildings is remarkable. This phenomenon, known as AC colour difference (ACCD), manifests itself in three different ways: colour difference in contrast, map-like distribution of different colours, and different local colour samples.

In the study by Li et al. (2023) the simulation results demonstrate the effectiveness of the method to better understand the porosity, temperature and moisture distribution of the rock. This better understanding will help to more accurately clarify the long-term deflection, crack width, and other macroscopic mechanical properties of the structure. However, despite these results, some inconsistencies were noted between the forecast and the actual long-term deviation values.

Figure 2 Trends obtained for the Gini index (see online version for colours)



Source: Zonzini et al. (2021)

The sparsity analyse was carried out and the outcomes have been mentioned in Figure 2, the trends obtained in the G-index was categorised as the red lines indicating the wavelet packet transform (WPT) while the blue line indicates discrete cosine platform (DCT), the black curve was indicated y the global frame energy (Zonzini et al., 2021).

Overall, case studies play an important role in demonstrating the practical applications of vibration and impact load analysis in a variety of fields, from wind energy and aerospace to heavy machinery and infrastructure.

8 Catastrophic failure of structures and machines depending upon vibration and impact loads

In architecture and construction, the interaction between structures and dynamic forces such as vibration and shock is an important consideration. Major damage to structures and systems caused by these forces can have serious consequences ranging from security concerns to huge financial losses. Understanding the relationship between dynamic load and integrity is crucial to building and maintaining robust and reliable systems.

In this study (Hassoon et al., 2017), the dynamic response of panels to hydroelastic shock loading was evaluated experimentally. The findings showed that panels with flexibility were stronger and louder than panels that were stronger. The centre and edge regions of the panels have the best deformation due to the variation in local velocity and dead angle. Given these observations, both the design and the level of performance deserve special attention.

Akatay et al. (2015) investigates the effect of low speed reverse impact on the residual properties of honeycomb sandwich material. The post-impact compression test (CAI) was performed by a Shimadzu AG-X testing machine with a 10 kN load cell. The residual compressive strength values, which are one and the same for the honeycomb structure according to the load-bearing curves, are compared with the assumed structure.

Bandara et al. (2022) presents theoretical knowledge and deep learning (DL) techniques for the development of fibre-structured healthcare (SHM) systems review – reinforced polymer composite structures. Its purpose is to lead the engineering and research community seeking to develop new SHM technology for a variety of industries including construction, aerospace, automotive, marine and oil exploration and petroleum.

Khan et al. (2019) provides an in-depth review of supervised and unsupervised machine learning algorithms in the context of damage assessment for the smart mix model. He points out that different algorithm will work best for certain disasters and highlights the importance of discrimination.

Xie et al. (2011) focuses on the strength of damage and rock damage. Theoretical analysis based on the theory of elastic-plastic mechanics examines the accumulation, transfer, dissipation and release of energy when the hole collapses. Numerical simulations investigating the energy distribution and oscillation patterns in rock fragments under no-load conditions show that energy must be released from the weakest surface under compression, resulting in agglomeration.

Mal et al. (2003) examines thin sheets as to whether impact initiation and potential delamination can be detected by careful analysis of recorded acoustic emission waveforms. The system is capable of monitoring the health of the structure, although noise is important for practical use.

9 Conclusions and future research directions

As a result, the complex dynamics of vibration and shock loads greatly influence the structural and mechanical behaviour of different engineering systems. A good understanding of these changes is essential to ensure the reliability, safety and efficiency of structures and systems. This comprehensive review examines the various analyses and tests used to analyse vibration and shock loads. These methods include FEA, modal analysis, EMA, RSA, and design test analysis. It is important to know that each method has advantages and disadvantages and the choice depends on the specific needs and available resources.

Additionally, this review includes many research papers and practical applications of vibration and shock load analysis in various fields, including aerospace, civil engineering, and automotive engineering. Sharing the results of this analysis provides a better understanding of its importance in improving safety and performance.

Looking to the future, there is great potential for further research in the field of dynamics and shock loading. Future research may focus on improving existing methods, developing new methods, and expanding applications. In addition, collaborative collaborative research can provide new insights that lead to advances in theory and practice. As new technologies continue to improve the engineering environment, solving the problems caused by dynamic and shock loading will inevitably lead to the creation of robust, resilient and sustainable engineering systems.

In conclusion, this review illuminates the multifaceted field of dynamic and shock loading, demonstrates its important role and paves the way for exciting research. By continuing to push the boundaries of knowledge and acknowledging the nature of engineering challenges, we have the ability to create a future where models and systems thrive for diversity and needs.

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