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STRUCTURAL COLLAPSE OF CONCRETE BRIDGE AND ITS RESULTANT EFFECTS

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ABSTRACT

This document provides a comprehensive analysis of bridge failure and its associated direct and indirect consequences statistics. The analysis is based on an extensive literature review and information obtained from various websites, with a particular emphasis on RCC, PSC, and steel composite bridges. Failures have been categorized into two types: complete collapse of the bridge and partial collapse that leads to loss of serviceability. The process of categorizing prevalent causes of failure and failure modes is being carried out. The findings on bridge failures reveal that collapses arising from natural hazards, design flaws, and insufficient knowledge are the most frequently observed in bridges, followed by incidents and human fallibility. Upon chronological analysis, the data exhibits a declining pattern in collapses caused by inadequate knowledge and a rising trend in failures caused by accidents and natural calamities. The results derived from the analysis of bridge failures are of significant value, as they furnish a vast repository of information for civil engineers to augment their understanding of the factors contributing to such failures. Through the analysis and assessment of the structural deficiencies of these bridges, future errors can be prevented by leveraging historical knowledge. Statistical analysis can assist in identifying the potential impact of significant hazards on bridge structures and aid in developing plans to mitigate their consequences. Fatigue failures are the primary mode of failure observed in steel bridges under non-collapse conditions. The manuscript culminates with an analysis of the implications of bridge collapse and their importance in evaluating the risk of bridge constructions.

Keywords: Bridges, Failure, consequences, risk assessment

1. INTRODUCTION

Analyzing historical failures can be beneficial in reducing the occurrence and likelihood of future failures. The occurrence of bridge failures is a critical issue in the field of infrastructure, which often results in substantial financial damages and human casualties. The initial phase in comprehending and measuring the potential for bridge failure involves obtaining insights into the failure modes of current structures and the underlying factors that contribute to their collapse. Bridge failure analysis involves identifying the predominant causes and modes of failure for each type of bridge in order to understand the failure and consequence patterns. Statistical analysis can assist in identifying and comprehending the potential of the most significant hazards impacting bridge structures and aid in devising strategies to mitigate their consequences. In recent decades, engineers have recognized the significance of gathering and storing data on structural failures and have endeavored to analyze this data in a collaborative fashion. The assessment of structural design and the evaluation of structural system robustness require the essential consideration of failure consequences. The establishment of consequence classes serves the purpose of distinguishing reliability and specifying the minimum recommended values for the reliability index.

2. BRIDGE FAILURE AND CONSEQUENCES

Bridge failures have been documented since the inception of bridge construction several millennia ago. A significant portion of the technical expertise related to bridge engineering in contemporary times is founded on the historical malfunctions of bridges. Over the last century, bridge engineers have gained significant insights by analyzing past bridge failures. Each instance of bridge failure exhibits distinct characteristics, rendering it arduous to generalize the underlying causes of failures for subsequent application to analogous bridges. This article provides an overview of the prevalent causes and mechanisms underlying bridge failures. The factors that contribute to failure can be categorized into two groups: natural factors, such as floods, landslides, earthquakes, cyclones, wind, and scour, and human factors, such as improper design and construction methods, overloading, collisions, corrosion, lack of inspection and maintenance, human error, and fire. Additionally, this article examines several instances of bridge failures that have occurred in India within the past few decades. There is a dearth of recorded data on bridge collapses in developing nations. Data pertaining to this type of information, if available, can be utilized to ascertain the annual count of bridge failures in the area. Bridge collapses are determined through numerical analysis and are correlated with the negative impacts of fatalities and the average daily traffic volume that the structure supports. A bridge failure database can be created and utilized for the purpose of comparing the rate of failure by cause with its corresponding consequences. The qualitative and quantitative evaluation of failure rates based on cause and consequence can be applied in subsequent risk analysis of fault trees and in making decisions related to risk management. The bridge failure database is utilized to demonstrate the historical risks associated with bridge failures, calculate the failure rate based on the root cause of failure, and develop a conditional probability of failure that takes into account the underlying features of the structure. The qualitative determination of engineering judgment is used to establish the consequences of bridge failures. Quantitative risk assessment is conducted by analyzing historical data and comparing it to a predetermined set of safety guidelines for structural integrity. A qualitative consequences framework is developed to facilitate a risk management decision-making hierarchy. Furthermore, life loss parameters are determined for the purpose of evaluating risk through fault tree analysis. The inadequacy of the bridge failure database is manifested in two ways: insufficient data on a failure and unregistered failures. To enhance the accuracy of bridge failure rate assessment, identification of the most likely causes and failure modes, and implementation of preventive measures in design and maintenance procedures, a more resilient data acquisition system is imperative.

Causes of Bridge Failure

Table No-1 presents an endeavor to recognize the perils that result in the collapse of bridges. Familiarity with potential bridge hazards is a viable approach to risk mitigation. Bridges fail due to a combination of factors that are individually insufficient to cause a bridge collapse. However, when they occur simultaneously, they lead to catastrophic outcomes.

Table No 1: Bridge collapse hazards

Category	**Subcategories**
Hydraulic	Flood, Scour, Debris, Ice, Drift, & Dam Failure
Collision	Auto, Truck, Barge or Ship, Train Collision or Derailment, & Airplane
Geotechnical	Slide Plane Failure, Foundation Instability, Abutment Collapse, Sink Hole, Consolidation ,Anchor Failure, Unreinforced Piers, & Inadequate Soil Compaction
Fire	Fire, Explosions, & Fire and Collision
Deterioration	Concrete, Steel, Decay, Pier, Pile, & Abutment
Overload	Posted, Overload with Deterioration
Nature	Storm, Hurricane, Wind, Tornado, Earthquake, Volcanic Eruption, Avalanche, Freezing, Insect Attack, & Tree Fall
Other	Fatigue, Design Error, Construction, Bearing, Cable Rubbing, Miscellaneous, or Unknown

Currently, there is no departmental facility in India that records data on the causes of bridge failures, post-impact effects, and their consequences. However, the Indian bridge management system has recently been established to gather inventory data on bridge conditions for timely maintenance based on structural deficiencies. In countries such as the USA, UK, and Canada, there exist documented records of inventory data pertaining to bridge conditions, as well as information regarding the causes and consequences of bridge failures, with a degree of estimation. Table No-2 displays the causes and instances of bridge failure in India. Based on the existing data found on websites, journals, and reports.

A few Bridges failure and causes in India is described in Table No. 2

SI.No.	Bridge Name	Reason of Collapse
1.	Under construction flyover collapse on 28 July 2018 in Varanasi, UP, India	The collapse was caused by a combination of factors including inadequate safety considerations in the design, traffic movement under the flyover, insufficient safety measures at the work site, and inadequate oversight.
2.	An under-construction over-bridge of the Delhi Metro collapsed at 5 AM on July12, 2009 at Jamrudpur site in south Delhi	" The collapse of the under-construction bridge was attributed to a design deficiency. The cantilever section of the pier cap became detached from the pier shaft subsequent to the launch of the girder onto the bearing pedestal.

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3.	A portion of an under construction bridge of the Delhi Metro collapsed in Laxmi Nagar and fell on passing vehicles, including a bus, in Delhi at about 7:05 AM on Oct 19,2008	A mechanical malfunction in the lifting crane resulted in the failure of a 34-meter-long span, causing it to collapse.
4.	The Kadalundi River rail disaster was one of the biggest accidents on the Indian railway network in 2001.	One hypothesis regarding the accident suggests that the collapse of the British-Era Bridge pillar was the cause, while another hypothesis proposes that the reservation coach's bogie frame, which fell, was faulty. The reservation coach, along with the unreserved coaches and a brake van, experienced derailment on the bridge.
5.	Valigonda train disaster occurred on 29 October 2005, as flash flood swept away a small rail bridge at Valigonda in Nalgonda district, about 80 km from Hyderabad, on October 29, 2005	The collapse was caused by a combination of high flood levels and a breakdown in communication between the railway and irrigation departments regarding the significant discharge of water from the upstream reservoir. The railway line was suspended due to the embankment being breached by flash floods resulting from intense precipitation, which also compromised the structural integrity of the bridge.
6.	Balance cantilever concrete bridge, linking Chamba town in Himachal Pradesh with Pathankot in Punjab, collapsed on Oct 2018	The bridge's structural failure can be attributed to either an error in the construction blueprint or substandard utilization of building materials during the construction process.
7.	Pier cap cantilever portion fractured on Dec 2019 due to design flaws in superstructure load in service condition of newly constructed Bridge (2009) across Karamnasa River on NH2 connecting UP to Bihar in District- Chandauli, UP.	The pier cap experienced fracturing as a result of insufficient reinforcement. The thickness of the cap is intended to withstand the load exerted by the superstructure. This is a failure caused by human factors such as design inadequacies, quality control issues, or lack of supervision.

Table No 2: List of some Bridge failure in India

SI.No.	Bridge Name	Reason of Collapse
8.	Flyover on National Highway 28 collapsed in Uttar Pradesh's Basti early on Saturday morning 12th August 2018.	The incident occurred after an overloaded truck hit the superstructure part of flyover.
9.	The 190 meter long under Construction Bridge above Aleksandra River in Srinagar Garhwali Pauli district, Uttarakhand collapsed at 3 AM onMarch 25, 2012.	The structural failure took place during the process of pouring concrete into the deck slab of the bridge. The construction process deviated from standard engineering practices as the casting of the deck slab commenced from the middle span instead of starting with the end span.
10	A 35 meter long portion of a skew slab of the under construction flyover in Surat collapsed from 30 feet height on June 10,2014 , when its	The bearing pedestal lacks design considerations for accommodating skew slab loads at the bearing point. The collapse of the curved span between piers CP-14 and CP-15 of the flyover was attributed by CAG to an erroneous calculation of reaction forces by the consultant. According to

	shuttering props were being removed.	the report, the compressive strength tests conducted on the core yielded negative results. The collapsed span CP 14-15 was constructed using materials that did not meet the required standards.
11.	Failure of Vivekananda flyover (Kolkata) at 31st March 2016	It should be noted that the failure has been attributed to a deficiency in the design. The longitudinal beams that extend between the portal hammer head frames lacked bracing on their compression flanges, which would have otherwise prevented lateral buckling. The portal frame box girders experienced additional horizontal loads due to buckling. The failure post photograph depicts the torsional twisting of steel plate girders situated atop cantilever girders, suggesting that the failure may have resulted from lateral torsional buckling of the girders. This could be attributed to insufficient bracing on their top flanges.

Bridge Failure Consequences

The assessment of post-hazard impact is conducted to determine the vulnerability of the bridge to such hazards and to perform a suitable risk assessment. The ramifications of unsuccessful outcomes, which are crucial in the risk-based design and evaluation of bridges in both qualitative and quantitative aspects, as well as in the assessment of their robustness. The severity of the aftermath resulting from a bridge structure's malfunction serves as a reliable gauge of its significance. The transportation infrastructure elements are also integrated into the electricity, telephone, water, and gas networks (Stimpson, 2009). Hence, the ramifications of bridge failures may have a broader impact beyond the confines of transportation systems to other categories of essential infrastructure. The consequences of an event can vary from physical harm to people and infrastructure, impairment of network operations, and potential effects on the environment and society. Table 3 illustrates that bridge failures can be classified into four primary categories: human, economic, environmental, and social consequences. Incorporating the evaluation of these outcomes is crucial in conducting risk-based design and assessment, regardless of whether it is qualitative or quantitative in nature. The outcomes can be broadly categorized as either direct or indirect. Possible injuries or fatalities and reconstruction costs of the bridge in case of total collapse or repair costs in case of damage are direct consequences. Conversely, the bridge failure and subsequent unavailability may result in indirect repercussions stemming from the transportation network's functional impairment. These expenses can be linked to traffic interruptions and delays resulting from repair work or the need to redirect traffic due to a bridge's complete closure. They may include costs associated with traffic management, as well as social and environmental impacts. In certain scenarios, bridges may be non-existent. The repercussions of a malfunction differ greatly based on the edifice, and can be influenced by various elements such as the peril, the structure's design and function, and the adjacent surroundings. The consequences of the bridge collapse will be significantly influenced by the origin and characteristics of the hazard. It is hypothesized that there exists a direct correlation between the magnitude and duration of a hazard and the resultant consequences. Specifically, it is anticipated that an increase in either or both of these factors will lead to a corresponding increase in the severity of the outcomes. The susceptibility and resilience of a bridge, along with its associated outcomes, are subject to the influence of its structural configuration, construction materials, age, condition, and workmanship. Moreover, the bridge type is a critical factor that affects these aspects.

Table No -3: Categorization of bridge failure consequences

Consequence Categories	Examples
Human	Fatalities Injuries Psychological damage
Economic	Replacement / repair costs Loss of functionality / downtime Traffic delay / re-routing costs Traffic management costs Clean up costs Rescue costs Regional economic effects Loss of production / business Investigations / compensations Infrastructure inter-dependency costs
Environmental	CO_2 Emissions Energy use Pollutant releases Environmental clean-up / reversibility

Social	Loss of reputation Erosion of public confidence Undue changes in professional practice

Factors Affecting the Consequences of Failure

The repercussions of a potential failure exhibit considerable diversity across different structures and are contingent upon a multitude of factors, encompassing the nature of the hazard, the structure's intended purpose, and the ambient surroundings.

(I.) The nature of the hazard Will have a significant impact on the outcomes under consideration. It is apparent that the severity and duration of a hazard are directly proportional to the magnitude of its consequences. The nature of the hazard is a determining factor as it can potentially increase the peril to humans or animals via contact, inhalation, or consumption. In the event of a fire, the mechanical properties of a structure may be negatively impacted, leading to a reduction in load-bearing capacity. Additionally, the combustion process can produce hazardous fumes and pollutants that have the potential to disperse into the surrounding atmosphere. Additionally, it is feasible for a peril to initiate a cascading impact, such as an explosion that may be succeeded or preceded by a fire, or an impact that may be succeeded by a fire, and so on.

(II.) The properties of the structure The external factors can have an impact on both the susceptibility and resilience of a bridge or any other structure. The impact of the outcome will be contingent upon variables such as the composition of materials, the category of bridge, its age, dimensions, elevation, configuration (including the convenience of egress), method of assembly, and standard of assembly.

(III.) Stated differently, the consequences resulting from a failure event will be heavily influenced by the placement of a structure. The consequences of bridge failure are significantly influenced by the location of the bridge. vehicles or trains that pass over the bridge, which in turn affects its load capacity and structural design. Individuals who have encountered a specific peril, along with the expenses incurred due to traffic delays. Urban areas are expected to have better availability of emergency services and accessibility to treatment for injuries, similar to buildings. Conversely, rural areas are likely to have easier access, and interdependency issues may be less critical. Stated differently, the consequences resulting from a failure event will be greatly influenced by the placement of a structure.

(IV.) Time-dependent usage, is a crucial aspect for bridges, as they encounter significant traffic volume during peak hours. The increased exposure density can lead to a higher likelihood of certain hazards, as well as a greater potential for mass casualties. Temporal fluctuations may manifest on a daily, weekly, monthly, or seasonal basis, and it is crucial to consider the correlations between these fluctuations and their resultant outcomes.

(V.) The temporal scope, incorporated (days/weeks/years) within the consequence analysis will have a substantial impact on its resultant. To account for the enduring impact of a bridge failure, it is necessary to factor in the entire duration until reconstruction is finalized. Furthermore, there may be persistent effects that could persist for several years beyond that timeframe before they are fully eliminated. The failure of the bridge and its consequential impact on the transportation network can lead to the establishment of a new long-term equilibrium, which may differ significantly from the pre-existing equilibrium.

(VI.) Finally, the meteorological conditions, both during and after the failure event, may have some impact on the consequences. In particular air conditions (including wind direction, wind speed, terrain etc.) will influence the level of dispersion of any toxic pollutants, leading to an increase or decrease in the environmental consequences accordingly.

Consequences Hierarchy

Consequences are diverse, naming a few: life loss, injury, critical or emergency routes, economic loss, environmental concerns, and historical significance. When considering decision management alternatives, a hierarchy is sure to exist on the potential outcomes if a bridge or portfolio of bridges were to experience extreme loadings. The comparison of consequence categories gives rise to ethical concerns, but these concerns can be addressed within a hierarchical judgment framework. Preference of what routes are critical in the event of a major earthquake is an example of how a hierarchy can be utilized in risk management. Each category has both direct and indirect effects. For example, economic loss can have direct cost through litigation and expedited bridge replacement while indirect loss could be stifled economic development and high user cost. Direct consequences are often simpler to measure and records exist of this nature. On the other hand, indirect consequences are inclined to be onerous to collect and complex, as such records are rare at best. Assessment of consequences in this investigation is a framework for evaluating direct life loss in a fault tree risk analysis.

Qualitative Consequences to Life Loss

Qualitatively life loss consequences for bridge failures are mainly a function of the failure cause, structural configuration and traffic characteristics. The collapse rate of a bridge, whether it is sudden catastrophic or ductile, and the length of the failed span(s) are dependent on the interrelation between the failure cause and structural configuration. The collapse progression is time dependent and also plays an integral part. After assessing the probability and characteristics of failure, the traffic pattern that corresponds to the bridge's length or span and width will determine the quantity of vehicles that are in jeopardy. The traffic's composition, diurnal flow, vehicle lengths, persons per vehicle, flow rate, density, number of lanes, and stopping sight distance (SSD) are all factors that impact the number of individuals who may be at risk in the event of a failure. Composition of traffic relates to the diversity of the traffic, whether it is semi- tractor trailers, transport busses, or passenger vehicles, and a mix. The maximum number of vehicles that can be accommodated on a particular bridge length is determined by the vehicle length feasibility. The conversion of vehicles at risk to the population at risk is accomplished through the utilization of persons per vehicle values. The flow rate is an estimate of the number of vehicles per hour passing a point, whereas density refers to the number of vehicles on the road. The relationship between the two is the higher the density the lower the flow rate, with the maximum density being gridlock and flow is near zero.

Quantitative Consequences to Life Loss

In general, major bridge disasters of historical significance have been thoroughly studied. The Minneapolis I-35W Bridge and the Queen Isabella Causeway, which collapsed in 2001 and 2007, respectively, are two instances. Due to the Queen 55 Isabella Causeway being the only road leading to South Padre Island, Texas, the collapse is unusual. Due to the lack of a detour when the breakdown happened, the residents of South Padre Island were isolated, and the utilities that crossed the bridge were cut off. In addition to the loss of life caused by the bridge collapse, the whole community was also affected by its effects (Wilson, 2003). However, the ADT of 140,000 is an example of life loss and high user cost from the resulting metropolitan traffic congestion (Hao, 2010). The detour length for the Minneapolis I-35W Bridge was only a little over a mile.

Quantification of consequences

The damage, destruction, expenditure, or loss of assets and services, such as raw materials, commodities, services, and lives, may be used to quantify the consequences. Intangibles may also be a part of them, either practically or theoretically, particularly when it comes to social repercussions and long-term environmental impacts. They are often represented as a vector C = [C1, C2,... Cm], whose members should be in the correct units for the kind of consequence being thought about. Consequences should, wherever feasible, be conveyed in monetary terms, even if it may not always be desired or even generally accepted.

3. CONCLUSION

Despite the annual construction of numerous bridges worldwide, only a small percentage experience collapse, primarily due to natural factors such as floods, scour, earthquakes, landslides, and wind, as well as human factors such as improper design and construction methods, collisions, overloading, fire, corrosion, and inadequate inspection and maintenance. Certain incidents lead to not only financial loss but also fatalities. Bridge designers employ failure analysis techniques to mitigate the risk of failures by identifying their root causes and leveraging this knowledge to inform future design decisions. In light of the aforementioned failure factors, the adoption of new construction technologies, updated efficient substructure and superstructure forms, and the development of new materials that allow for longer spans and longer life are being pursued. Currently, longer service life of bridges, approximately 100 years, is attributed to the incorporation of lessons learned from previous bridge failures. The acquisition of knowledge from each collapse and subsequent implementation of safety measures in the design and construction of future bridges falls under the purview of engineers and contractors. A bridge failure database is utilized to conduct a comparative analysis between the failure rate and the associated consequences based on the cause of failure. The qualitative and quantitative evaluation of the failure rate based on cause and consequence can be employed in the subsequent analysis of fault tree risk and decision making related to risk management. A failure database is utilized to exhibit the historical hazards of bridge failures, calculate the failure rate according to the cause of failure, and establish a conditional probability of failure that takes into consideration the features beneath the structure. The qualitative assessment of engineering judgment was utilized to determine the ramifications of bridge failures.

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