ENHANCED DECISION-MAKING FOR INCREASED RESILIENCE – NATURAL HAZARDS

By Sachidanand Joshi, Atharvi Thorat, Mayuri Tundalwar
Researcher - UBMS Research Group, INDIA.

ABSTRACT

Recent events indicate natural calamities have been erratic in their occurrences and severity. The concept of a rare event needs redefinition. The resilience of the bridge infrastructure defines the success of speedy relief and rescue missions. Conventional bridge management did not venture into the domain of increment of resilience in the face of natural disasters. The adage that humans cannot control natural occurrences was the accepted norm. Rectification of the impact is post occurrence scenario. This nullifies or negates the philosophy of mitigation. Mitigation of impact essential demands the need to proactively create a resilient bridge structure. Two important issues can ensure this increased resilience. To enable a proactive approach, one must perform a risk assessment focused on natural hazards that affect the region where the bridge is located. Once we have the risk assessed, it is critical to redefine the decision-making to identify and secure the route that is best suited for mitigation and relief efforts. This aspect of risk assessment was incorporated by the introduction of the Risk Assessment Module within bridge management. The present research aims to redefine the decision-making from post-occurrence to a proactive mitigation philosophy. This redefinition revolves around the proactive approach in mapping the risk to the bridge due to natural hazards. Using this understanding to proactively eliminate or reduce the risk and mitigate the impact. The paper presents the approach to increase the resilience of the bridges with a focus on natural hazards.

1. Introduction:

Natural calamities, ranging from earthquakes and Cyclones to floods and Landslides, pose significant threats to human life, infrastructure, and the environment. As these catastrophic events continue to impact communities worldwide, the need for effective disaster management strategies becomes increasingly paramount. One such strategy, central to the field of disaster management, is the concept of mitigation philosophy. Mitigation philosophy is an essential approach that focuses on reducing the adverse impacts of natural calamities through proactive measures, planning, and risk-reduction strategies.

Mitigation philosophy recognizes that while one cannot control the occurrence of natural disasters, this can minimize their devastating consequences through preparedness and strategic actions. Governments worldwide, including the Indian government, have initiated comprehensive Disaster Management plans with a primary aim of achieving mitigation of such impacts [1]. These plans encompass various key high points, such as creating awareness at all levels, risk mapping to improve understanding about the nature of the risk, utilizing available technologies for mitigation and disaster risk reduction, enhancing local capacities, and learning from past events.

Recent events have highlighted the unpredictable and worsening severity nature of natural disasters, necessitating a re-evaluation of our understanding of rare events. In this, the resilience of critical infrastructure, particularly bridges, emerges as a defining factor in ensuring the success of speedy relief and rescue missions during and after such calamities. Historically, conventional bridge management has largely operated under the assumption that humans are powerless to control or prevent natural occurrences. As a result, the primary focus has been on rectifying the impact of disasters once they have already struck, often neglecting the essential philosophy of mitigation.

The essence of mitigation philosophy lies in proactively creating bridge structures that can withstand and adapt to the challenges posed by natural disasters. Achieving this heightened resilience hinges on two crucial components. Firstly, it necessitates a comprehensive risk assessment tailored to the specific natural hazards prevalent in the region where the bridge is situated. Secondly, it requires a fundamental shift in decision-making processes to identify and secure routes that are best suited for mitigation and relief efforts before the occurrence of a disaster.

The initial step towards a proactive approach was taken with the introduction of the Risk Assessment Module within bridge management. The present research seeks to push the boundaries further by advocating a paradigm shift from a post-occurrence mindset to a proactive mitigation philosophy. This redefined approach revolves around the proactive mapping of risks associated with natural hazards and, more importantly, leveraging this understanding to pre-emptively eliminate or reduce risks and mitigate the possible impact on bridge infrastructure.

This research aims to present a comprehensive approach to encourage the resilience of bridges in the face of natural calamities, emphasizing the critical role of proactive mitigation strategies [2]. By bridging the gap between risk assessment and decision-making, we aspire to contribute to the safeguarding of vital infrastructure and the enhancement of disaster response capabilities, ultimately minimizing the devastating effects of natural disasters on our communities.

2. Risk Assessment for Natural Hazards:

The Risk Assessment Module introduced in Global Analytics for Bridge Management [**GABM**] represents a ground-breaking advancement in the field. Until now, bridge management has largely remained untouched by the domain of risk assessment for natural hazards. The introduction of the Risk Assessment module within GABM signifies a paradigm shift necessitated by the alarming increase in large-scale devastation and, in some instances, the outright collapse of vital bridges. This shift reflects the realization that mitigating the risks posed by natural hazards is not a luxury but an urgent imperative.

To conduct an effective risk assessment for natural hazards, one must first evaluate the potential impact of these occurrences on the geographical area where a bridge is situated. This forms the fundamental cornerstone of the assessment process. This evaluation hinges on historical data, particularly data derived from past events of a similar nature that have taken place in the region. Notably, this process has seen refinement over time.

Recent years have witnessed an alarming surge in the frequency and severity of natural events. Consequently, the traditional definition of rare events no longer holds, prompting the need to reassess historical data which focused on extended periods of the “last 100 years” to focus on the recent “10 years”.

Once the impact of a natural event on the region is determined, the next step involves assessing how this event will affect the specific bridge. This assessment evaluates the vulnerability of the bridge to withstand the event [3,4].

The bridge's vulnerability depends significantly on its present condition, which is assessed during the most recent inspection/evaluation, along with various other engineering and geometrical properties of the bridge. The vulnerability is evaluated along with the risk impact on the region where the bridge is located, which are two interdependent factors. These two pivotal factors, the impact assessment on the region and the bridge's vulnerability assessment, converge to determine the risk index of the bridge for a particular hazard, representing its susceptibility to that hazard. When evaluation is carried out for all types of hazards (Earthquake, Flooding Cyclone Landslides) it provides a Risk Index of that bridge for all hazards.

Currently, the primary focus of this Risk Assessment Module in GABM is directed towards four major natural hazards: Earthquakes, Flooding, Cyclones, and Landslides. These hazards are singled out due to their widespread impact, affecting over 65 per cent of the land mass of India. This selection aligns with the module's objective of addressing the most significant threats to bridge infrastructure. The Risk Assessment Module in Global Analytics for Bridge Management marks a pivotal moment in the domain of evolution in Bridge Management. It acknowledges the pressing need to confront the increasing risks posed by natural hazards to bridge infrastructure [5,6]. The module's approach leverages historical data, evaluates impact, assesses vulnerability, and calculates risk indices, all with a focus on the most prevalent hazards in India. By doing so, it seeks to transform bridge management from a reactive to a proactive discipline, better equipped to mitigate the impact of natural disasters on critical infrastructure.

Bridge Collapse due to Flooding

Bridge Collapse due to Cyclones

Bridge Collapse due to Landslide

Bridge Collapse due to Earthquake

3. Decision-making in Bridge Management:

The conventional decision-making process in bridge management has historically centred on the optimization of available funds. This approach was primarily driven by the need to allocate limited financial resources efficiently. Under this paradigm, funds were allocated to bridges in need of remedial interventions, with a focus on those requiring the most urgent attention. The determination of which bridges would receive funding was contingent upon two key factors: the degree of distress observed in the bridge and the cost associated with the required remedial interventions.

The degree of distress in a bridge was a crucial criterion in this decision-making process. Bridges exhibiting severe distress were considered primary contenders for financial allocation, especially if they also met other relevant decision-making criteria [7,8]. Essentially, the more deteriorated a bridge was, the more likely it was to secure funding for necessary repairs or improvements. This approach was rooted in the concept of optimizing funds to address immediate infrastructure needs.

However, when considering the imperativeness of enhancing a bridge's resilience to natural hazards, a different perspective on decision-making becomes essential. The primary objective is to strengthen the bridge's capacity to withstand the impact of hazardous events, thereby preventing its collapse and ensuring the continuity of the bridge being able to provide the service of ensuring connectivity in the face of such occurrences. Achieving this objective necessitates a shift away from the strict pursuit of fund optimization.

The focal point here is understanding how some bridges can be important when we plan to deal with disasters. These bridges can be identified as "critical" due to their pivotal importance in facilitating post-disaster relief and rescue operations. Critical bridges act as lifelines during times of crisis, enabling the swift movement of emergency response teams, vital supplies, and affected populations. So, the important step in decision-making is to identify such a “Critical Bridge”.

Given the strategic significance of these critical bridges, the decision-making process should be oriented towards ensuring their resilience and readiness for potential natural disasters. Rather than singularly aiming for fund optimization, decision-makers should focus on determining the funding requirements necessary to refurbish and strengthen all critical bridges to the greatest possible extent [9].

In essence, the revised decision-making approach acknowledges that disaster preparedness and mitigation take precedence over the rigid pursuit of fund optimization. The emphasis shifts towards proactively addressing the vulnerabilities of critical bridge infrastructure, in anticipation of natural calamities. This realignment of decision-making priorities aligns with the broader objective of disaster management, which seeks to safeguard lives, protect infrastructure, and expedite relief and rescue operations during crises. To sum up, as we confront increasingly severe natural disasters, decision-making in bridge management must evolve to address these new challenges. Prioritizing the resilience and preparedness of critical bridges over traditional fund optimization strategies can significantly enhance disaster response capabilities and minimize the disruptions caused by natural calamities.

4. Decision-making for enhanced resilience of the bridge:

Decision-making for enhancing the resilience of bridges in the face of natural disasters presents a set of formidable challenges. Firstly, it is essential to accurately assess the risks associated with various natural hazards that could affect a particular region. These hazards may include earthquakes, floods, cyclones, and landslides, each requiring a unique approach to mitigation. Accurate risk assessment is complex, as it involves not only understanding the probability of an event but also its potential magnitude and impact on the bridge infrastructure.

Secondly, there is a need to prioritize bridges based on their criticality for disaster management. Determining which bridges are essential for post-disaster relief and rescue operations requires a comprehensive understanding of local infrastructure and emergency response plans. Balancing these priorities while optimizing fund allocation is a complex and delicate task, particularly when resources are limited.

The birth of Bridge Management was primarily driven by the objective of establishing a protocol for fund optimization. This approach was crucial in ensuring that limited financial resources were allocated judiciously to bridges in need of maintenance and rehabilitation. The underlying principle was to prioritize the provision of funds to the most deserving bridges that exhibited distress or structural deficiencies. However, this approach, while effective in the context of managing available resources, inherently conflicted with the proactive approach essential for enhancing bridge resilience [10].

Bridge management heavily relies on data related to the observation of distress and the subsequent evaluation of the causes of distress. Distress, in this context, serves as a key metric that correlates with the condition of the bridge. Based on these observations and evaluations, remedial measures and maintenance strategies are designed and implemented. While this approach is essential for addressing existing issues and maintaining the structural integrity of bridges, it falls short of achieving the proactive measures necessary to enhance resilience.

To truly enhance the resilience of bridges in the face of natural calamities, it becomes imperative to pre-empt the occurrence of distress. This proactive stance requires the adoption of measures that not only address existing vulnerabilities but also prevent distress from occurring in the first place. Such measures may include advanced structural design strategies, improved construction materials, and rigorous quality control during bridge construction and maintenance [11].

Furthermore, the implementation of remedial intervention must also be proactive to effectively avoid distress. Rather than waiting for distress signals to emerge, bridge management should incorporate predictive and preventive maintenance practices. Regular inspections, structural health monitoring, and timely repairs based on early warning signs can play a pivotal role in averting distress and bolstering the resilience of bridges.

In addition to proactive maintenance and distress prevention, another critical aspect of bridge management pertains to the identification of the best routes for providing relief and rescue during and after a natural calamity. The location of the calamity itself dictates the response strategy, and the extent of the impact zone can be defined post-occurrence. It is only after this identification that the best route to reach the impact zone can be determined. This involves factors such as assessing the structural integrity of bridges in the area, road accessibility, and overall safety considerations.

When a disaster event occurs with high severity, Bridges crumble, and bridges undergo deterioration which could lead to subsequent collapse. Many examples of such collapses or severe deterioration are known in the Gangetic plains of India.

Elsewhere even in the USA, the bridges collapsed, (Earthquake resulting in collapse in California, Hurricane induced damage in New Orleans) over 150-plus bridge collapses are reported in China due to natural calamities. (Statistical Analysis of the Causes of Bridge Collapse in China by Zhongqiu Fu and others, November 2012, at Sixth Congress on Forensic Engineering)

4.1 Challenges [11]:

The challenges faced in the realm of Bridge Management stem from its historical focus on fund optimization, which often hinders the proactive approach necessary to enhance bridge resilience. To overcome these challenges, a shift is needed towards a more proactive stance that includes pre-emptive measures to prevent distress and early intervention strategies. Additionally, the identification of optimal routes for relief and rescue operations is crucial for effective disaster response. By embracing these proactive principles, Bridge Management can better prepare critical infrastructure to withstand the impacts of natural calamities and ensure the safety and functionality of bridges during times of crisis.

Identification of the best route for providing relief and rescue is dependent on the location of the calamity. Post occurrence of the calamity, the extent of the impact and boundaries of the impact zone are defined. Based on this identification, the best route to reach the impact zone can be decided.

To address these challenges, decision-making for the enhanced resilience of bridges should adopt a proactive and systematic approach. This approach involves several key steps:

A. Comprehensive Risk Assessment: Begin with a thorough assessment of the natural hazards prevalent in the region where the bridge is located. Utilize historical data, geological studies, meteorological information, and expert analysis to identify potential hazards. Assess the likelihood, severity, and potential consequences of these hazards on the bridge infrastructure.

B. Criticality Assessment: Develop a clear understanding of which bridges are critical from a disaster management standpoint. These are the bridges that must remain operational for relief and rescue operations during and after a natural calamity. This assessment should involve collaboration with emergency response agencies and local authorities to ensure alignment with disaster response plans.

C. Resilience Enhancement Strategies: Based on the risk and criticality assessments, formulate strategies for enhancing the resilience of bridges. These strategies may include structural reinforcements, retrofitting, and the incorporation of advanced materials and construction techniques designed to withstand specific hazards.

D. Fund budgeting and Allocation: Shift the focus from mere fund optimization to fund budgeting and allocation based on the identified critical bridges and their specific resilience enhancement needs. Allocate funds to ensure that these bridges are adequately prepared and strengthened to withstand potential disasters. Prioritize resources for preventive measures rather than reactive repairs.

4.2 Approach:

The approach to decision-making for enhancing the resilience of critical infrastructure, such as bridges, begins with the identification of regions most susceptible to natural disasters. In India, this process is facilitated by the collaboration between the meteorological department and the National Disaster Management Authority (NDMA), which has identified over 200 districts prone to natural disasters. These districts are susceptible to four primary hazards: Earthquakes, Cyclones, Flooding, and Landslides. Earthquakes, for instance, affect approximately 58.6% of India's land area, while Cyclones impact 8% of the land or 75% of the coastline. Flooding affects 12% of the land area, and Landslides affect 15% of the land area.

The NDMA has played a pivotal role in developing comprehensive guidelines for the management of these four major hazards. These guidelines not only serve as a reference but also provide a framework for decision-making in disaster management. One of the fundamental objectives of the NDMA's formulation is the creation of resilient structures and infrastructure that can withstand the impact of these natural disasters [13].

Within the framework of disaster management guidelines, there is a specific clause (viii) that emphasizes the importance of outlining critical life-line structures and infrastructure. These life-line structures include essential components such as bridges, roads, school buildings, hospitals, and communication networks. Importantly, this clause also highlights the necessity of developing arrangements for the maintenance and management of these structures during disasters. This underscores the significance of proactive measures to ensure the functionality and resilience of these lifeline structures in the face of natural calamities.

Once the hazard-prone areas are classified based on severity and risk, the next step involves identifying the most critical routes within these disaster-prone regions. These critical routes are those that cover a significant portion of the land mass in the hazard-prone area and are essential for facilitating disaster response and relief efforts. Major bridges located along these critical routes must undergo proactive maintenance measures to ensure they remain in a state of "Zero Distress bridges" consistently.

The term "Zero Distress bridges" implies that these critical bridges are maintained to a level where they are free from any structural or functional distress even in the event of a disaster. This proactive approach involves regular inspections and maintenance and incorporating resilience-enhancing features and technologies into bridge design and construction.

The decision-making approach for enhancing bridge resilience in disaster-prone regions involves a comprehensive process that begins with hazard identification, continues with the development of guidelines and frameworks, and culminates in the proactive maintenance and management of critical bridges. This approach aligns with the broader goal of creating a resilient infrastructure capable of withstanding natural disasters and facilitating effective disaster response and relief efforts.

4.3 Solution:

For ensuring the safety and resilience of bridges within a critical route, it is imperative to recognize that rendering these bridges safe through remedial interventions is just the initial step. While such interventions may eliminate identified distress causes and reinstate the bridges to a near-original state, they may not necessarily enhance the overall resilience of these structures. This is a critical consideration because the next cycle of calamities could impact these bridges once again. To truly enhance the resilience of these bridges in the face of natural hazards, the focus must extend beyond mere restoration.

One key aspect to address in the design of remedial interventions is the elimination of disparities between the bridge's current functionality and its original design, which had already considered the natural forces that could act upon it. This encompasses vertical and horizontal forces associated with phenomena like earthquakes, floods, landslides, and cyclones. Assessing functional parameters during bridge inspections allows for an evaluation of adequacy concerning aspects such as overtopping, waterway clearance, and vertical clearance—essential factors for disaster resilience.

Designing remedial interventions that target the elimination of both functional and design inadequacies ensures an enhanced level of resilience against natural hazards. Such interventions may require a one-time comprehensive effort, but their long-term impact in safeguarding bridges from future calamities is invaluable [14,15].

For example, addressing functional inadequacies by increasing the deck slab height of a bridge to a level above the maximum water level anticipated during peak flooding. This proactive measure ensures that even during extreme flooding events, the bridge remains passable. Additionally, widening the span of the bridge can provide sufficient space for water to flow smoothly beneath it, reducing the risk of structural damage during floods. Installing buffers and barricades at strategic locations can act as debris and rock arrestors during flood events, further enhancing safety.

Another critical aspect of resilience enhancement is protecting the bridge's foundation against scour, especially during flash floods characterized by high velocities. Increasing the level of scour protection around the foundation ensures that the bridge remains stable and secure, even in the face of rapidly flowing water.

However, it's essential to acknowledge that the availability of funds for such comprehensive remedial interventions may be limited. Consequently, the decision-making process must adapt to this reality. Rather than focusing solely on making bridges safe, it has been modified to include estimating the funds required not just for safety but also for resilience. This shift in decision-making philosophy recognizes that investing in the resilience of critical bridges is a proactive and cost-effective approach to disaster management, ultimately minimizing the impact of future calamities on vital transportation infrastructure.

5. Conclusion:

Recent events have underscored the need for a paradigm shift in bridge management, particularly in the context of natural disasters. The traditional approach of prioritizing fund optimization has proven insufficient in addressing the increasing frequency and severity of these calamities. To enhance the resilience of critical infrastructure like bridges, a proactive and comprehensive approach to decision-making is imperative.

This research paper has explored the evolution of decision-making in bridge management, highlighting the importance of transitioning from a reactive stance to a proactive mitigation philosophy. It has emphasized the critical role of risk assessment in understanding the potential impacts of natural hazards on bridges and the need to identify critical bridges essential for disaster response.

The proactive approach outlined in this paper involves a series of steps, including comprehensive risk assessment, criticality assessment, resilience enhancement strategies, and funding allocation. By prioritizing the resilience of critical bridges and implementing proactive measures, decision-makers can better prepare the infrastructure to withstand the impacts of natural disasters.

Furthermore, the paper has emphasized that simply making bridges safe through remedial interventions is insufficient. To truly enhance resilience, these interventions must address both functional and design inadequacies, considering the specific natural forces that could impact the bridge. Such proactive measures, although requiring initial investment, prove cost-effective in the long run by minimizing the impact of future calamities on vital transportation infrastructure.

In short, as natural disasters become increasingly severe and unpredictable, decision-making in bridge management must adapt and evolve to meet these new challenges. Prioritizing resilience and disaster preparedness over fund optimization is essential to safeguard lives, protect infrastructure, and expedite relief and rescue operations during times of crisis. Ultimately, this proactive approach contributes to the resilience of bridges and the overall resilience of our communities in the face of natural calamities.

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