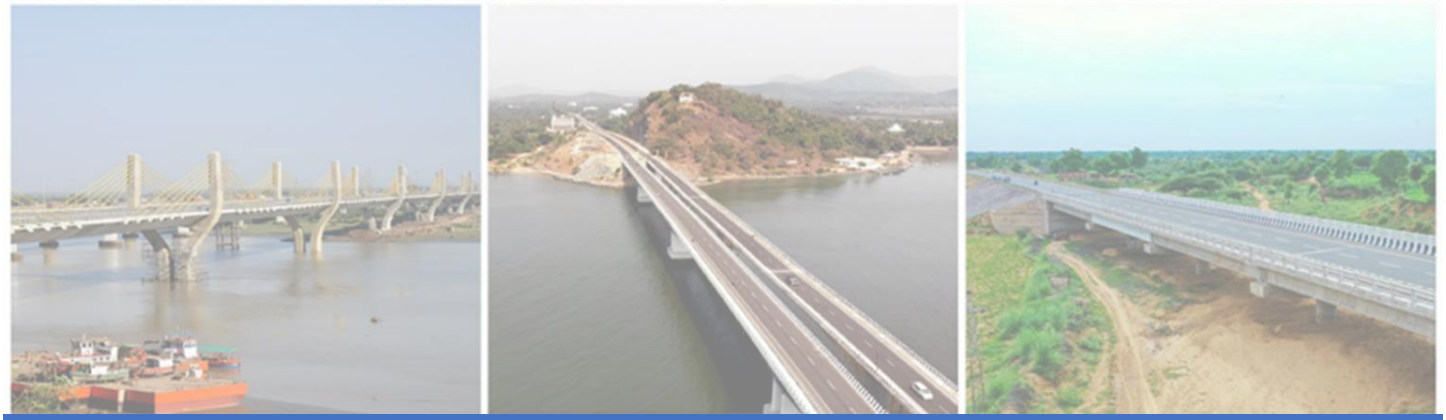

UBMS RESEARCH GROUP [URG]

SHAPING THE FUTURE OF BRIDGE MANAGEMENT

NAVIGATING FROM DETERIORATED TO RESILIENT BRIDGES – [VOLUME TWO]

AUTHORS: Atharvi Thorat and Mayuri Tundalwar

CONCEPT: Sachidanand Joshi

NAVIGATING FROM DETERIORATED TO RESILIENT BRIDGES

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IMPACT OF RESILIENCE OF BRIDGES ON POST CALAMITY SCENARIO

By Atharvi Thorat, Mayuri Tundalwar.
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A) ABSTRACT:

The resilience of the region is the ability and swiftness of that region to bounce back to normal conditions in a cost-efficient manner. Regional resilience depends on the overall development of the region, which assist to withstand the vagaries of natural hazards. Transportation network contribute to this requirements. Bridges within the region play a crucial role in this property of the region. Connectivity ensures regional resilience.

Bridges enable connectivity and are important components of any road or railway network. Resilient bridges enable not just the provision of connectivity but also ensure the continuation of the needed connectivity. Collapse of bridge during occurrence of natural hazards would lead to loss of connectivity. Success or failure of any rescue and relief operation depends on this connectivity. The multiplicity of key routes increases the chances of success of relief operation. Timely rescue and relief results in reduction of loss of lives and restoration of normalcy in the region. Normalcy results in revival of economic activities resulting in stability in the region [1, 2, 3].

Loss that accrues to the region can be manifold due to absence of resilience. The loss is not restricted to economic growth or loss of asset due to the collapse of the asset, loss can accrue due to lost human lives, lost livelihood, loss to businesses and traders due to reduced productivity, loss arising from lost connectivity and breakage in supply chain, loss due to trauma arising due to occurrence. All these cannot be accounted in Dollar terms and hence leave a gap in estimation of loss.

B) INTRODUCTION [1, 2, 3]:

Definition of Resilience of the region is the ability and swiftness of that region to bounce back to normal conditions in a cost-efficient manner. Resilience of the region defines how a region is able to maintain the normalcy at all times including post occurrence of natural hazards. Natural hazards magnify into a calamity when there is disruption to normalcy. Loss of lives, stoppage of economic activities, and collapse of infrastructure all define Calamity. Not every occurrence of Natural hazard leads to calamity. Stronger the resilience of the region, less are the possibility of natural hazard becoming a calamity.

Regional progress is measured and heavily dependent on the establishment of stable infrastructure. Stable infrastructure is an enabler for stable and steady economic growth. Economic growth can translate into higher income

for the community and good employment opportunities for the residents of the region. Infrastructure are facilitators for this growth. Transport networks constitute an important component of Infrastructure.

Bridges enable connectivity and are important components of any road or railway network. Bridges within the region play a crucial role in maintaining the resilience of the region. Resilient bridges enable not just the provision of connectivity but also ensure the continuation of the needed connectivity. Connectivity ensures Regional resilience. The multiplicity of key routes increases the promptness of post-disaster rescue and relief operations. This result in an exponential decline in time required for response mobilisation.

C) IMPACT OF RESILIENCE OF BRIDGES [4, 5, 7, 8, 10]:

New infrastructure / bridge assets designed and planned, built and maintained to account for the occurrence of any natural hazard of the highest severity during the life cycle of the infrastructure, result in resilience. Aging and deteriorated bridge infrastructure will undergo rehabilitation and future maintenance designed to render bridges safe and stable for the forces of natural hazards of high severity. Certain measures like dyke walls, increased height of dam will provide the much-needed protection against the changes in water level during floods or cyclones. Even natural protections systems are encouraged like mangroves, wetlands. Rules and codes preventing construction of housing in disaster prone areas also contributes to resilience in the region.

Resilience of bridges is not accidental. Research, Efforts and Sustained planning and maintenance results in resilience of bridges. The impact of resilience in bridges ensures resilience of the transport network. Post occurrence of natural hazard in the region, the resilience of bridges and the resulting resilient transport network yields direct benefits to the immediately mobilized rescue and relief work in the affected zone. The resilience also contributes indirectly to the region. The indirect benefits arise from the faster revival of economy, lesser loss of human lives and other similar benefits.

- **DIRECT IMPACT**

1. **Restoration of normalcy**: Rapid response to the affected people and area is key to survival and restoration of normalcy in the affected zone. Essentially, linked to the sustenance of economic activities and growth in the region's productivity, results in revival of normalcy. Success of rescue operations depends on the lives saved. The arrival of rescue teams within few hours of the occurrence of the hazard enables the teams to offer relief and rescue the most needed people. Golden hour is the term used to define the time-period when people affected need the rescue and relief the most. Lives are saved when the rescue teams reaches the hazard zone within the golden hour. Connectivity directly affects the arrival of the rescue team in the zone of influence within the golden hour. Availability of seamless travel route is critical for the team.

Multiplicity of routes from the zone of mobilization to the zone affected enable the rescue and relief agency to choose the most suitable route. Multiplicity also offers availability of an alternative route should any hurdle obstruct usage of one route.

2. **Regional economic growth:** Under normal circumstances, the same network of roads increases the productivity of industrial and agricultural activities. Road networks act as catalytic agents for economic activities during normal times. The multiplicity of routes with resilient bridges ensures to increase in the efficiency and preparedness of the region towards rescue and relief operations.
   Incorporation of resilience in bridges is never a short-term investment. All out, efforts by all active stakeholders in the region ensure total resilience of the region. Such resilience enables speedy Disaster recovery preparedness and reduces the risk to the region. The benefits of investing in resilient bridges and infrastructure go beyond the primary objective of disaster recovery. Such investments provide long-term benefits to the region by fortifying the region to withstand future calamities. By prioritizing and having a mandatory policy at the planning stage to incorporate resilience in basic design philosophy, the region invests their finances, efforts and time to fortify itself to ensure rapid and effective response in times of crisis. Such efforts and planning has other benefits like long-term increments in economic growth of the region and employment opportunities for the community. It empowers businesses and trade.

3. **Disaster recovery:** Bridges have a multiplier effect on the efficiency of disaster recovery. Bridges ensure much-needed connectivity and access to rescue operations. Bridges ensure mobility for relief activities. Relief activities require ease of mobility for personnel and medical equipment, medicine, water, relief equipment like tents, mobile sanitation centres, and other essential items. Resilient bridges ensure the safety during movements and connectivity required for sustained mobility. They ensure the restoration of normalcy. Normalcy is essentially required for sustained economic activities. Resilient bridges ensure speedy recovery progress and economic revival. Past research and UNDRR studies revealed that every single dollar investment in resilience resulted in four times the return on investment. During normal times, this investment results in increased employment and trade.

- **INDIRECT IMPACT**

Unaccounted impact of resilience, are the indirect benefits that accrue to the community due to resilient infrastructure. Generally, the estimation or evaluation of the benefits and the costs account for only those amounts that are evident and tangible. Intangible benefits and costs are difficult to evaluate and hence unaccounted in the estimates and evaluation.

1. **Regional Resilience:** Resilience of the region or country tantamount to a scenario, where the entire systems essential for disaster risk reduction are in place and efficiently geared for the next occurrence of the natural hazard. Under such circumstances, the local communities are in a high level of preparedness. The entire population is relaxed due to their faith in the systems implemented. Such a relaxed population will yield very high productivity. The region will witness sustained economic growth. Infrastructure is evolved and efficient. Economic growth results in safety and security to the population.

2. **Safety and security:** The benefits of stability, sustained overall economic growth, employment opportunity, safety and security of all essential parameters like food, fuel, energy, water, shelter. Fuel and energy security arises from stability in the region and enhanced economic growth of the region or country. This security provides impetus to economic activities resulting in growth of long-term nature. Contribution from resilience towards this growth is difficult to evaluate and hence not considered in estimation of benefits or cost. The fuel and energy security should percolate to the rural regions also for the long-term benefits to accrue.

3. **Resilient population:** Stability in the country offers another security. This is security of shelter, food and water to the population of the country. Various studies have highlighted the fact that population with these securities (shelter, food and water) are very resilient and are involved in the overall development of the region. When the stability of the region/ country is in conjunction with the social and environmental stability, not much migration occurs. The percentage of Population displaced is low and refuge seekers are non-existent. Lower percent of displaced population yields very high productivity. UNDRR in their study in 2023 recognized this disparity and focused on eliminating this disparity.

- **DISASTER PREPAREDNESS**

The existence of resilience in any infrastructure is not accidental. A lot of research is required to frame standard procedures for design and construction, which adopt environmentally friendly. In the post-disaster scenario, hazards cause havoc to the infrastructure. Many historical narratives confirm that bridge collapse is a reality. Estimates of global loss of about USD $350 billion are lost due to natural hazards only in infrastructure damage or collapse. World Bank estimates global cost due to natural hazards is upwards of USD $520 billion in consumption loss, human and economic loss.

United Nations reiterated these findings in the interactive discussion on the International Day for Disaster Reduction in 2018. It further recognized that Reducing Disaster Risk is the biggest challenge for development.

Researchers in various countries have also accepted that the study of past collapsed bridges signifies how and why bridges have collapsed. It has also highlighted the need to bring a new perspective in risk assessment to overcome limitations of the current methodology to determine which ageing bridges survive after a natural hazard occurrence.

In real scenario bridges, which are the key components of any network, restore speedy normalcy and act as catalysts for recovery progress by ensuring continuous commercial activities, which are critical for the revival of economies. Resilient bridges ensure protection to regions from future disasters. Many researchers have attributed the title of LIFELINE to the transportation network. The World Bank for a document published by them also adopts this.

Bridges have gained importance. Now for any network, bridges play a major role in normal activities of the region. The demographic distribution of bridges globally is aging. Aging bridges will have witnessed deterioration process. Post occurrence of a natural hazard, many bridges are susceptible to collapse. It is critical for the bridges to be resilient so they are able to provide required connectivity.

Implementation of adequate framework is essential to enforce the concept of resilience. Such legislation would enforce proper designs and construction of resilient bridges. It would allow the additional four to five percentage of expenditures to the required resilience in bridges. Research indicates that approximately five percentage of cost increases. Also regular inspection and maintenance is essential.

D) IMPACT DUE TO INADEQUATE RESILIENCE OF BRIDGES:

In scenarios where the regional network fails to incorporate resilience into its infrastructure, particularly bridges, the consequences can be severe, leading to a state of total chaos. The effect arising from inadequacy are either direct impact or indirect impact.

- **DIRECT IMPACT**

1. **Disruption of Transportation:** Inadequate resilience of bridges can lead to their failure during occurrence of extreme natural hazards (events such as earthquakes, floods, or hurricanes). This directly disrupts transportation networks, making it difficult for people and goods to move across regions. The collapse of bridges hampers the normal flow of traffic, affecting daily commutes and emergency response routes. Disruption of transportation leads to total collapse of all other systems that are essential for resilience. The various benefits that arise from an efficient transportation network towards safety, security, economic growth are all lost.

2. **Loss of Lives and Injuries:** Bridge failures can result in the loss of lives and injuries. When a bridge collapses unexpectedly, vehicles and

pedestrians on or around the structure come in the harm's way, leading to fatalities and casualties. The immediate impact on human life can be devastating, especially if the collapse occurs during peak traffic times. This complicates the scenario and diverts the attention of rescue and relief agencies. If the bridge collapse occurs on the route to the disaster zone, the rescue and relief operations in this bridge collapse zone delays the actual rescue operations from the actual zone of influence.

3. **Property Damage:** Beyond the loss of lives, inadequate bridge resilience can cause significant damage to surrounding infrastructure and properties. The collapse of a bridge may damage roads, buildings, and utilities, exacerbating the overall impact on the community.

4. **Economic Disruption:** Transportation disruptions and damages to infrastructure can lead to economic losses for businesses and individuals. Bridges ensure connectivity within the transportation network. A collapse results in loss of seamless connectivity. Alternate routes are available within the network but are time consuming and cost inefficient. Connectivity results in ease of movement for employees and goods. This is lost. The inability to transport goods and services efficiently can result in financial setbacks for industries and communities, further exacerbating the economic impact.

- **INDIRECT IMPACT** [6, 7]

1. **Delayed Rescue and Relief Operations:** The lack of resilience in bridge infrastructure hinders the timely response of emergency services. Challenging scenario arise for emergency personnel impeding speedy Rescue and relief operations as damaged bridges make difficult to reach affected areas swiftly. Delays in assistance can escalate the severity of injuries and increase the risk of further casualties. Every hour of delayed rescue and relief inputs results in more fatalities and collapse of community's faith in the system. The community in long-term lose their faith, resulting in delayed resilient community establishment.

2. **Isolation of Communities:** Inadequate resilience in bridges can isolate communities, cutting them off from essential services, supplies, and support systems. This can lead to a breakdown in community resilience as people struggle to cope without access to medical facilities, food, and other necessities.

3. **Long-Term Economic Consequences:** The indirect impact of inadequate bridge resilience extends to the long-term economic consequences. Communities that face prolonged disruptions in transportation and infrastructure may experience a decline in property values, loss of businesses, and a slow recovery from the overall economic downturn. Delay caused due to time lost in reconstruction of the bridge, results in shifting of business to locations that offer ease of

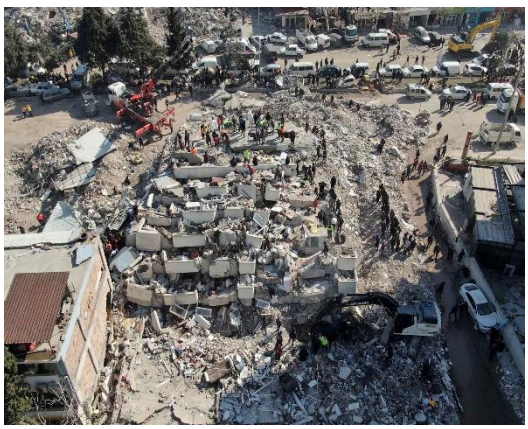
movement. Such shift of business has cascading effect on employment, trade and economic growth of the region.

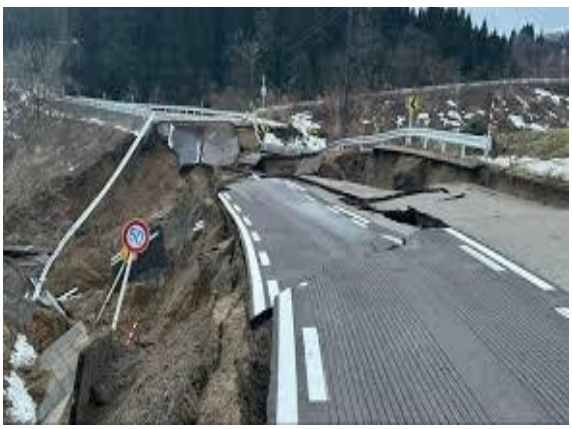
4. **Psychological and Social Impacts:** Witnessing the collapse of critical infrastructure, such as bridges, can have lasting psychological effects on communities. Fear, anxiety, and trauma may persist among residents for a long time even after restoration of the connectivity, affecting the social fabric and mental well-being of the affected population. Scepticism in the regional population is collapse of regional resilience.

The impact of inadequate resilience in bridge infrastructure is multifaceted, affecting not only the immediate safety and well-being of individuals but also the long-term stability and prosperity of communities and regions. Addressing these vulnerabilities through improved resilience measures is crucial for ensuring the overall safety and sustainability of infrastructure networks.

E) DISASTER PREPAREDNESS: HOW CRITICAL IT IS TO SAVE LIVES[9, 11, 12]:

The comparison of similar hazard occurrences brings out this fact more acutely. Two similar earthquakes in two different countries bring out the reality of importance of preparedness for any disaster. Turkey experienced a 7.8-magnitude earthquake in February 2023, while Japan experienced a 7.6-magnitude quake also in February 2023. In Turkey the fatalities was about 59000 while in Japan the death toll was about 50. The severity was nearly same. The energy released by the earthquake in Turkey must have been higher than that released by the earthquake in Japan. The location played a decisive role. Densely populated Turkey suffered large number of fatalities.





(Photo credit Boston University and Kashmir Life news)

Influence of regional social and economic instability, damaged infrastructure, and international relations affect Rescue operations. Social instability results in fear in the minds of international rescue agencies to reach out to the communities in the zone of disaster. Economic instability keeps away most of the agencies. When instability is not an issue, damaged infrastructure makes the area inaccessible hampering rescue operation or causing delay in

mobilization. Delay in mobilization directly affects the number of fatalities. Existence of congenial relations around the World also results in prompt help pouring the country affected. These three factors are contributory factors.

The main factor affecting the disaster response is the level of preparedness and the population density in the zone of disaster. Level of preparedness has to be holistic in nature. Proper regulatory framework is essential. Stringent adherence to the codes of construction and maintenance ensures the resilience in infrastructure. Hazards magnify to calamity when infrastructure collapses. Natural disasters are unavoidable; mitigation of the impact happens with proactive measures such as the enforcement of stringent rules and codes. The community has to adhere to the rules and codes to avoid occurrence of collapse. This adherence leads to overall development of resilient infrastructure. Population survives the disaster; response is faster and effective to enable revival of normalcy in the community affected by the hazard.

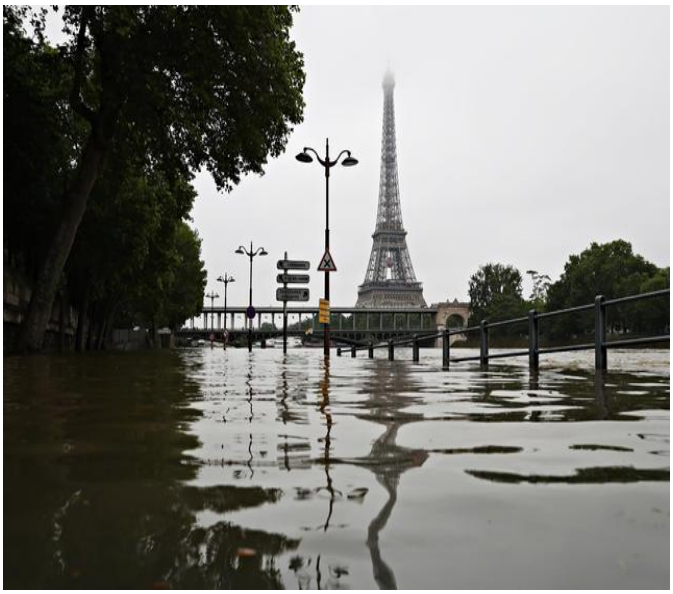
The regulatory framework alone is not sufficient. Communities need proper information dissemination and warning systems need to be in place. Untrained population's response will lead to chaos. Disciplined population results in early revival of normalcy. Training in Self-preservation techniques is essential in every community at micro level. At Macro level, the authorities and the community react in tandem to ensure a structured approach in post disaster scenario.

In contrast, survival of the asset in absence of regulation and codes for creation of assets is a chance. Post disaster, large-scale collapse of infrastructure in conjunction of collapse of houses or shelter used by the majority of the population, leaves entire communities without shelter, without food and fuel supply. This brings in insecurity to the community and individual traumatized minds. The loss is indirect and massive. Evaluation of loss due to disaster does not account for such loss. The loss is at times long terms. The trauma can have devastating influence on an individual for years. Evaluation of lost future is not accounted in calculations. Lost career and missed out opportunity are all around. Similarly, children loose valuable days. Their focus is on the struggle to survive rather than on studies and education. Repeat exposure to disaster under same circumstances, results in spiralling impact. Generations lose their bearings and results in missed out opportunities. UNDRR aptly seeks to stop this Spiral.

The importance of critical bridges and the entire transport infrastructure highlights, with their vulnerabilities to diverse hazards. Emphasis on the need for resilience quantification comes to the front. Significance of assessing bridge and network vulnerabilities, prioritizing restoration, and the role of resourcefulness in resilience necessitates speedy restoration. Security and safety (with respect to shelter, food, fuel, employment, economic growth) brought by resilient transportation is lost. The recent events in Europe during flooding highlights this scenario [11].

F) OECD MODELLING AND CLIMATE-RESILIENT INFRASTRUCTURE[10]:

Major floods devastated Paris recently. Successive floods occurred in 2016, 2018 and again in 2021. Organization for Economic Cooperation and Development (OECD) initiated a policy paper [10] for action initiation to avoid the recurrence of damage due to flooding. Called the OECD modelling and climate resilient infrastructure, this model deals to ensure resilience. The model of the potential impacts of a major flood in Paris evaluated that Infrastructure would bear 30% to 55% of the direct flood damages, while business would suffer loss to the tune of 35% to 85% caused by disruption to the transportation and electricity supply. Therefore, the impact on business would result in an indirect impact and not by the flood itself. The planning document also stipulated that expenditure on ensuring resilience would result in reduction of direct losses and the indirect costs of disruption. Flexible, adaptive approaches to infrastructure reduce the costs of building climate resilience given uncertainty about the future.



Climate model projections are a significant source of uncertainty, particularly on a regional or local scale, but other factors (such as socioeconomic changes) are also relevant for climate resilience. Decisions about infrastructure should consider relevant uncertainties to ensure resilience across a range of potential future scenarios

(Photo credit CBS news)

Floods reoccurred in 2023 due to Strom Oscar and Strom Gerrit. This affected not just France but many other European countries. Cancellation of trains resulted in United Kingdom. Trains cancellation between main land Europe and UK occurred. This stranded passengers on both side of English Channel. Germany witnessed flooding due to wild weather. North Europe had severe weather warning for days.

Tools discussed in OECD report were multiple aimed to encourage investment to secure resilience. The need to shift development away from high-risk areas was the key. Outlined was the need to include strategic environmental impact assessment prior to start of major infrastructure project.

G) EUROPEAN FLOOD RESILIENCE AND DISASTERS[11, 13, 14]:

Many countries suffered from flooding in Europe during the past few years (2016, 2018, 2021, and 2023). Entire Europe has accepted the directive to ensure reduction of risk where hazards are severe or significant. Different Countries have to multiple risk assessment and management models. Key outlined directive include shifting the development away from risk prone areas. This will need changes to happen over a period. Climate changes plays havoc with the planning process. The shift in flooding area over years makes it difficult to identify which area is safe from the risk. In many countries, prevention is the main stay of the risk reduction plan. In few countries, focus is on disaster response and recovery.

UNDRR outlined a five points program. This was after the European floods of 2021. UNDRR wants the countries to understand the present and future risk better. Based on this understanding, the countries should strengthen the emergency response preparedness and coordination. Further Insurance of loss due to natural hazards to the best possible extent be undertaken. Europe is a small continent. Natural hazard occurrences do not limit to one country. This makes it essential for cross border coordination. Multi-level strengthening of risk governance is essential.

Decisions states that the built environment should become less vulnerable to extreme weather conditions and potential hazard related damage.

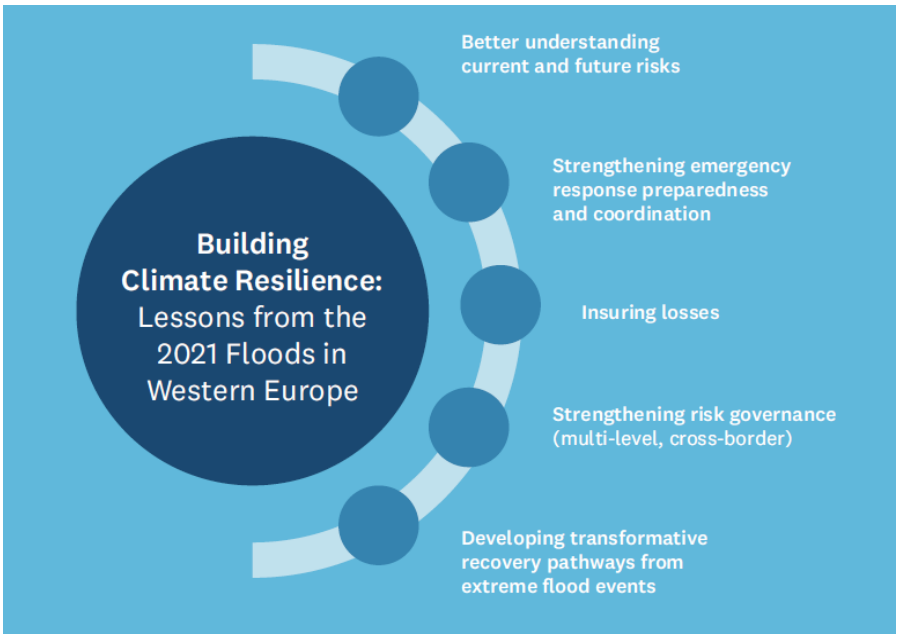


Image credit: UNU /UNDRR

H) FRAMEWORK FOR STRENGTHENING PREPAREDNESS [2, 3, 4]:

The Sendai Framework for Disaster Risk Reduction established in 2015 (Sendai Framework) provides with seven point with concrete actions to protect development gains from the risk of disaster. The seven global targets outlined include substantial reduction of global disaster risk and mortality,

number of affected people globally, economic loss, disaster damage to critical infrastructure and disruption to physical, social, cultural and environmental assets of people, communities, businesses and countries. It outlines increasing the number of countries with national and local disaster risk reduction strategies, to enhance international cooperation to developing countries, ensure global availability of and access to multi-hazard early warning system. Four priorities outlined need an understanding of disaster risk, strengthening disaster risk governance to manage disaster risk, investing in disaster risk reduction for resilience, enhancing disaster preparedness for effective response, and to "Built Back Better" in recovery, rehabilitation and reconstruction. UNDRR recommends gearing framework essential for preparedness to ensure disaster risk reduction. Consolidate existing framework.

Many organizations and research bodies devoted their research efforts to consolidate the above aim and objectives. The research resulted in methodologies proposed to achieve resilience. Three critical areas of impact outlined included Social impact, Environmental impact and Economic impact.

1. Social Impacts: The analysis of social impacts focuses on strengthening the resilience of vital road structures, particularly the weakest part in the most rural area. Identify vulnerabilities, highlighting areas for targeted infrastructure improvements. Involvement of local communities in the task brings insight. This lays the groundwork for strategic enhancements in design and maintenance policy and implementation, ultimately bolstering the overall resilience of crucial transportation network.

- **Safety Concerns:** The analysis of social impacts emphasizes safety concerns, highlighting the vulnerability of infrastructure, particularly in regions prone to frequent hazard occurrences. The potential threat to public safety due to failures underscores the urgency of addressing vulnerabilities in critical infrastructure. The analysis stresses the need to safeguard communities and maintain reliable lifeline structures to prevent disruptions in emergency responses and ensure the well-being of residents during natural hazard events.
- **Connectivity Disruption:** The analysis of social impact of event occurrences centres on connectivity disruption due to failures, affecting economic activities and cultural interactions. Beyond physical connectivity links, transportation infrastructure serve as critical lifelines, supporting communities and their compromise during events hampers daily life and emergency responses. Ensuring resilience of bridges is crucial for maintaining the flow of people, goods, and services, highlighting the pivotal role in societal well-being during natural disasters.

2. Environmental Impacts: The analysis of environmental impact focuses on developing design guide with a comprehensive structural model, anticipating failure scenarios and enhancing structural resilience during peak events. It contributes to sustainable infrastructure development by

optimizing designs for extreme conditions, thereby reducing environmental consequences associated with natural hazards.

- **Damage Costs:** The study highlights the significant environmental impacts of natural hazards, with a focus on damage costs. It emphasizes the interconnected consequences, revealing that the insured costs associated with natural hazard events extend beyond financial losses to encompass broader environmental tolls. The destruction of infrastructure, especially bridges, leads to the release of hazardous materials, ecosystem disruption, and contamination. The economic burden of reconstruction efforts and environmental rehabilitation underscores the importance of recognizing and comprehending these impacts for informed decision-making and resilient infrastructure planning.

3. Economic Impacts: The analysis of economic impact assessment is a thorough evaluation that focuses on prioritizing transportation infrastructure like a bridge structures by considering the potential consequences of closure. It takes into account a range of factors, including delay costs incurred by emergency services, road-surface wear costs, and freight delay costs. To achieve a comprehensive understanding, the study introduces detailed costing models that encompass various elements such as detour routes, vehicle operating costs, accident costs, local air pollution costs, greenhouse gas emission costs, road surface wear costs, as well as costs associated with delays for the police, firefighting, and ambulance services. The ultimate goal of this comprehensive economic analysis is to establish a robust framework for conducting cost-benefit analyses in the prioritization of transportation network including bridges. This designed framework will be instrumental in facilitating funding applications and building business cases for public projects, ensuring that economic considerations play a pivotal role in the decision-making process related to critical transportation / bridge infrastructure.

- **Infrastructure Costs:** The Economic Impacts section emphasizes the significant financial repercussions of natural hazard events on infrastructure, stressing the potential for catastrophic economic losses. It underscores the broader economic implications beyond immediate repair costs, including impacts on the overall infrastructure network and regional economic well-being. The narrative highlights the urgency of addressing seismic vulnerabilities through resilient design and retrofitting to prevent prolonged reconstruction timelines and mitigate economic setbacks caused by disruptions in transportation, trade, and emergency response services.
- **Research Importance:** In light of economic impacts, such similar research stresses the urgency of investigating the natural hazard vulnerability of vital transportation infrastructure like bridges. It highlights the potential for substantial economic losses due to insufficient hazard resilience, encompassing infrastructure damage,

transportation network disruption, and broader societal consequences. Advocating for proactive research, it aims to bolster the resilience of critical transportation network including bridges, emphasizing the long-term benefits of investing in resilient infrastructure for sustained regional stability and economic robustness.

Results and Recommendations brought out by previous research indicate the need to prioritise reconstruction abiding the environmental and economic assessment principles. Ensure to explore alternate construction methods to speed up restoration. The delay or loss of connectivity results in social and economic impacts to the region serviced by the bridge. Ideally, it is best to offer alternate arrangement to keep the connectivity available.

I) Conclusion: The need for Resilient Bridge infrastructure

The need for resilience in bridge infrastructure is paramount. In the past decade, frequency and severity of natural hazards has increased. This has resulted in the need to provide rescue and relief promptly to the most needed communities. The increase in severity of the natural hazard has resulted in an undefined strain on the transportation networks. Bridges experience the worst of the onslaught. Many bridges have collapsed. The loss of connectivity results delay in rescue and relief emergency operations and delayed recovery of the community.

Resilient bridge infrastructure ensures that essential continued connectivity and transportation routes remain intact. Intact transportation network ensures continued movement of goods and services, essential for rescue and relief operations in the short-term and in the long-term; it facilitates continued commercial activities, trade, commerce and economic activities. All this enables prompt rescue and relief operations and recovery post occurrence of the natural hazards. The speed with which the region rebounds to normalcy is critical to avoid massive regional economic loss. Reduction in fatalities and economic loss is critical in Disaster Risk Reduction. This prevents the hazards from becoming a calamity.

Existence of resilient bridge reduces the need for exploring multiple route for the rescue and relief mobilization. Integration of technologies today make it possible to identify the least congestion route. Speedy recovery of the entire community and region is feasible due continued connectivity offered by resilient bridges. The speed of recovery post occurrence of the natural hazards also aids increased trust of the population of the region on the infrastructure. Such high trust is critical for the establishment of resilient region. Investment on establishing resilient bridges goes beyond the short-term benefits it offers for speed mobilization of rescue and relief operation to the long-term benefits, which results in enhanced resilient economy and resilient region.

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