Published by :
https://www.ijert.org/
An International Peer-Reviewed Journal

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

Taxonomy for Progressive Collapse of Bridge Structure

Rina Kumari[1*], Vikash Kumar[1], Dr. Manish Kumar Mandal[1], Dr. Raja Sonal Anand[1], Himanshu Kumar Yadav[1], Randhir Kumar[1]

[1]Assistant Professor, Department of Civil Engineering, Government Engineering College, Lakhisarai, Bihar, India

Abstract **- Bridges is a structure which serves as a backbone for roadways and railways over the obstacle like river, deep valley, a rail and a road. 9/11 event growing the interest in research work for progressive collapse and structural sturdiness. Mechanism of progressive collapse of bridges are quite different from the building structures. The guidelines of progressive collapse analysis for bridges are very few and still in progress. This research study described major bridge failure and provide comparison between bridge collapse in India with other countries. The objective of this research to explain collapse mechanism of bridge and their causes, type of progressive collapse and suggest various design measures used to prevent bridge collapsed.**

Keywords - Progressive Collapse; structure; sturdiness; mechanism

I. INTRODUCTION

Bridge failure due to progressive collapse of structure originated by localized structural damage and after that its increases and converted into a failure of a whole structure. Structural collapse is measured by disproportioned in magnitude of triggering action and magnitude of resulting collapse. Structural robustness reduced and collapse occurs may be because of diverse reasons, e.g., fire, seismic load, gas explosion, terrorist attacks with explosive, removal of structural member, vehicle load impact and wind impact. Due to complexity in dealing with structural collapse and robustness, in threat-dependent approach such as blast, fire and seismic load etc act as a triggering event generally follow codes and guidelines, but in threat-independent approach such as vehicle and wind mostly implementing alternate load path method. Research on progressive collapse of a structure stated in 1970's and gain attention in 1995 after the bombing of the Alfred P. Murrah Federal Building in Oklahoma City but after the incident of 11th September, 2001 it's become more intensified.

Mostly bridges are horizontal aligned structures having extension in the direction of one main axis, having different mechanism of collapse as compared to the buildings. In construction practices, several bridges such as rail bridge, vehicle bridge and foot bridges are in existence. Due to various structural form, bridges are classified into beam-bridge, truss bridge, cantilever bridge, arch bridge, suspension bridge and cable-stayed bridge. For different type of bridges, there are various different reasons for the collapse, such as impact loads from collision of ships and heavyweight vehicles, lateral load from strong wind and ground motion due to earthquake.

II. BRIDGE PROGRESSIVE COLLAPSE EVENTS

A. Kutai Kartanegara Bridge (Indonesia) Collapse

This bridge collapsed into Mahakam River. It is a suspension bridge of main span 635m long and it collapsed during hanger maintenance work. The collapsed event was originated from one or more hanger failure. The connections between truss and hangers were subjected to corrosion and fatigue due to traffic load during their service life. The investigation report by Lynch, 2012 (Indonesia's Ministry of Public Works), collapse occurred when engineers were jacking beneath the deck. Due to collapse of hanger extra stresses generated on the hanger connection, it triggers failure of the bolt connection between the bridge deck & steel hangers in shear. Failure in one connection, increased stress in other connection due to this continuous reaction, bolts failed in the remaining connection, and thus structure collapsed.



Fig. 1. Collapsed of Kutai Kartanegara Bridge

B. Skagit River Bridge (USA) Collapse

In 2013, truss bridge over Skagit river (USA), one span of the bridge collapsed into the river. An oversized loaded truck collides with several overhead support beams of the bridge, thus northern span of bridge collapse. In this bridge there is four consecutive independent spans, therefore failure due to progressive collapse in any one of the spans did not initiate collapse in other structural member. Pier below the bridge deck were not damaged but only deck and overhead superstructure of the northernmost span collapsed.

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026



Fig. 2. Skagit river bridge collapsed

C. Bai Hua River Bridge (China) Collapse

On 12th May, 2008 due to Wenchuan earthquake of magnitude 8.0 several bridges were distorted in Sichuan Province, China. Bai Hua bridge is a post-tension concrete girder bridge. This four spans bridge were collapsed due to strong ground motion and due to detachment of lateral beam, pier was broken into two pieces. According to investigation report, the inadequate amount of reinforcement in lateral beam caused brittle failure at the joints, which was the main reason of the bridge collapse.

D. Tacoma Narrows Bridge (USA) Collapse

On 7th November, 1940 Tacoma Narrow bridge collapsed due to strong wind. Aeroelastic flutter generated by the strong wind flow which is the main reason behind the collapse. Failure due to collapse of Tacoma Narrow bridge boosted the research study in bridge aerodynamic and aeroelastic, which stimulus the preventive design measures for all the long span bridges built after 1940.



Fig. 3. Tacoma Narrow Bridge Collapse

III. INDIAN BRIDGE FAILURE EVENTS

In India, report has been prepared during the period of 1977-2017, from various resources, including published literature and media report. Rajeev Kumar Garg, Satish Chandra and Aman Kumar et al. (2020) concluded that the number of bridge damaged or collapsed during their service life and construction period are 2010 & 123. Failure of bridge due to natural disaster made most disturbing effect on the existing of bridge structure. Utmost affected component of bridge during their service life is superstructure, followed by the substructure and foundation. Bridge collapsed incidents during construction and service period has increased with an average rate of 129 bridge per year (2007-2017).

On 25th March 2012, under construction Chauras bridge collapsed during deck slab casting. Birajdar et al. 2014, found that upper chord member of the truss bridge suffered excess stress by 16% above the allowable stress, thus causing buckling of the member. After that, a significant tension force induced in the bottom chord member, which resulted in the snapping of the member which tends to collapse.



Fig. 4. Chauras Bridge Collapse

On 6th May 2015, Digaru river bridge in Kamrup district, a PSC girder bridge were collapsed during the construction phase. Supervising agency explained that earthquake in Nepal (2015) therefore girder was displaced from their stable position which caused to failure of the girder from the pier.

Under construction flyover in Kolkata, collapsed on 31st March 2016 during its construction period. Inquiry committee found that due to poor design construction, raw material and inadequate supervision of sites are the reason behind the sudden collapsed of this fly over.

In 2017, bridge over Ravi River, Chamba, Himachal Pradesh were collapsed when one overloaded brick carrying truck and only one car & motorcycle were moving over it. The cantilever ends of the two adjacent spans fell without damaging the rest of the superstructure. Overloaded truck, failure of bearings, design load and its distribution from superstructure were not taken adequately during construction of bridge.

A railway bridge having span length of 36.6m was built in 1916 over the Dhawa river in Bihar. This railway bridge was collapsed in Rafiganj, Bihar 2002, due to lack of maintenance of fastening and deteriorating condition of the bridge. In this accident 200 person were died and 150 persons were injured. Two piers got crushed and the foundation of one of the piers was damaged.



Fig. 5. Rafiganj Railway Bridge Collapse, Bihar

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

IV. COMPARISON OF BRIDGE COLLAPSED IN INDIA, USA, CHINA AND WORLDWIDE

Table I summarizes the bridge failure statistics reported for India, the USA, China, Nigeria and worldwide.

TABLE I. COMPARISON OF BRIDGE COLLAPSES IN INDIA, USA, CHINA, NIGERIA AND WORLDWIDE

S. No.	Parameters	India	USA (Lee et al. 2013)	China (Tan et al. 2020)	Nigeria (Ede et al. 2019)	Worldwide (Imam & Chryssanthopoulos et al. 2012)
1	Event Period (Years)	1977-2017	1980-2012	2009-2019	2010-2018	Before 2014
2	No. of bridge failure	2010	1062	298	45	164
3	Average life of failed bridge	34.53	51.70	23.60	NA	NA
4	Percentage failure due to					
i	Overloading	3.28	12.71	12.76	17.78	5.00
ii	Deterioration	10.10	6.69	Nil	Nil	3.00
iii	Natural Disasters	80.30	50.66	38.85	62.22	21.00
iv	Design, Construction & maintenance	4.13	11.11	12.06	4.44	35.00
v	Man made Disaster	2.19	18.17	26.23	15.56	14.00
vi	Miscellaneous	Nil	0.66	10.10	Nil	22.00

V. COLLAPSE MECHANISM OF BRIDGES & THEIR CAUSES

In past, progressive collapse of bridges has not been drawn attention from researchers like progressive collapse in buildings, but due to several collapse incidents of bridges all over the world emphasized to understand the collapse mechanism of bridges and its causes. The collapse mechanism profoundly dependent on the different type of bridge structure.

A. Impact Load (Accidental Load) Triggered Collapse

Collision of ship with bridge pier, side collision and collision with bridge deck like accidental events causes serious damage. Flood conditions, type of structure and type of waterway etc are the various factor that affect the impact loading. Several methods are used to calculate impact loading.

AASHTO specification (2007) provide the formula:

$$F = 1.11 \times 0.88 \sqrt{DWT} \times V / 8 \quad (1)$$

where F = Equivalent average impact load in MN; V = Ship impact speed in m/s.

Eurocode 1, part 2-7 (2003) provides another method to calculate the design collision

$$F = V \times \sqrt{KM} \quad (2)$$

where K = Equivalent stiffness; M = Impact mass; V = Velocity.

B. Earthquake-Induced Collapse of Bridge

Earthquake cause damages the several components of bridge. Due to earthquake several modes of failures like shear failure, flexural failure at base, bond failure of lap slice and combine shear – flexural failure occurs in concrete pier. Concrete bridge pier failure is the most important factor in collapse failure. For concrete pier, failure in shear and flexure are very common.

1) Flexural Failure of Piers

Flexural failure is one of the major concerns in bridge design. Piers fails in flexural when horizontal motion is very high. Occurrence probability of flexural failure is more than the occurrence of shear failure. To ensure sufficient amount of ductility in pier designer should provide sufficient amount of longitudinal reinforcement with enough anchorage and lapping. For avoiding brittle failure, hoop should be designed to offer enough lateral confinement to the joints. Plasticity helps to scatter the earthquake energy.

2) Shear Failure of Piers

Piers should be designed in such a manner to resist shear failure. Shear failure exhibits sudden and brittle characteristic. Short columns avoided in pier construction because they are prone to shear failure. Pier reinforcement details, height, its connection to the deck and type of foundation used in pier construction also affected the shear failure of the pier. Failure of transverse reinforcements cause shear failure in concrete pier.

C. Wind-Induced Collapse

Suspension bridge and Cable stayed bridge should designed to resist strong wind force. These bridges are susceptible to strong wind and caused major role in bridge collapse. Due to strong wind aeroelastic flutter caused bridge collapse.

VI. TYPE OF PROGRESSIVE COLLAPSE

A. Pancake-Type Collapse

This type of collapse initiated due to the failure of vertical load-bearing members. Thus, upper part of the structure falls in vertical rigid body motion. During downward movement of a member energy transform from potential to kinetic energy. This kinetic energy from separated member gives impact loading to the other vertical load bearing elements. Therefore, whole structure collapsed and the direction of failure is in vertical direction. region. Failure of twin towers of World Trade Centre is the best example of this type of collapse.

B. Zipper-Type Collapse

In this type of collapse, failure of one or few tension member redistributed the force they carried to the other remaining structural member and induced an impulsive load to the structure. As result of impulsive loading structure display dynamic response which lead to failure of the structure in transverse direction. Tacoma Narrow bridge collapse is a famous bridge failure due to wind induced distortion which twisted girder of the bridge.

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

C. Section-Type Collapse

This type of collapse occurs when part of cross-sectional member like beam and bar etc split into parts then internal forces transmitted by these cross-sections is redistributed to the remaining cross-section. Therefore, at some location stress will increases and cause rupture for other cross-sectional part and failure progress in same manner throughout the cross-section. This type of collapse of structure looks similar to fracture incident instead of progressive collapse.

D. Domino-Type Collapse

A series of dominoes exhibits in domino type of collapse. This type of collapse display chain reaction mechanism. Due to initial overturning of one element and fall of that element in an angular rigid body motion around the bottom edge. Continuous application of lateral impact on the upper edge of the element and side face of the adjacent element leads to overturning. In this type of failure potential energy transform to kinetic energy. The direction of overturning is the direction of failure.

E. Instability-Type Collapse

Structural equilibrium can be also weakened by the additional structural elements like stiffeners and bracings. Local failure of these additional structural elements makes the whole structure unstable without any failure propagation and thus leads to structure failure. Failure of I-35 W steel deck truss bridge is the best example of instability type collapse.

F. Mixed-Type Collapse

Mixed type collapse is the combination of two or more types of collapse. Mixed type collapse exhibits characteristics of all interacting type of collapse during failure propagation. P. Murrah Federal Building failure is the example of mixed type of collapse which displays both pancake type collapse and domino type collapse.

VII. DESIGN MEASURES TO PREVENT BRIDGE COLLAPSE

A. Beam Bridge

In construction of beam bridge and continuous beam bridge, design of pier is very crucial. Pier should be designed in a such way to resist abnormal loading and protected from initial local failure by increasing safety level. Bridge is very important and expensive structure so that buffer zone and cofferdam should be designed to protect pier from any abnormal loading, like ship collision. Starossek et al. 2006 suggested that Segmentation design method. In segmental design method, a series of independent span constructed, therefore, failing of any one span by accident or any other reasons, rest of the span is unaffected and kept integral.

B. Cable-Stayed Bridge

Above all bridges, cable-stayed bridge exhibits higher degree of static indeterminacy. For collapse design of cable-stayed bridges, cable is the key element. Loss of cables always subjected to overloading and failure of the adjacent cables. According to Post tensioning Institute (PTI), 2001, and International Federation for Structural Concrete (FIB), 2005, structural stability of cable-stayed bridge should maintain and capable enough to withstand the loss of any one cable. PTI recommendation for cable loss load combination is:-

$$1.2\,DC + 1.4\,DW + 0.75\,(LL + IM) + CLDF \qquad (3)$$

where DC = Dead load of structural and non-structural component; DW = Self load of Wearing surface; LL = Vehicular live load; CLDF = Accidental load or impact load or cable failure load.

C. Suspension Bridge

Failure of Kutai Kartanegara Bridge collapse due to sudden failure of hangers. Zoli and Steinhouse found that the hangers are linked with deep stiffening trusses and due to loss of structural member hangers are not able to redistribute localized loading efficiently, which lead to their failure. Design of superstructure of suspension bridge cannot be simply taken as a protection of adjacent hangers. To avoid progressive collapse, large margin of safety should provide during hanger design.

VIII. CONCLUSION

Progressive collapse analysis for bridge structure is quite underestimated as compared to building progressive collapse. Bridge is a massive, expansive structure and providing smooth movement between two inaccessible ways. Collapse of bridge indicate loss of life, loss of economy, loss of easy transportation.

Progressive collapse triggered by various triggering events. Accidents, use of poor-quality construction material, earthquake heavy wind flow, heavy traffic and overloaded vehicles etc trigger collapse for bridge structure. Suspension bridge and cable stayed bridge more susceptible to wind induced collapse than other type of bridges.

Progressive collapse mechanism classified into six categories are pancake-type collapse, zipper-type collapse, section-type collapse, domino-type collapse, instability-type collapse and mixed-type collapse. Collapse mechanism features are different for different type of collapse.

Combination features of various collapse mechanism comes under the sixth type of collapse called Mixed-Type collapse. Combination of pancake-type collapse and domino-type collapse called Impact Collapse and combination of zipper-type collapse and section-type collapse called Redistribution of collapse. Impact and Redistribution of collapse is sub-category of mixed-type collapse.

Different collapse mechanism uses different preventive measures. Pancake-type collapse treated by deterministic approach and zipper-type collapse treated by probabilistic approach.

Failure pattern is similar to some extent in section-type collapse and zipper-type collapse and in both type of collapse fracture mechanics is applicable.

Design measures to prevent progressive collapse for different type of structural bridges are different. Large safety measures taken during hanger design in suspension bridge, segmental method minimize impact of progressive collapse event in beam bridges and continuous beam bridges.

REFERENCES

[1] AASHTO 2007, standard specification for highway and transportation. Washington, DC:AASHTO

[2] European Committee for standardization 2003. Eurocode 1: action on structures, part 2: traffic loads on bridges. EN 1991-2 European committee for standardization.

[3] FIB (International Federation for Structural Concrete), 2005. Acceptance of stay cables systems using prestressing steels.

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

[4] GSA (General service administration) 2003. Progressive collapse analysis and design guidelines for new federal office buildings and major modernization projects. Washington, DC: GSA.

[5] Lynch, D. 2011. Hanger work suspected in Indonesia bridge collapse. New civil engineer, December 1.

[6] PTI (Post tensioning Institute). 2007. Recommendation for stay cable design, testing and installation. 5th ed. Phoenix, AZ: Cable – stayed bridge committee.

[7] Starossek, U. 2006. Progressive collapse of bridge – aspect of analysis and design, Invited lecture at international symposium on Sea-crossing long span bridge, Mokpo, South Korea, Feburary 15-17.

[8] Zoli, T.P and Steinhouse, J. Some consideration in the design of long span bridges against progressive collapse.

[9] Starossek, U. 2006. Typology of Progressive collapse, Engineering structures 29 (2007) 2302-2307.

[10] Rajeev Kumar Garg, Satish Chandra and Aman Kumar (2020), Analysis of bridge failure in India 1977 to 2017, Structure and Infrastructure engineering.

[11] Imam, B. M and Chryssanthopoulos, M.K. 2012, Cause and consequences of metallic bridge failure. Structural engineering international, 22(1), 93-98.

[12] Lee, G. C., Mohan, S. B., Huang, C., Fard, B. N. 2013. A study of US bridge failures (1980-2012)

[13] Tan, Js., Elbaz, K., Wang, Z. F., Shen, J. S., and Chen, J. (2020). Lessons learnt from bridge collapse: A view of sustainable management. Sustainability, 12(3), 1205.

[14] Ede, A., Nwankwo, C., Oyebisi, S., Olofinnade, O., Okeke, A., and Busari, A. 2019. Failure trend of transport infrastructure in developing nations: Cases of bridge collapse in Nigeria. IOP conference series: Materials science and engineering, 640, 012102.

[15] IRC:112(2011). Code of practice for concrete road bridges. New Delhi: Indian road congress.

[16] Starossek, U. 2006. Progressive collapse of bridge – Aspects of analysis and design, Invited lecture. In: Proceedings, International symposium on sea-crossing long span bridges. 2006.

[17] Starossek, U. 2006. Progressive collapse of structure: Nomenclature and procedures. Structural Engineering International 2006; 16(2): 113-7.

(This work is licensed under a Creative Commons Attribution 4.0 International License.)