

IOP Conference Series: Materials Science and Engineering

PAPER • **OPEN ACCESS**

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To cite this article: A Ede *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **640** 012102

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Failure Trend of Transport Infrastructure in Developing Nations: Cases of Bridge Collapse in Nigeria

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Abstract. Sustainable transport system must be supported by resilient infrastructure such as bridges. Bridge is an essential transportation structure that offers unique solutions for road and rail traffic to cross rivers, gorges and difficult ground conditions or for reducing conflict points in transportation system by carrying one mode of traffic over the other. Due to its pronounced economic importance to the society, bridge design aspects must go beyond the physical bridge structures and must cover all the factors that impact on the safe operation throughout its serviceable life span. The environment and the obstacle it crosses, the soil which carries it, the self-weight, imposed dead weights and the moving live loads must be adequately taken care of. The considerable conflicting factors of the site's soil characteristics, river hydrology, ecosystem environmental impact, aesthetics, historical and archaeological impacts, permanent and transient loads, construction technologies and construction materials bring together a vast expertise of professionals. These sizeable factors must be well managed and harnessed by the vast team of experts involved to guarantee a positive outcome. The vast decay of Nigerian transport system is visible in all complimenting infrastructure including bridges. Cases of bridge collapse abound in Nigeria within the last decade. This research studies the failure trends of bridges in Nigeria and forty-five documented cases are considered for the research. Structural health monitoring approaches were combined with statistical measures to assess the causes and to proffer solutions to the failure trend. Poor maintenance, torrential rainfall/flooding, terrorist attacks, faulty design, poor materials and construction quality and truck overloading were found to be the major causes of bridge failures in Nigeria.

Keywords: bridge; collapse; transport infrastructure; sustainable development; steel; concrete

1. Introduction

The term bridge as per the Federal Ministry of Works “applies to structures over waterways, grade separation structures, road over rail structures and elevated highways” above 6metres which conveys traffic [1]. This bridge structure supports its own weight, loads due to do natural elements and daily traffic loads. Infrequent man-made conditions or extreme natural hazards coupled with frequent non-extreme loads, can compromise a bridges functionality [2]. Bridge failure occurs when the primary load-carrying portions of a bridge can no more perform its intended function and bridge collapse occurs to the entire bridge or a main component when partial or total replacement is required [3].



Bridge collapse has occurred as long as bridges have been in existence and will continue in future. There is a need for students and practicing engineers to be failure literate; continuously learning from the failure of structures including bridges [4]. Nigeria as a developing nation allocates more to transport infrastructural development each year and as more attention is put in constructing new roads and bridges, there is need to study the failure trends of existing bridge infrastructure. Concise knowledge of bridge collapse cases and causes will help guide future construction toward building more resilient bridges. From the study of bridge failures, new methodologies can be developed to reduce failures and increase the service life a bridges [5].

Bridge collapse in Nigeria has been given very little or no attention and in the last two decades there have been over ninety bridge collapse cases all over Nigeria. Good road transportation and the level of transport infrastructure directly affect the economic growth of Nigeria as they helps to complete business activities and facilitate trade of micro businesses [6]. Road transportation is responsible for 95% of both passenger and freight movement in Nigeria making it undoubtedly the prevalent means of transport in the country.

Official investigations are scarcely carried out to determine the cause of bridge failures in Nigeria consequently, technical data hardly exists. The primary sources of data for this study were online news sources. This paper aims at reviewing forty-five bridge collapses cases that have occurred in Nigeria from 2010 – 2018. Due to limited structural investigations carried out on bridge collapse in Nigeria, most of the bridge damage information only includes general descriptions.

2. Causes of Bridge Collapse

In 2015, *Choudhury and Hasnat* classified bridge collapse around the world into natural and human factors. Natural factors caused by the occurrence of wind, earthquake, cyclone, flood, scour and landslide and human factors caused by design and construction errors, overloading, collision, fire, lack of inspection and improper maintenance [7]. These factors individually may not cause collapse, but collapse may occur because of an interaction of several events [8]. The prevalent causes of the collapse of Nigerian bridges identified from this study are flooding, overloading, terrorist attack, design and construction errors and lack of proper maintenance and inspection.

2.1. Flood

Flooding in Nigeria cost human lives, social and economic disruption and degradation of the delicate ecosystem [9]. In this study the effect flooding of bridges is categorized in two; collapsed support and collapsed approach. Complete collapse of bridges can occur when the supports (piers and abutments) of the bridge are damaged as a result of flooding. A bridge could also have its major components in good condition but when the access to a bridge is compromised in such a way that the bridge cannot be used, or the safety of the bridge users is compromised the bridge is said to have failed.

Table 1 outlined the bridges that collapsed as a result of flooding. Sixteen bridges collapsed as a result of damaged bridge supports due to flooding while twelve bridges were still standing after the floods but the earth behind the bridge abutments, supporting the approach slab was washed away as a result of flooding.

Table 1 Bridge collapse cases due to flood

S/N	Bridge	Location	State	Year of Collapse	Source
Collapsed Support					
1.	Eme bridge	Amoji-Imenyi, Bende	Abia	2017	<i>Egejuru</i> , 2018 [10]
2.	Dubaidna river bridge	Dubaidna (Durumi 3)	Abuja	2014	<i>Naija Gist</i> , 2014 [11]
3.	Imiringi bridge	Imiringi, Ogbia	Bayelsa	2012	<i>Alagoa</i> , 2017 [12]

4.	Bebuo Bomaji bridge	Bebuo Bomaji, Boki	Cross River	2017	<i>The Guardian</i> , 2017 [13]
5.	Dubban Fulani bridge	Dubban fulani, Debba	Gombe	2015	<i>Ikeji</i> , 2015 [14]
6.	Yar'randa bridge	Yar'randa, Charanchi	Katsina	2013	<i>Vanguard News</i> , 2013 [15]
7.	Iyaji River bridge	Ekiti	Kwara	2017	<i>Fashikun</i> , 2017 [16]
8.	Alagbado bridge	Ilorin East	Kwara	2017	<i>Ahmad</i> , 2017 [17]
9.	Pandaragi bridge	Pandaragi, Edu	Kwara	2017	<i>Azeez</i> , 2018 [18]
10.	Tatabu bridge	Tatabu, Mokwa	Niger	2017	<i>Nwogu</i> , 2017 [19]
11.	Gulbim Boka bridge	Mariga	Niger	2018	<i>Channels Television</i> , 2018 [20]
12.	Odo pako bridge	Agbado	Ogun	2013	<i>Baffour</i> , 2012 [21]
13.	Idi-Iroko bridge	Iwo	Osun	2017	<i>Egobiambu</i> , 2017a [22]
14.	Chibiri bridge	Langkaku, Qua'an Pan	Plateau	2016	<i>Ikeji</i> , 2016 [23]
15.	Bridge along Wukari-Jalingo road	Along Wukari-Jalingo road	Taraba	2018	<i>AIT</i> , 2018; <i>Hunkuyi</i> , 2018 [24-25]
16.	Mararraban Gassol Bembal bridge	Along Wukari-Jalingo road	Taraba	2018	<i>National Helm</i> , 2018 [26]
Collapsed Approach					
17.	Emelogu bridge	Emelogu, Aba	Abia	2017	<i>The Sun</i> , 2018 [27]
18.	Ufuma bridge	Orumba North	Anambra	2015	<i>Maduforo</i> , 2015 [28]
19.	Uwaka Bridge	Umudim, Nnewi	Anambra	2017	<i>Egobiambu</i> , 2017b [29]
20.	Nkpor bridge	Nkpor,	Anambra	2015	<i>Njoku</i> , 2015 [30]
21.	Eguho-Ebonyi bridge	Agba, Ishiellu	Ebonyi	2013	<i>Okutu</i> , 2013 [31]
22.	Abakpa-Nike bridge	Abakpa-Nike, Enugu	Enugu	2012	<i>Dejiroony</i> , 2012 [32]
23.	Dangana bridge	Lapai	Niger	2017	<i>Grassroots.ng</i> , 2018 [33]
24.	Karamin-rami bridge	Mashegu	Niger	2018	<i>Akeem</i> , 2018 [34]
25.	Atuwara River bridge	logbo, Ado Odo/Ota	Ogun	2016	<i>Awoyinka</i> , 2016 [35]
26.	Shendam bridge	Shendam town	Plateau	2012	<i>Inyang</i> , 2012 [36]
27.	Kwalkwalawa bridge	Sokoto	Sokoto	2010	<i>El-Kurebe</i> , 2011 [37]
28.	Gusau bridge	Bungudu council area	Zamfara	2015	<i>NTA News</i> , 2015 [38]

Fig. 1 showed the Gulbim Boka Bridge with the earth supporting the approach slab of at one of its ends completely washed away after a heavy rainfall in 2018.



Fig. 1 Gulbim Boka Bridge

Source. *Channels Television*, 2018 [20]

2.2 Overload

The first, second and third national development plans from 1962-1968, 1970-1974 and 1975-1980 respectively after the country's independence in 1960 saw a surge in the level infrastructural development in the country [39]. Many prefabricated steel truss bridges were constructed over rivers in rural areas, linking communities. Years after that surge, the combined effect of fatigue on the bridge components and the increase of traffic loads have led to the collapse of many bridges in the country. The load considerations for the bridge at the time of design are no longer adequate for this present time. Outlined in Table 2 are eight bridges that collapsed due to overloading. Ikem bridge is a steel truss bridge in Isi-Uzo local government area (LGA) of Enugu state that was constructed in 1960. The bridge reportedly collapsed when a truck carrying 900 bags of cement plied on it [45].

Table 2 Bridge collapse cases due to fatigue and overloading

S/N	Bridge	Location	State	Year constructed	Year of collapse	Source
1.	Ndi Ebe Abam bridge	Arochukwu	Abia	1984	2014	<i>The Abia State Government</i> , 2017 [40]
2.	Mbio Ekene bridge	Nsit Ubium	Akwa Ibom	1960's	2010	<i>Idogar</i> , 2016 [41]
3.	Owa Abbi bridge	Owa Abbi, Ukwuani	Delta		2017	<i>Okoro</i> , 2017 [42]
4.	WRPC bridge	Ubeji, Warri south	Delta		2013	<i>O'Neil</i> , 2014 [43]
5.	Ovu river bridge	Agbani-Ugboka, Nkanu East	Enugu	1979	2013	<i>Ozor</i> , 2013 [44]
6.	Ikem bridge	Over Ebenyi River, Isi-Uzo	Enugu	1971	2015	<i>Eze</i> , 2015 [45]
7.	Urasi bridge	Amaruru, Orsu	Imo	Before 1967	2018	<i>Orsu24News</i> , 2018 [46]
8.	Ohan bridge	Near Alapa, Moro	Kwara	1972	2012	<i>Kwara News</i> , 2016 [47]

2.3 Terrorist Action

The actions of the extremist Islamic terrorist group Boko haram since 2009 in the North Eastern part of Nigeria have disrupted the social and economic activities of the people by crippling the road infrastructure [48]. The destruction of bridges was a strategy used by the insurgents to hinder transportation and interaction between communities, ultimately halting socio-economic growth of communities.

Table 3 lists seven bridges that were destroyed as a result of terrorist attacks. Fig. 2 and Fig. 3 show Kudzum and Katarko bridges respectively. Bombs were placed at strategic locations on the bridges by terrorists to render them unusable by motorists.

Table 3 Bridge collapse cases due to insurgent action

S/N	Bridge	Location	State	Year of collapse	Source
1	Kudzum bridge	Michika	Adamawa	2015	<i>Premium Times Nigeria</i> , 2017 [48]
2	Dilichim bridge	Over River Yedzaram, Michika	Adamawa	2014	<i>The Guardian Nigeria</i> , 2017 [49]
3	Mubi bridge	Mubi town, Adamawa North	Adamawa	2015	<i>Latest Update</i> , 2015 [50]
4	Biu Highway Bridge	Maiduguri-Biu Road	Borno	2014	<i>The Scoop</i> , 2014 [51]
4	Gwoza Bama bridge	Limankara, Gwoza	Borno	2014	<i>Ameh</i> , 2014; <i>Premium Times</i> , 2015 [52-53]
5	Nbulu river bridge	Ngala town	Borno	2014	<i>Vanguard News</i> ; 2014, <i>Trezyhelm</i> , 2016 [54-55]
6	Katarko bridge	Buni Yadi, Gujba	Yobe	2014	<i>H-Interactive</i> , 2014; <i>Duku</i> , 2016 [56-57]



Fig. 2. Kudzum bridge

Source. *Premium Times Nigeria*, 2017 [48]

Fig. 3. Katarko bridge

Source. *Duku*, 2016 [57]

2.4 Design and Construction Errors

There are numerous codes regulating the design and construction of bridges and in the absence of any abnormal external condition, bridges should last more than fifty years. Even with the access to a lot more technical information now on bridge design, several bridges collapse from design and construction errors. Omo river bridge in Ethiopia partially sank into the river during construction, the main bridge did not show any major distress but failure occurred due of a weak link between the main bridge and the launching nose [58]. Faulty design and construction can occur when bridge contracts are awarded based on sentiments and not qualifications such that, unqualified persons design and construct bridges; when all the loads meant to act on a bridge are not catered for in the bridge design; when ineffective methods and machinery are used for construction; and when proper subsoil investigation is not carried out for the right foundation type to be selected. The lists of bridge collapse due to design and construction faults are showed in Table 4.

Table 4 Bridge collapse cases due to design and construction errors

S/N	Bridge	Location	State	Year of collapse	Cause of collapse	Source
1	Agbokim bridge	Etung	Cross River	2016	Settlement of middle pier	<i>Channels Television</i> , 2017 [20]
2	Odili bridge	Port Harcourt	Rivers	2012	Failure of abutment wall	<i>Channels Television</i> , 2012 [59]

The middle pier of the Agbokim bridge in Cross River state from Table 4 sank after a year of its construction in 2015. There are some indications that a proper sub soil investigation was not carried out before the construction of the bridge leading to an obvious foundation failure [20]. A portion of the abutment wall of Odili bridge in Rivers state collapsed just after seven years of its construction [60]. These two cases points to faulty designs or construction.

2.5 Lack of Proper Inspection and Maintenance

There is a need for developing countries to provide adequate infrastructure to accommodate their rapid growing population in their urban areas but financing, implementing and maintaining the needed infrastructure is a major challenge facing many developing countries today [61]. Available funds cater for the immediate needs of the population such as portable water, electricity, roads, sanitation, and education and not much focus is placed on maintenance of the infrastructure that is already in place [62]. Roads and bridges are constructed and adequate funds are not provided to maintain them [63]. With an increase in the rate of urbanization in the country, the focus has gradually shifted to urban centers over the years. Even though the problem of maintenance exists both in rural and urban communities, rural communities face more neglect as existing infrastructure in rural areas are left to decay by the government but in some cases are salvaged by members of the community. Bridges in Nigeria especially in the rural parts of the country have been left to decay and this has led to the partial and complete collapse of many bridges. Fig. 4 showed one of the bridges along Wukari-Jalingo road in Taraba state as at September 2018.



Fig. 4 Bridge along Wukari-Jalingo road
Source. *Hunkuyi*, 2018 [25]



Fig. 5 Bridge along Wukari-Jalingo road after 2 months
Source. *AIT* 2018 [24]

Significant portions of the earth filling behind the abutment was washed away by floods and no significant remedial work was done by the road maintenance agencies. The bridge deteriorated further as the back fill was exposed to the flow of the river. Fig. 4 Bridge along Wukari-Jalingo road Fig. 5 Bridge along Wukari-Jalingo road after 2 months

Source. *Hunkuyi*, 2018 [25] showed the bridge as at November 2018, after two months in a detrimental state. The lack of maintenance culture in Nigeria has been attributed to a political factors where current political administration fail to maintain existing infrastructure built by previous admirations, inexistent working policy and legislation on maintenance, lack of enlightenment by the populace on the need of maintenance and corruption [64-65]. Most bridges prior to collapse give warning signs and it is when these signs are ignored that collapse occurs [8]. In the developed world, the cheapest way to preserve such costly infrastructure is by using structural health monitoring tools to update the safe state at any time, so as to know when to intervene and save the structure from collapsing [66-68]. Irrespective of the triggering cause of bridge collapse cases in Nigeria many collapses that have happened could have been prevented if proper inspection and maintenance had taken place prior to the collapse.

3. Discussion

Forty-five bridge collapse cases were identified, and the causes of failure are shown in the Fig. 6 below. Of the forty-five cases identified twenty-eight collapsed due to flood, eight due to overload and fatigue, seven as a result of terrorist attack and two collapsed due to faulty design and construction. The lack of proper bridge inspection and maintenance was also identified as the root cause of failure of many bridges in Nigeria. Fig. 7 showed the trend of the identified bridge collapse cases from 2010 – 2018.

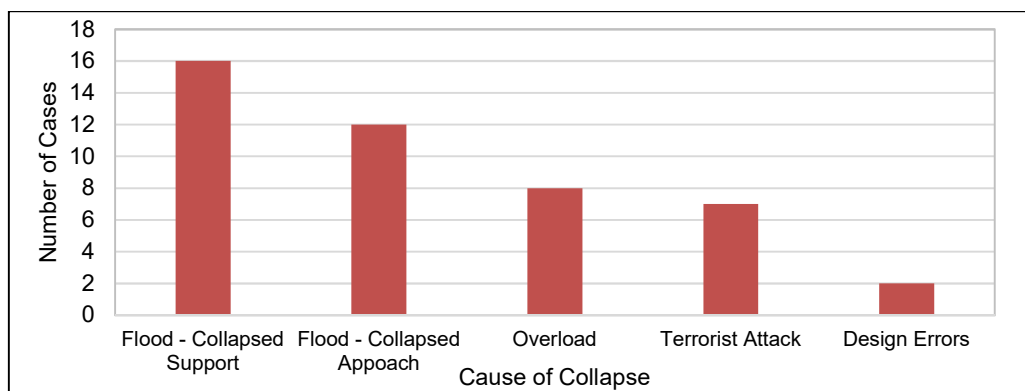


Fig. 6. Bridge collapse causes in Nigeria

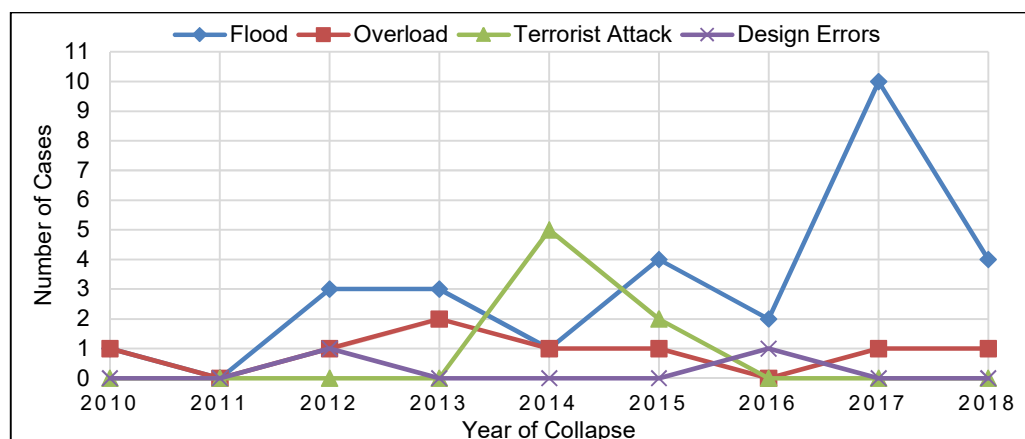


Fig. 7 Collapse causes by year

Flood can be immediately identified as the prevalent cause of collapse in Nigeria. Through the years, flood has been the major cause of bridge collapse in Nigeria except for 2014 where bridges collapsed mainly because of terrorist attacks. A study on Tatabu bridge collapse in Niger state revealed a significant increase of the stream flow from 2015 to 2017 due to increased rainfall and change of land use. Flood water reached heights far above the bridge approach at about 1.7 meters. This increase, coupled the high water velocity and pressure during the flood because of the meandering nature of the river caused the bridge to collapse [69]. Many rivers in Nigeria do not have proper river training works that properly guide the river during floods. Collapse due to overload is seen to be constant over the years.

4. Conclusion and Recommendation

The following conclusions and recommendations are drawn from this study:

- The result of this study causes us to question Nigeria's bridge maintenance policy and the implementation of these policies. As more funds go into building more bridges, commensurate amount should go into monitoring and preventive maintenance of bridge infrastructure.
- Majority of the bridges in Nigeria collapsed as a result of flooding hence, proper river training works should be carried out towards bridge locations to protect the encroachment of water during floods and to properly direct river flow.
- For the design of bridges over rivers, adequate hydrological data should be obtained from the Nigerian Hydrological Services Agency to predict the flow heights of the river during peak periods. Bridge piers and abutments should then be designed in view of with maximum flow heights and the effects of water pressure on bridge components should be effectively designed for.
- Nigerian curriculum of study on bridge design and construction technology must be enhanced and local environmental factors and blast loads from bombs adequately considered during design.
- Thorough assessment of bridges built before 1980 should be carried out and bridge load limits need to be determined and indicated for each bridge.

Acknowledgements

The authors would like to appreciate the Centre for Research, Innovation and Discovery, Covenant University, Ota, Nigeria for supporting this research.

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