International Journal of Engineering Sciences &Research Technology

(A Peer Reviewed Online Journal)
Impact Factor: 5.164

IJESRT

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

GLOBAL BRIDGE FAILURES RESULTING DEATHS: A FRACTAL ANALYSIS

Rossini B. Romero[*1], Jean Paul Q. Logronio[2], Lilibeth D. Amador[3], Prince Jude O. Bomediano[4], & Melchor S. Llorono[5]
[*1,2,3,4,5]CE Dept., College of Engineering, Biliran Province State University, Philippines

DOI: 10.5281/zenodo.3228746

ABSTRACT

This study wanted to find out the hidden dimensions behind the bridge failures across the globe resulting to deaths using fractal analysis, a different lens to analyze available data. Fractal statistical analysis revealed that there were four (4) top and four (4) bottom of the list of bridges (or 3 percent of the 117 bridges) that caused the highest and lowest number of deaths, respectively. Examining the common characteristics in terms of the bridges' failures, the results implied that the bridges that were built in the past did not give the most durable bridge structures and they caused more casualties. Meanwhile, the bridges that were built recently gave the least number of casualties. This leads to the conclusion that the hidden dimension is innovative bridge construction engineering and technology to prevent structural failures in bridges.

KEYWORDS: bridge failures, engineering and technology, fractal, fractal analysis, innovative bridge construction.

1. INTRODUCTION

Fractal analysis is assessing the self-similarity, roughness or ruggedness of data. It consists of several methods to assign a fractal dimension and other fractal characteristics to a dataset which may be a theoretical dataset or a pattern or signal extracted from phenomena, including natural geometric objects, sound, market fluctuations, etc. [1]Fractal analysis is now widely used in all areas of science, but its important limitation is that coming up with the empirically determined fractal dimension does not necessarily attest that a pattern is fractal; rather, other needed characteristics have to be considered. [2]

Bridge failures are often tragic but are also fascinating for bridge engineers as they usually provide puzzles to solve and often lead to major changes in design, construction and management. [3] Bridge construction is a great challenge to all involved generally more so than in other areas of structural engineering, in spite of the fact that for most bridge systems the actions and effects of the forces involved are more easily determined than in some other load – bearing structures. Most bridge failures are cost by multiple factors. [4] Flood that damages the bridge piers might not have caused a collapse – except for a poor design flaw and poor maintenance. [5]

The collapse of bridges have the following common causes: seismic damages; bridge hydraulics which has something to do with bridge scour, being clogged by ice or debris, approach and road washouts, and just being pushed over by water; collision of boats as well as collision by trucks; earthquakes; fire; train crash; boat impact; flood; construction accidents; manufacturing defect; design defect; poor maintenance; odd occurrences; element of surprise; and by keeping bridges. [6], [7], [5],[3]

The more common causes and mechanisms of some bridge failures around the world are classified into natural factors (flood, scour, earthquake, landslide, wind, etc.) and human factors (improper design and construction method, collision, overloading, fire, corrosion, lack of inspection and maintenance, etc.). [8]

Similarities among collapsed bridges include bridges being classified as structurally deficient, bridges that have had the load carrying capacity lowered below the normal legal limit of vehicles, and bridges which have limited vertical clearance under the structure and a roadway under the structure. Age influences bridge failure for only specific causes of collapse. The causes of bridge failure were numerically determined and associated with

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

adverse effects of loss of life and average amount of traffic per day using the structure. Life loss occurred on about four (4) percent of bridge failure. [9]

Although it had been pointed out by various researchers the various reasons why bridges collapsed which caused the loss of lives of people, there had been no study yet regarding the factors behind the failure of bridges with the highest and lowest number of casualties. It is in this context that the researcher wanted to find the hidden dimensions behind the bridge failures across 117 countries resulting to deaths from 18th century to year 2000. Moreover, this paper sought to determine the natural (fractal) state of the data, found out if there existed a fractal distribution, and analyze the hidden dimensions and fractality of the data.

2. MATERIALS AND METHODS

This study used fractal statistics to measure fractal dimension, the measure of the roughness or ruggedness of the data. Histograms of the data of deaths due to bridge failures were determined and inspected if it is exponential and fractally distributed to establish a certain pattern or model for the phenomenal trend of the deaths resulting from bridge failures worldwide.

In this study, the researcher used data from the study of W. [1] To determine the fractal dimension of the tabulated data set, the log $(\frac{x}{\theta})$ was first computed, obtained the mean of the log of x, and assessed the entire ruggedness index lambda (λ) of the data. From the world of concrete geometry, we migrate to the world of ideas or data by using the following formulas:

Exp. (data/ø) (i)

$\lambda = 1 + \frac{1}{\bar{y}}$ (ii)

Where: λ = log $(no.\ of copies of x)$ / log $(scale of x)$ = log ( ) / log$(\frac{x}{\theta})$ (iii)

θ =min$_i\{x_i\}$ (iv)

λ = the fractal dimension of the variable x (v)

It is not always easy to detect whether X is fractal or not based on its histogram. The fundamental theorem for fractal statistics was used: “X is fractal if and only if log (x/θ) has an exponential distribution with rate parameter $\beta= \lambda-1$.” Thus, if the histogram of y=log (x/θ) is not exponential, then X is not fractal.

This definition leads to: $f(x) = A(x/\theta)^{-}$, λ> 0 and x > θ (vi)

As the density or probability distribution of x, large values of x will have smaller probabilities of occurrence, while small values of x will have larger probabilities of occurrence. In order for X to have a probability distribution f(x), it is required that:

$A = (\lambda-1)/\theta and > 1; \theta > 0$ (vii)

The fractal dimensions of fractal random variables X will have to be greater than 1 in order for a probability distribution to exist.

3. RESULTS AND DISCUSSION

The data presented in this section shows the frequency distribution and exponential distribution of the deaths global bridge failures.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

In analyzing the data of the number of deaths resulting from bridge failures, the natural (fractal) dimension was determined to show roughness or ruggedness of the distribution using fractal statistical analysis (FSA). It was first established that the dataset was fractal.

Table 1 presents the list of the worldwide bridge failures resulting to deaths.

Table 1.Worldwide bridge failures resulting to deaths

No.	Bridge	Death Count
1	Eitai Bridge (Eitai-bashi)	1500
2	Ponte das Barcas	4000
3	Saalebrücke bei Mönchen-Nienburg	55
4	Yarmouth Bridge	79
5	Dee Bridge	5
6	Angers Bridge	226
7	Gasconade Bridge	31
8	Desjardins Canal Bridge	59
9	Sauquoit Creek Bridge	9
10	Wootton Bridge	2
11	Platte Bridge	20
12	Chunky Creek Bridge	7
13	Train bridge	46
14	Dixon Bridge	92
15	Ashtabula River Railroad Bridge	75
16	Tay Rail Bridge	5
17	Inverythan Rail Bridge	3
18	Bussey Bridge	30
19	Camberwell Bridge	37
20	Norwood Junction Rail Bridge	71
21	Point Ellice Bridge	60
22	Maddur railway bridge collapse	150
23	Dry Creek Bridge	111
24	Cimarron River Rail Crossing	100
25	Quebec Bridge	75
26	Romanov Bridge	13
27	Division Street Bridge	7
28	Quebec Bridge	11
29	Fremantle Railroad Bridge	11
30	Fremantle Railroad Bridge	14
31	Appomattox River Drawbridge	4
32	Honeymoon Bridge (Upper Steel Arch Bridge)	18
33	Deutz Suspension Bridge	28
34	Ludendorff Bridge	5
35	John P. Grace Memorial Bridge	29
36	Inotani Wire Bridge	4
37	Duplessis Bridge	2
38	Bury Knowsley Street Station Footbridge	112
39	Harrow & Wealdstone Station Footbridge	151
40	Whangaehu River Rail Bridge	90
41	St. Johns Station Rail Bridge	19
42	Severn Railway Bridge	5
43	Beaver Dam Bridge	6

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

44	General Rafael Urdaneta Bridge	7
45	Kansas Avenue Bridge	1
46	Heron Road Bridge	9
47	Boudewijnsnelweg Bridge	2
48	Silver Bridge	46
49	Queen Juliana Bridge	15
50	West Gate Bridge	35
51	Cleddau Bridge	4
52	South Bridge, Koblenz	13
53	Sidney Lanier Bridge	10
54	Makahali River bridge	140
55	Tasman Bridge	12
56	Reichsbrücke	1
57	Granville Railway Bridge	83
58	Almöbron (Tjörnbron)	8
59	Sunshine Skyway Bridge	35
60	Hayakawa Wire Bridge	7
61	Hyatt Regency walkway collapse	114
62	Cline Avenue over the Indiana Harbor and Ship Canal and surrounding heavy industry	14
63	Ulyanovsk Railway Bridge (USSR)	177
64	Mianus River Bridge	3
65	Amarube railroad bridge	6
66	Schoharie Creek Bridge collapse Thruway Bridge	10
67	Glanrhyd Bridge	4
68	Sultan Abdul Halim ferry terminal bridge	32
69	Tennessee Hatchie River Bridge	8
70	Cypress Street Viaduct	42
71	Swinging Bridge	5
72	Astram Line steel bridge	15
73	CSXT Big Bayou Canot rail bridge	47
74	Temporary bridge	2
75	Seongsu Bridge	32
76	I-5 Bridge Disaster	7
77	Baikong Railway bridge	2
78	Maccabiah bridge collapse	29
79	Eschede train disaster	4
80	Injaka Bridge Collapse	101
81	Hoan Bridge	14
82	I-10 Twin Span Bridge	26
83	Run Pathani Bridge Collapse	5
84	Highway 325 Bridge over the Xijiang River	8
85	Gosford Culvert Washaway	5
86	Minneapolis I-35W bridge over the Mississippi River	13
87	Tuo River bridge	34
88	Shershah Bridge – Section of the Northern Bypass, Karachi	5
89	Flyover Bridge	30
90	Cần Thơ Bridge	55
91	Chhinchu suspension bridge	19
92	Jintang Bridge	4
93	Road Bridge	8
94	Overpass on Hongqi Road	9
95	Northside Bridge, Workington.	2

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

96	Tarcoles Bridge	5
97	San Francisco – Oakland Bay Bridge (California)	1
98	Laajasalo Pedestrian Bridge	20
99	Kutai Kartanegara Bridge	2
100	Eggner Ferry Bridge over the Tennessee River	3
101	Jernbanebroen over Limfjorden	2
102	Guangchang Hedong Bridge	2
103	Yangmingtan Bridge over the Songhua River	3
104	Bridge under construction for road E6 at Lade/Leangen	2
105	Scott City Roadway Bridge	7
106	Belo Horizonte Overpass	3
107	Motorway Bridge collapse during construction	2
108	Plaka Bridge	1
109	Grayston Pedestrian and Cycle Bridge	2
110	Vivekananda Flyover Bridge	27
111	Yellow 'Love' Bridge	9
112	Lecco Overpass	3
113	Sanvordem River Bridge	2
114	Troja Footbridge	4
115	Chirajara Viaduct	16
116	Florida International University Pedestrian Bridge	6
117	Aschaffenburg Main River Freeway Bridge	4

Fig. 1 and 2 show the frequency distributions of bridge failures causing deaths and the fractal distribution of the same dataset, respectively.

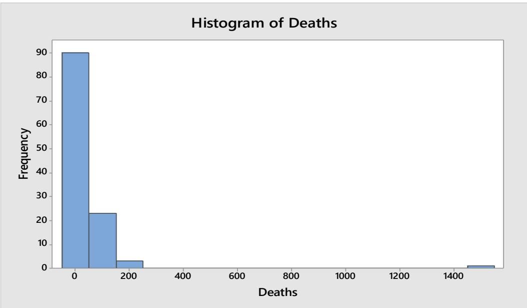

Figure 1.Frequency distribution

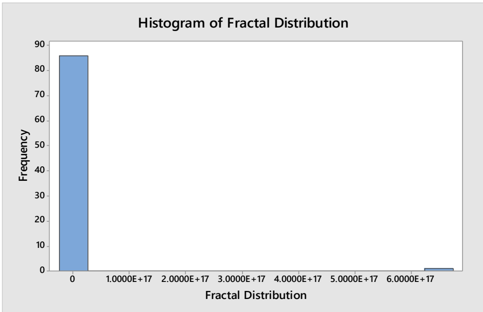

Figure 2.Exponential distribution

As gleaned from Fig. 1, the frequency distribution of bridge failures resulting deaths is positively skewed, but it cannot be safely assumed that the data set is really fractal.

The exponential of (x/θ) was used to ascertain that the data set was fractal**.** Fig. 2, the exponential representation of the percent of the number of bridges, verified that the dataset was indeed fractal.

Table 2 below shows the number of bridge failures causing deaths, the mean percentage, the minimum value, and the computed fractal dimension of the distribution of global bridge failures causing deaths.

Table 2. Distribution of bridge failures

N	Mean	Minimum Value (θ)	Fractal Dimension (λ)
117	44.1	1.0	1.02268

Table 2 shows that, among the 117 bridges that failed across the globe, the mean percentage was 44.1 with a minimum percentage value of 1.00 percent. The computed fractal dimension lambda reached 1.02268. This implies that the distribution of the bridges across the globe causing deaths due to failure deviated from normality by 3 percent.

Tables 3 presents the ranking of the four (4) top list of bridges causing the highest number of deaths, or the 3 percent of the 117 bridges across the globe.

Table 3. Top four (4) bridges with highest death count

Name of Bridge	Death Count
Eitai Bridge / Eitai-bashi (Japan)	1500
Angers Bridge (France)	226
Ulyanovsk railway bridge (USSR)	177
Whangaehu River Rail Bridge (New Zealand)	151

The Tabled discloses that the top 4 bridges with the highest number of deaths were Eitai Bridge (Eitai-bashi), Angers Bridge, Ulyaneusk Railway Bridge, and Whangaehu River Rail Bridge. The said bridges had been built during the latter part of the 18th century to the middle part of the 19th century.[1] This implies that the bridges used the old bridge construction engineering and technology.

Tables 4 presents the ranking of the bottom four (4) bridges with the lowest number of deaths, or the 3 percent of the 117 bridges across the globe.

Table 4. Top four (4) bridges with lowest death count

Name of Bridge	Death
Kansas Avenue Bridge (United States)	1
Reichsbrücke Bridge (Vienna)	1
Aschaffenburg Main River Freeway Bridge (Germany)	1
Oakland Bay Bridge (San Francisco)	1

The top 4 bridges with the lowest number of deaths were the Kansas Avenue Bridge, Reichsbrücke Bridge, Aschaffenburg Main River Freeway Bridge, and Oakland Bay Bridge. Each of these bridge failures caused only one (1) death. Those bridges were built during the latter part of the 19th century, specifically from 1976 to1989.[1] This implies that those bridges used innovative concepts or advanced bridge construction engineering and technology.

4. CONCLUSION

The Fractal Statistical Analysis revealed that frequency distribution of global bridge failures resulting deaths is fractal. The hidden dimension behind such incidence could be attributed to bridge construction engineering and technology. The bridge failures with the highest number of deaths could be attributed to the use of old bridge construction engineering and technology. On the other hand, the use of innovative concepts or advanced technology in bridge construction engineering and technology contributed much to low death count resulting from bridge failures.

5. ACKNOWLEDGEMENTS

This work would not have been made possible without the concerted effort of all the researchers who have shown their genuine commitment and support thereby motivating themselves to pursue this academic endeavor despite the challenges they encountered. They also greatly recognized the support and inspiration given by their university President, Dr. Victor C. Cañezo, who had driven all faculty to undertake intellectual endeavors like this to bring the university to greater heights. Above all, to the Almighty Father, for being the source of strength and wisdom therefore making this work a success.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

REFERENCES

[1] R. Mulligan, "Fractal Analysis of Highly Volatile Markets: An Application to Technology Equities," in the quarterly review of economics and finance, Vol. 44, No.1, February 2004
[2] B. Mandelbrot, "The fractal geometry of nature," Macmillan, ISBN 978-0-7167-1186-5, August 1982.
[3] J. Brownjohn, "Explainer: why do bridges collapse?", in http://theconversation. com/ explainer -why-do-bridges-collapse-14653, June 2013.
[4] J.Scheer, "Failed bridges: case studies, cause and consequences", inhttps:// www.researchgate.net/publication/ 316936857 _Failed _bridges _Case_studies_ causes_ and_ consequences, May 2017.
[5] E. Grabianowski, "Ten reason why bridges collapse", inhttp://science.howstuff works. com /engineering/structural/10-reasons-why-bridges-collapse.htm, April 2019.
[6] L.Mingqi, "Seismic risk management framework of bridge engineering", in http://www.Researchgate.net/publication /238514506www. research gate. Seismic_ Risk_ Management_ Framework_of_Bridge_ Engineering, September 2018.
[7] W,"Bridges 101 – What Causes a Bridge Failure?", in becauseicantn.wordpress.com/2012/01/31/bridges- 101-what-causes-a-bridge-failure/,January 2012.
[8] J.Choudhury, "Bridge collapses around the world: causes and mechanisms", (http://www.researchgate.net/publication/281280663_ Bridge _collapses_around_the_world_causes_and_mechanisms, August 2015.
[9] W. Cook, "Bridge failure rates, consequences, and predictive trends", doctoral diss., All Graduate Theses and Dissertations. 2163. https://digitalcommons.usu.edu/etd/2163, March 2014.