Analysis of Recent Bridge Failures in the United States

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Abstract: Over 500 failures of bridge structures in the United States between 1989 and 2000 were studied. The age of the failed bridges ranged from 1 year (during construction) to 157 years, with an average of 52.5 years. The most frequent causes of bridge failures were attributed to floods and collisions. Flood and scour, with the major flood disaster in 1993, contributed to the frequency peak of bridge failures (almost 53% of all failures). Bridge overload and lateral impact forces from trucks, barges/ships, and trains constitute 20% of the total bridge failures. Other frequent principal causes are design, detailing, construction, material, and maintenance. Comparison made among three periods of similar studies (1977–1981, 1982–1988, and 1989–2000) revealed almost similar trends, with most failures occurring during the bridge's service life. Also, human-induced external events occurred frequently in all three periods, but were most dominant in the first and third periods. Technological advances in information systems have a great impact on data collection and analysis.

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CE Database subject headings: Bridge failure; Bridge inspection; Bridge maintenance; Collapse; United States.

Introduction

In its latest report, the National Bridge Inventory (FHWA 2001) revealed that 691,060 bridges currently exist in the United States. The Federal Highway Administration rated nearly 30% of these bridges as substandard (although as compared with the 1988 data, this figure was 12% lower). Despite this discouraging figure, detailed information on the number of U.S. bridges that have failed or were in a severe condition is not readily available elsewhere. The New York Department of Transportation (NYDOT) is thus far the only agency that is attempting to collect information and develop a database on bridge failure cases in the United States.

Following the tragic collapse of the Thruway Bridge over Schoharie Creek in 1987, NYDOT took several steps to reduce and prevent future bridge failures. One of those steps was the creation of the Bridge Safety Assurance Unit, which began in 1990. The initial undertaking in 1990 was to collect as much information as possible regarding bridge failures in the United States. This information was then used to create several bridge vulnerabilities that are classified into hydraulics, steel details, concrete details, collision, seismic, and overload vulnerabilities (Scott Lagace, personal communication, 2001). Each class has a procedure that helps arrive at a vulnerability rating. This then identifies bridges that require corrective actions. NYDOT also stated that the information has been obtained through the news media as well as through responses to a survey they send every 12 years to all 50 states. The unit has received much information from some states and little to none from others; hence, despite the valuable source of data the unit has compiled, at this stage, the database does not constitute a complete listing of all failures that have occurred in the United States.

Despite a dearth of information regarding this important issue, studies have been conducted on the failures of constructed facilities. For example, Eldukair and Ayyub (1991) researched 604 structural and construction failures in the United States from 1975 to 1986. A more specific study about bridge failures in the United States was conducted by Harik et al. (1990) for the period of 1951–1988. In addition, earlier failure analyses of constructed facilities were carried out by Hadipriono (1985) and Hadipriono and Diaz (1988) for the periods 1977–1981 and 1982–1988, respectively.

This paper continues the latter studies to investigate and analyze failures of bridges that have occurred in the past 12 years, i.e., the period between 1989 and 2000. The information contained in this paper is collected from the NYDOT database; from engineering journals and magazines (*Engineering News Record*, *Roads and Bridges*, and *Civil Engineering*); from the home pages of the Federal Highway Administration (FHWA) and the Department of Transportation of New York, Ohio, Utah, Wisconsin, Texas, and Illinois; from personal experience; and through E-mail contacts. Although numerous minor bridge failures may not have been reported in published sources, the writers believe that the information assembled here is sufficient to draw useful conclusions.

Failure Defined

Earlier analyses that have become the basis for the study in this paper revealed 57 cases of published bridge failures that occurred in the United States between 1977 and 1981 (Hadipriono 1985). The second study of such failures between 1982 and 1988 disclosed 24 cases of bridge failures (Hadipriono and Diaz 1988). These figures represent a number of much publicized and well-known failure cases that were collected rigorously yet manually, without the advantage of the information technology we currently have. In reality, there could have been unrecorded bridge failures (depending on how we define the term failure) that were overlooked during the analyses; hence, the above figures could have

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been higher. In this paper, the writers have collected 503 cases of bridge failures that occurred from 1989 to 2000. The writers believe that defining the type of bridges and the term failure is important to present sufficiently accurate figures of the failed bridges in the United States.

The Association of American State Highway and Transportation Officials (AASHTO 1999) defines a bridge as ‘‘a structure, including supports, erected over a depression or an obstruction (such as water, highway, or railway), having a track or passageway for carrying traffic or other moving loads and having an opening measured along the center of the roadway of more than 20 ft between undercopings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes; it may also include multiple pipes where the clear distance between openings is less than half of the smaller contiguous opening.’’ The types of bridges investigated in this study fall under this definition.

While there is no concerted opinion regarding the definition of failure, throughout this paper, the term failure refers to two conditions, collapse and distress. Failure is defined as the incapacity of a constructed facility (in this case, a bridge) or its components to perform as specified in the design and construction requirements. Bridge collapse is the failure of all or a substantial part of the bridge, where full or partial replacement may be needed. In terms of functionality, collapse occurs when the entire or a substantial part of a structure comes down, in which the structure loses the ability to perform its function. Collapse can be further classified into two categories, total collapse and partial collapse.

Further, total collapse implies that several primary structural members of a span have fallen down, such that no travel lane is passable. Partial collapse suggests a condition where some of the primary structural members of a span have fallen down, where such a condition endangers the lives of those traveling on or under the structure. Distress is the unserviceability of a structure or its component(s) that may or may not result in a collapse. Moreover, distress is a particular condition of the structure, which has undergone some deformations without losing the whole structural integration. In sum, both collapse and distress are subsets of failure.

Causes of Failures Defined

The principal causes of bridge failures were categorized as deficiencies in design, detailing, construction, maintenance, use of materials, and inadequate consideration of external events. The first four deficiencies represent integral roles in the building of a bridge. Deficiency in design constitutes errors, mistakes, oversight, omission, or conceptual flaw that could have taken place during the design process of the bridge. Detailing is a process between design and construction periods, in which the details of the structural design are prepared for their implementation through shop drawings. Design detailing is commonly performed by the contractors and approved by the engineers. Changes are often made emphasizing workability and constructibility of the facility. Previous studies revealed that this process is vulnerable to discontinuity or loss of the original design concepts (Hadipriono 1985). Therefore, deficiency in design detailing may be considered as a class by itself. It includes errors, mistakes, omissions, and discontinuity/loss of design concept. Construction deficiency occurs as problems with workmanship and deviation of results from the specifications. Examples of such deficiencies are improper installation and inadequate temporary structure to support the bridge components. Maintenance deficiency, such as corrosive or damaged components, takes place during postconstruction or the service life of the bridge.

When construction components are precast or prefabricated, material deficiency originated by the manufacturer may contribute to bridge failures. Examples of such deficiencies are the use of defective and substandard materials. The first five deficiencies are considered as those associated with problems having internal effects on the bridge components. On the other hand, the bridge or its components may also suffer from external effects, such as vehicle impact or a corrosive environment. Such causes may be classified as external events. Note that these deficiencies may be correlated but that such correlation may not be readily apparent; hence, in this study, only the most probable principal cause in each case was considered.

In addition, with respect to the effects on the bridge or its components, these deficiencies may be categorized as enabling, triggering, and procedural causes. The enabling causes are related to the internal condition or performance of the bridge or its components. Hence, the first five principal causes (design, detailing, construction, maintenance, and material-related problems) discussed in the preceding fall into the category of enabling causes. The triggering causes are external events that could initiate failure of a structure. The procedural causes are related to management problems and the interrelationship between parties involved in a project. The latter causes are difficult to prove because they are usually hidden and unpublished; thus, their evaluation is beyond the scope of this study.

Results of Study

Results of the study presented in this paper include discussions of failure occurrences, principal causes, and specific causes of bridge failures.

Failure Occurrences

Investigative studies conducted for bridge failures revealed that 503 bridges of various types failed in the past 12 years (1989–2000) in the United States. Out of the total recorded failures, 456 cases of bridge collapses were found from the NYDOT database. Publications such as engineering journals, magazines, and web sites revealed 65 failure cases, 18 of which overlapped between the two sources. Hence, only 13% of the major failure cases were reported in the civil engineering news media. The age of the failed bridges ranged from one year (during construction) to 157 years, with a mean of 52.5 years, a median of 52 years, and a mode of 63 years.

Table 1 shows failure occurrences of over 17 bridge types that range from arch to tied-arch. In addition, the study also identifies floating and pedestrian bridge failures. About 12% of these bridges could not be identified; hence, they are classified as miscellaneous. Components of these bridges are primarily made of steel, concrete, and timber.

Table 1 shows that the dominant types of failed bridges are the steel beam/girder and steel truss bridges, with 145 (29%) and 107 (21%) occurrences, respectively. Note that these failed bridges constitute over 50% of the total bridge failures. The next significant cases involve failures of concrete beam/girder and concrete slab bridges, representing 29 (6%) and 25 (5%) occurrences, respectively. While significant, failure occurrences of these concrete bridges are pale in comparison with the former two types of failed bridges.

Table 1. Type and Number of Bridge Failures

Bridge type	Material	Number of failures	Percentage
Arch	—	17	3.38
Bailey	Steel	1	0.20
Bascule	—	2	0.40
Beam/girder	Concrete	29	5.77
—	Steel	145	28.83
—	Timber	13	2.58
Box	Concrete	2	0.40
—	Timber	5	0.99
Box girder	Concrete	9	1.79
—	Steel	3	0.60
Cable	Steel	1	0.20
Corrugated pipe	Steel	4	0.80
Covered	Timber	6	1.19
Culvert	Steel	17	3.38
—	Other	2	0.40
Slab	Concrete	25	4.97
—	Steel	1	0.20
Span	Steel	7	1.39
—	Timber	8	1.59
Stringer	Steel	12	2.39
—	Timber	12	2.39
Truss	Steel	107	21.27
—	Timber	9	1.79
Tied arch	Concrete	1	0.20
Floating	—	2	0.40
Pedestrian	—	2	0.40
Miscellaneous	—	61	12.13
Total	—	503	100.00

Distribution with respect to the year when failures occurred is presented as a bar chart in Fig. 1. From a total of 503 bridges that failed during the 1989–2000 period, 112 failures (22%) occurred in 1993, which seems to be an anomaly. Further investigation reveals that most of these 1993 failures coincided with the occurrence of a major flood in the Midwest. In 1993, the Mississippi and Missouri Rivers and their tributaries overflowed and flooded several Midwest states, namely, Illinois, Iowa, Kansas, Minnesota, Missouri, North Dakota, South Dakota, and Wisconsin. This flood caused damage in many constructed and transportation facilities, including the failures of numerous bridges, particularly in Iowa, Minnesota, and Missouri.

Fig. 1 also shows other peak occurrences of failures such as the years 1989 and 1996. The 1989 Loma Prieta earthquake and a 1996 flood contributed to these peaks. The chart also reveals that, in recent years, failure occurrences seem to have declined, despite

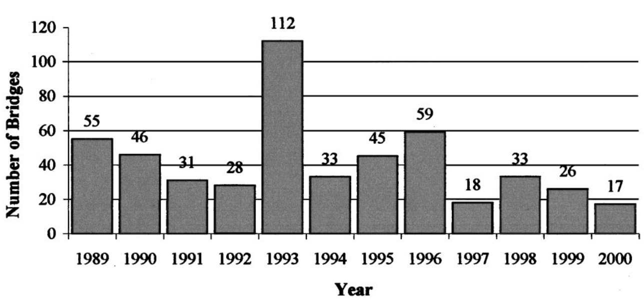

Fig. 1. Number of failed bridges distributed by year (1989–2000)

Table 2. Number of Failures with Respect to Phase of Failure Occurrences

Types of failures	Construction	Service	Unknown
Distresses	0	17	0
Partial collapses	3	80	13
Total collapses	5	12	21
Unknown	0	277	75
Total	8	386	109

the continual growth of the bridge population. According to the U.S. Department of Transportation [Federal Highway Administration (FHWA)], the number of new bridges being added each year ranges from 1,400 to 4,000 units, with an average of about 2,500 (FHWA 2000).

The types of failures and the phase in which these failures took place are shown in Table 2. The number of failures that occurred during service life (386 occurrences) is far greater than that during construction (eight occurrences). Such is expected for most structures, including bridges, because, at any point in time, the number of existing bridges during service life is far greater than that during construction. Also, the duration of the service life is much longer than that of the construction of bridges. Furthermore, loads applied to bridges increase with time, while efforts to upgrade and maintain bridges remain relatively the same throughout the years. Table 2 also shows that a large number (109 occurrences) of unknown failure phases exists because of the lack of information on the time the bridges were built.

The types of failures classified as distress, partial collapse, and total collapse are also presented in Table 2. Among these three failure types, partial collapse (80 occurrences) dominates, followed by distress. Here, too, an overwhelming number of unknown failure types (277 occurrences) are associated with incomplete data.

It would be interesting to know which states have experienced the most failures. The writers tabulated the 10 highest ranked states as shown in Table 3. In terms of the number of failed bridges, the highest ranked state is Iowa, with 85 failure cases, most of which were attributed to the flood disaster described earlier. Iowa happened to be the most effected state during the 1993 flood. The state of New York is ranked second, with 64 failures, followed by a distant third (Virginia).

Table 3 also shows the percentage of these failures with respect to the total number of bridges in the state. Note that Iowa and New York have about the same percentage of failures (0.3%). Since New York was not effected by flood, yet ranked on the same par with Iowa, it would be interesting to see the reasons behind the high failure frequency in New York. Also, a comparison can be made with other states having about the same or a greater number of bridges, i.e., Minnesota (21,696 bridges) and Missouri (26,060 bridges). These states were effected by the great flood of 1993, yet they have much lower percentages of failure frequency (0.08 and 0.05%, respectively) as compared with New York. One possible reason for New York's high failure frequency may be attributed to the fact that the state's Department of Transportation has initiated the creation of the bridge failure database and, hence, has the most complete information regarding bridge failures in New York. In addition, New York is an older state as compared with the aforementioned midwestern states; therefore, there is bound to be a greater number of older bridges that were rendered obsolete and vulnerable to failures. The highest percent-

Table 3. States, Ranked by Bridge Failure Frequency

Rank	Name of state	Failures	Percentage of total failures	Total number of bridges	Percentage of failures to number of bridges
1	Iowa	85	16.90	26,035	0.33
2	New York	64	12.72	22,121	0.29
3	Virginia	37	7.36	16,481	0.22
4	West Virginia	34	6.76	8,156	0.42
5	Arkansas	33	6.56	13,901	0.24
6	Maryland	29	5.77	5,895	0.49
7	California	22	4.37	16,752	0.13
8	Minnesota	18	3.58	21,696	0.08
9	Mississippi	14	2.78	17,979	0.08
	Missouri	14	2.78	26,060	0.05
10	Georgia	13	2.58	16,752	0.08

age of failures with respect to the total number of bridges in a state is held by Maryland, with 0.49% (29 failures of 5,895 bridges).

Principal Causes

As alluded to before, causes of bridge failures are classified into six principal causes, which include both enabling (design, detailing, construction, maintenance, and material-related problems) and triggering (external-related events) causes, as shown in Table 4.

Observation shows that only a small proportion of bridge failures experienced distresses, while the majority of bridges collapsed. Table 4 also reveals that 54 (11%) out of 486 collapses were attributed to enabling causes, while the majority of collapses (415 cases, or 85%) were due to triggering causes. In the distress mode, the percentage of enabling causes is higher than the triggering causes. This seems to suggest that triggering causes tend to result in collapses and enabling causes incline toward promoting distresses. While this may be true for the triggering causes, experience shows that enabling causes could also result in collapses when distresses are ignored over a certain period of time. Table 4 also shows that, aside from external events, maintenance and construction-related deficiencies predominantly caused the bridge failures. The table indicates that 43 (8%) collapses and distresses are maintenance related. Several of the latter cases are associated with obsolete and deteriorated bridges.

Specific Causes

Detailed information on various deficiencies is presented in Table 5. The leading causes of bridge failures are flood/scour, collision, and overload. These causes fall under the category of external or triggering causes.

Table 4. Number of Principal Causes of Failure

Principal cause	Collapse	Distress
Design	2	1
Detailing	0	0
Construction	11	2
Maintenance	37	6
Material	4	2
External	415	5
Others (NA)	17	1
Total	486	17

The most dominant figures are those related to flood and scour (165 and 78 cases). The Federal Highway Administration defines scour as ‘‘erosion or removal of streambed or bank material from bridge foundations due to flowing water, usually considered as long-term bed degradation, contraction, and local scour.’’ Therefore, failures caused by floods and scour are often one and the same (Scott Lagace, personal communication, 2001). While both causes may have produced similar failures, the figures in Table 5 were compiled from original sources available to the writers. One possible explanation for the different classification is that those who entered the information into the database might have used both terms interchangeably as the same source of failures (Scott Lagace, personal communication, 2001). Another possibility is that the flood-related cases are associated with the great flood of

Table 5. Type and Number of Failure Causes

Failure causes and events	Number of occurrences	Percentage of total
Hydraulic	266	52.88
Flood	165	32.80
Scour	78	15.51
Debris	16	3.18
Drift	2	0.40
Others	5	0.99
Collision	59	11.73
Auto/truck	14	2.78
Barge/ship/tanker	10	1.99
Train	3	0.60
Other	32	6.36
Overload	44	8.75
Deterioration	43	8.55
General	22	4.37
Steel deterioration	14	2.78
Steel-corrosion	6	1.19
Concrete-corrosion	1	0.20
Fire	16	3.18
Construction	13	2.58
Ice	10	1.99
Earthquake	17	3.38
Fatigue-steel	5	0.99
Design	3	0.60
Soil	3	0.60
Storm/hurricane/tsunami	2	0.40
Miscellaneous/other	22	4.37
Total	503	100.00

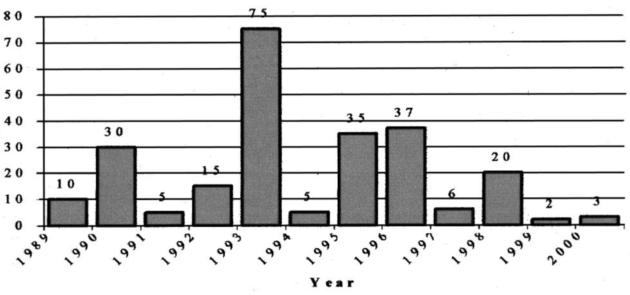

Fig. 2. Bridge failures caused by floods, distributed by year

1993, while the scour-related cases may have occurred elsewhere or are unrelated to the 1993 Midwest flood. Be that as it may, the combined figure of 266 flood/scour-related cases constitute 53% of the total causes of failures.

Further analyses of the failure data caused by flooding shows that 31% of the failures took place in 1993 (Fig. 2). This result also supports the role of Midwest flood of 1993 in causing numerous bridges to fail.

Table 5 also indicates debris as another specific cause listed in the hydraulic category with flood and scour. There are 16 cases of failure derived from debris flows, all of which occurred in the same year, 1995, and in the same state, Virginia. This coincidence is attributable to a flash flood that took place in Madison County in June of 1995. A flash flood is a flood that occurs in a short period of time as a result of rain falls at such a high rate that water does not have time to be absorbed into the ground (Watson 2001). Heavy rains in the mountains of Virginia caused mudslides and washed debris up against the bridges (National Weather Service 2001).

The next dominant cause is overloading (44 occurrences, 9%) of various types of bridges. While only two pedestrian bridges (Table 1) were observed to fail due to this cause, such a failure could produce a devastating effect on public safety. For example, the collapse of the Speed Motor Lowe's Walkway in Concord, North Carolina, resulted in 107 people being injured (GoCarolinas.com 2000).

One particular bridge—the Evergreen Point Floating Bridge on Lake Washington, WA—experienced a recurrence of distresses and collapses during its service life. The first failure took place when the pontoon bridge deck cracked open in 1989 due to an unknown cause. Then, again, in 1991 another problem emerged as the pontoon cracked. The third setback occurred in 1999, when the bridge was split in two by a strong wind. In 2000, the bridge was again damaged by collision.

Of the 503 bridge failures observed, the total number of recorded human-induced fatalities and injuries (excluding natural disasters and deterioration/obsolescence-related failures), is 76 and 161, respectively. Hence, the injuries resulting from a single case such as the Speed Motor Lowe's Walkway accident could easily reach 66% of the total injuries or 45% of the total human-induced fatalities and injuries observed in this study.

Another significant cause of bridge failures is collision by land and marine vehicles (Table 5). Notable among these are impacts from trucks (14 occurrences), barges/ships (10 occurrences), trains (three occurrences), and others/unknown (32 occurrences). These cases (59 occurrences) constitute 12% of the total bridge failures. Most of these failures were attributed to lateral impact forces of vehicles on bridges. Examples are collisions caused by backhoes improperly loaded on flatbed trucks, dump trucks with their dump bodies raised, and garbage trucks with the forks up (Scott Lagace, personal communication, 2001).

Deterioration of bridge components is also an essential cause of several failure cases. Forty-three cases have been observed, 14 of which are attributed to the deterioration of the bridges' steel components and six cases related directly to steel corrosion.

In addition, earthquake-related bridge failures represent over 3% (17 occurrences) of total failures. All occurrences are in California, and most of these are attributable to the 1989 Loma Prieta (six occurrences) and 1994 Northridge (10 occurrences) (Cooper et al. 1994) earthquakes. Note that, in this study, the collapse of an overpass of a similar type to bridges is considered as a single bridge collapse occurrence.

Comparison of Three Periods Surveyed

The total number of bridge failures in this study is far greater than those of earlier studies. In order to present a compatible comparison, failures due to natural disasters (e.g., inevitable earthquakes, storms, fires, and floods) and deterioration/obsolescence were excluded (Tables 6–8). While, on one hand, these exclusions will improve the compatibility of the comparative analysis, they also isolate human-induced deficiencies from act-of-God natural events. However, not all deterioration is due to old age; bridges that failed at a relatively young age (less than 50 years of service) were considered as having their service life expired prematurely. Thus, 18 out of 43 deterioration cases (40%) were included in this analysis as maintenance deficiencies. Table 6 is an abbreviated form of Table 4, where principal causes due to natural disasters and deterioration/obsolescence were excluded. From Table 6, a total number of 157 collapses and nine cases of distresses were found. A dominant cause of 115 occurrences (77% of all human-induced failures) is associated with external causes such as overload and lateral impact on bridges by land and marine vehicles.

By eliminating natural disasters and deterioration/obsolescence as causes of failure, the trend of bridge failure occurrences over the years appears to fluctuate every 2 or 3 years (Fig. 3).

The number of bridge failures in Table 6 is relatively large as compared with that of the previous studies. One possible explanation is the use of current technological advances in information dissemination that were nonexistent in the past. Most of the information gathered in this study is originated from the NYDOT database and the Internet.

Table 7 shows the comparison of failure occurrences among three periods of study, from 1977 to 2000. Failures are divided into collapses and distresses and, subsequently, classified into the time of occurrences, during construction or service life. Table 7

Table 6. Principal Causes of Failure Excluding Natural Disasters and Deterioration/Obsolescence

Principal causes	Collapse	Distress
Design	2	1
Detailing	2	0
Construction	10	2
Maintenance	17	1
Material	6	2
External	115	2
Others (NA)	5	1
Total	157	9

Table 7. Comparison of Failure Distribution with Respect to Stage of Occurrence in Three Survey Periods

Type/stage of failures	1977–1981		1982–1988		1989–2000	
	Number	Percent	Number	Percent	Number	Percent
Collapses during construction	3	9	4	17	8	5
Collapses during service	11	33	5	21	149	90
Distresses during construction	3	9	5	21	0	0
Distresses during service	16	48	10	42	9	5
Total	33	100	24	100	166	100

concludes that collapses and distresses consistently took place during the service life more often than during the construction process, for reasons described earlier.

Table 8 compares the three periods of time, in which the failure events are separated into six principal types of causes. The dominant principal cause of collapse from the first and third (present) studies is external causes, while the second study found construction-related deficiencies as significant. In all studies, construction and material-related deficiencies are the leading factors of distresses.

Summary and Conclusions

The study of over 500 bridges that failed in the past 12 years in the United States (1989–2000) revealed an average age of 52.5 years, with a range from one to 167 years. About 50% of bridges that failed are typically steel beam/girder and steel truss bridges. Other frequent occurrences are associated with failures of concrete beam/girder and concrete slab bridges. The study shows that failures took place primarily during the service life of the bridges. Records show that the states of Iowa and New York are ranked highest in terms of failure occurrences. Failures in Iowa are associated with the 1993 major flood, while those in New York are related to the bridges' obsolescence (of the total 64 cases in New York, 25 bridges were over 50 years old when they failed). In addition, New York is the first to develop a major database of bridge failures.

Overwhelming external events, both natural and man-made, representing 83% (420 occurrences) of all principal causes, triggered the bridges to fall. Nature-induced external events include floods, earthquakes, fires, ice, and hurricanes (with floods represents 53% of all failures), while the human-induced external events that constitute 20% of all failures include bridge overloads and lateral impact of land and marine vehicles on bridges (vehicular impact represents 12% of all failures).

Upon completion of this observation, a comparison among three periods of similar studies was conducted to discern possible trend of failure occurrences and causes. In all three observations, most failures took place during the service stage. This is expected, because the population of bridges during service is larger than during construction, service life duration is generally longer than that of construction, and there is a generally disproportionate increase of loads working on bridges and enhancement of bridge resistance through time. External events in the latest (third) study period are overwhelming; they stand out in comparison to all principal causes in all three studies. Even if—to achieve a more compatible comparison—information obtained from the NYDOT database is excluded, external events in the third study period are still dominant. This suggests that attention should be given to minimize such events.

Another point of comparison is the relatively larger number of failure occurrences in the latest study period as compared with the previous two studies. A reasonable explanation is that the latest study was conducted by taking advantage of information technology that was not available in the past. For instance, if the latest study was performed in a fashion similar to the first two (i.e., by excluding databases and the Internet), only 65 failure cases were observed. Despite these advantages, there is an urgent need to improve data collection and processing. The NYDOT database is clearly a winning start, but without a concerted effort from all U.S. states in maintaining a reliable repository of bridge failures, such information may be rendered nugatory. For example, multitudinous failure cases observed in the latest study are incomplete; many of them are not furnished with bridge types and phase of failures, two variables that are paramount for conducting statistical or other quantitative risk analyses.

Aside from cases familiar to the writers, the majority of the cases investigated in this study are provided with only limited information as to the causes of collapses and distresses. While interpretation can be readily made on the enabling and triggering causes, the procedural causes are not apparent; hence, no attempt was made to discern the latter cause. Procedural causes are often associated with inadequate responsibility delineation, communication problems, legal and contractual issues, and other indirect

Table 8. Comparison of Principal Causes of Bridge Failures

Principal causes	Collapse			Distress		
	1977–1981	1982–1988	1989–2000	1977–1981	1982–1988	1989–2000
Design	—	—	2 (1%)	2 (11%)	2 (13%)	1 (11%)
Detailing	2 (14%)	2 (22%)	2 (1%)	1 (5%)	1 (7%)	—
Construction	2 (14%)	4 (44%)	10 (6%)	6 (32%)	3 (20%)	2 (22%)
Maintenance	1 (7%)	1 (11%)	17 (11%)	2 (11%)	2 (13%)	1 (11%)
Material	—	—	6 (4%)	5 (26%)	3 (20%)	2 (22%)
External	9 (64%)	1 (11%)	115 (73%)	3 (16%)	3 (20%)	2 (22%)
Others (NA)	—	1 (11%)	5 (3%)	—	1 (7%)	1 (11%)
Total	14 (100%)	9 (100%)	157 (100%)	19 (100%)	15 (100%)	9 (100%)

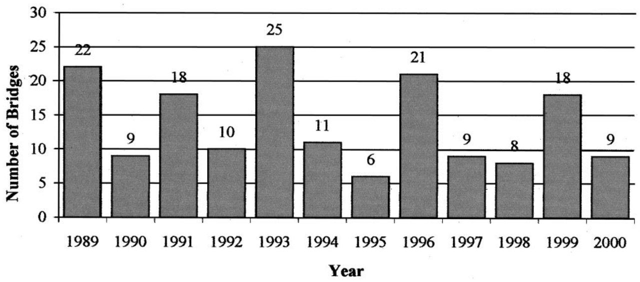

Fig. 3. Number of bridge failures excluding natural disasters and deterioration/obsolescence distributed by year

problems from which enabling and triggering causes may stem. Understanding all causes including procedural causes can motivate design and construction professionals to proactively minimize the recurrence of bridge failures. These latter causes can be obtained from legal records and insurance claims; they should be collected and included into existing or new databases.

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