Engineering Success and Disaster: American Railroad Bridges, 1840–1900

By Mark Aldrich

> One of the most fruitful sources of accident on American railroads arises from insecure bridges. On English railways accidents from such causes are seldom known.
>
> —*American Railroad Journal*, 1858

> I believe . . . that the time will come when the failure of an iron bridge from an ordinary accident of train service will be regarded as discreditable to its builder and not excused as a fault of the management.
>
> —Charles Stowell, New York State Bridge Engineer, 1889

Sometime after 8:00 p.m. on December 29, 1876, the Lake Shore & Michigan Southern's Pacific Express, traveling west out of Erie, Pennsylvania, approached the Ashtabula, Ohio, bridge, just east of the station. The train consisted of three express cars, one baggage car, three passenger coaches, and three sleepers hauled by two 4-4-0 locomotives — the *Columbia* and *Socrates*. The weather was foul, with snow and sleet driving off of Lake Erie, and the *Socrates*'s engine man Daniel McGuire slowed his train and cautiously approached the bridge. When he was nearly across, it gave way, dropping the entire train, save his own engine, about 65 feet into the chasm where car stoves ensured that the wreckage immediately caught fire (Fig. 1). The death toll was eighty-nine, including two officers of the railroad. It was the worst railroad disaster of the century.

Ashtabula was what civil engineers called a "square fall"—that is, the bridge failed for lack of strength. Immediately after the event, the state legislature commissioned an investigation by a panel of engineers. The bridge was an iron Howe truss that Amasa Stone had designed for the Cleveland & Erie after he had become its president. Stone was an old-time

Mark Aldrich, professor of economics at Smith College in Northampton, Massachusetts, is the author of several previous articles in *Railroad History* as well as the acclaimed 1997 book, *Safety First: Technology, Labor, and Business in the Building of American Work Safety, 1870–1939,* published by the Johns Hopkins University Press.

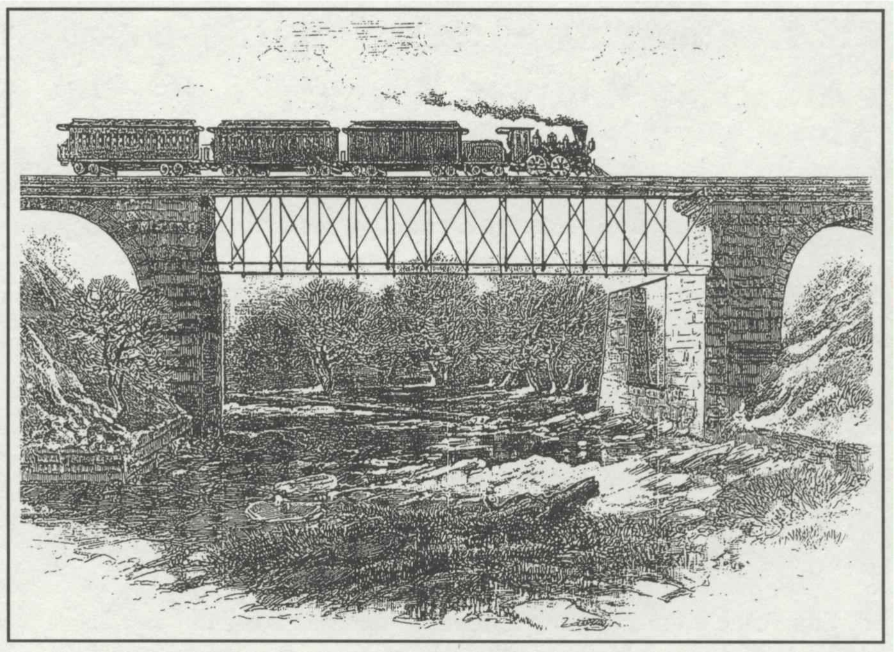
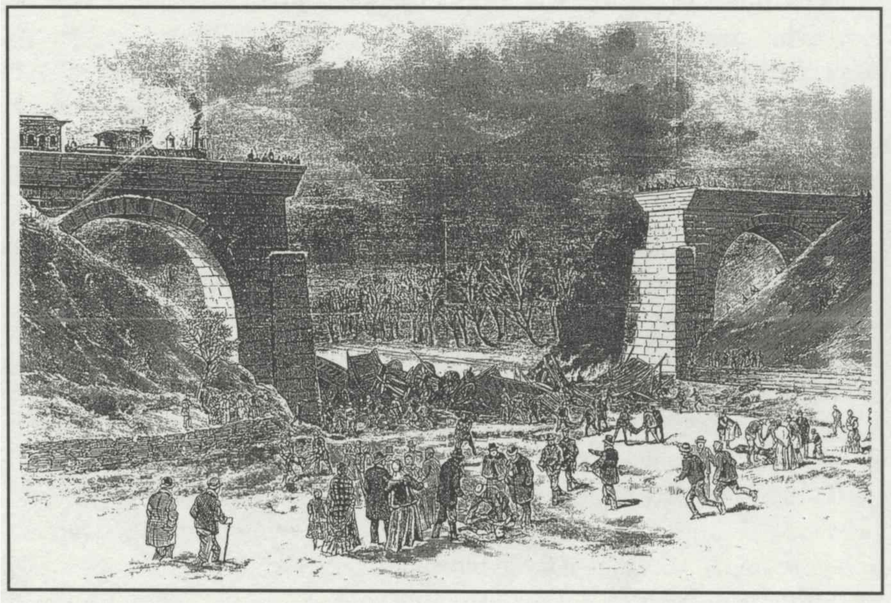


Fig. 1—The Ashtabula bridge, before and after the fall, as depicted in *Frank Leslie's Illustrated Weekly,* 20 January 1877. Investigators concluded that the bridge was sound but the design flawed.



bridge builder who had worked with William Howe himself and patented modifications of the original Howe truss. The engineers' report, which *Engineering News* termed "full and satisfactory," concluded that Stone's bridge was in sound condition but suffered from numerous design errors. Among the many such flaws was the top chord that had a factor of safety of only 1.6 when sound engineering practice at that time employed a factor of at least five. Moreover, the chord consisted of five unconnected beams, which implied that it had little lateral strength. Reviewing this evidence, the eminent bridge engineer Theodore Cooper concluded, "its failure has taught us nothing that we did not know before."[1]

To Cooper and to the other members of the newly emerging professional engineering community, Ashtabula symbolized the problem of bridge failures as they saw it. The old rules of thumb that had dominated American practice since the beginning led to unscientific designs which resulted in square falls. Thus the central problem of bridge safety, in this view, was the need for professionally trained bridge designers. Of course, bridges collapsed for many other reasons, but these were not engineering failures as Cooper and many other engineers saw matters. Even bridges that were knocked down by a train, for example, did not "fail."

A few critics subscribed to a broader conception that saw bridge failures not just in terms of engineering errors, but also as the result of design choices that distinguished American from British bridge-building technology and made the former inherently prone to knock-down. Thus bridge accidents raised questions central to the meaning of engineering design and error. Yet even this was too narrow a lens with which to view the problem, for bridge disasters resulted not only from errors, or the sorts of design choices the critics emphasized, but also from a broad array of construction and management practices that characterized nineteenth-century American railroad economics.

The Causes of Bridge Failures

The high cost of capital and comparatively thin traffic led early American railroads to choose relatively inexpensive construction methods for bridges as well as other components of the permanent way. As *Engineering News* wrote in the aftermath of Ashtabula, "there are many cases . . . where railroads have been pushed to completion with scanty means, and temporary structures have been erected to be replaced later; but . . . bad times necessitate postponement." While British railroad builders turned to iron bridge construction in the 1840s, in the United States—with wood cheap, familiar, and easy to work—nearly all the early bridges were wooden trestles or Howe trusses. American carriers also routinely skimped on bridge approaches, foundations, and abutments, and, instead of filling cuts, they built trestles. "The wooden trestle is emphatically an American institution," *Engineering News* noted. In fact, the journal claimed that "in no other part of the world have the conditions favored the use of timber so much as here," and it noted that "few of the roads . . . west of Ohio use anything but wooden trestle for their structures in first construction." Writing in 1893, the distinguished civil engineer George S. Morison explained why: "For immediate results, nothing equal to it [wood] has ever been known." Although wood bridges were "very short lived," for many years "the cost of frequent renewals of timber was less than the interest on the additional cost of iron." Hence, said Morison, "it was good engineering to build wood superstructures."[2]

In the 1850s and 1860s, as train weight rose and iron prices declined, American builders also began to construct iron truss bridges. As Morison put it, in Europe bridge superstructures evolved from masonry to metal and in the United States from wood to metal. But whether they chose wood or iron, American bridge builders used less material than did their European counterparts, and they chose designs that could be factory-made and quickly assembled in order to save labor. Until the mid-1880s, virtually all these choices were largely unconstrained by regulatory forces, and made American railroad bridges far more disaster-prone than those in Britain.[3]

Assessing the prevalence of nineteenth-century bridge failures requires information on the number and type of bridges in existence. The best available evidence on that topic was collected by Theodore Cooper and presented to the American Society of Civil Engineers in 1889. To assemble his data, Cooper relied on his wide contacts in the profession, writing the chief engineers of dozens of carriers and asking for information on their bridges. By this process he was able to obtain hard information from lines with about 37 percent of all track that he then extrapolated to estimate totals.[4] His findings are presented in Table 1.

As can be seen, the great majority of bridges were short, less than 20 feet, and here wood predominated. But for longer spans, iron had become the material of choice. These patterns obtained well into this century, with the share of iron (and, after 1880, steel) gradually rising and wood still employed for large numbers of short spans wherever it was plentiful and cheap. In 1895, an engineer of the Boston & Maine explained that while his company used iron for longer spans, building short wooden bridges was still a "live business." In Massachusetts only about 2 percent of the mileage of all bridges was iron in 1872; by the end of the century iron and steel constituted half the total.[5]

Table 1
American Railroad Bridges and Trestles (Wood and Iron), 1889

	Number of Bridges			Miles of Bridges		
Span (feet)	Iron	Wood	Total	Iron	Wood	Total
Under 20	5,100	722,100	727,200	17	2,407	2,424
20–50	12,900	5,250	18,150	86	35	121
50–100	4,600	4,500	9,100	66	64	130
100–150	3,900	4,100	8,000	93	97	190
150–200	2,100	1,200	3,300	69	40	109
Over 200	950	200	1,150	49	7	56
Total	29,550	737,350	766,900	380	2,650	3,030

Source: Theodore Cooper, "American Railroad Bridges," ASCE *Transactions* 21 (1889): 1–59, and "The Bridge Failures of Eleven Years," *Engineering News* 23 (19 April 1890): 373–374.

Just how many of these bridges were likely to fail during a year cannot be assessed with any precision. While a reading of the popular press reveals that bridge accidents date from as early as the 1840s, no one seems to have collected any statistics on either their number or causes until the civil engineer Thomas Appleton began the task. Appleton derived estimates for 1873–1877 from the list of train accidents published in the *Railroad Gazette* that he had checked and verified. Charles Stowell, long-time bridge engineer for New York State, later supplemented his work, and he, too, relied on the *Gazette*'s data, which he checked and supplemented from other sources. Their findings are presented in Table 2.

These data are not entirely comparable, for while Appleton tried to include all bridge accidents, Stowell ignored trestle collapses as well as failures in culverts and cattle guards—all of which were common. Both writers also omitted certain failures, such as washouts and fires, where no trains were involved, as well as other failures that involved train accidents but did not, in the authors' judgment, contribute to these accidents. Stowell's collection criteria ensure that his figures provide an undercount of *all* bridge accidents. For the class of bridges on which he focused, however, the data probably account for most accidents that resulted in casualties; when Stowell published his data, he always asked readers to supply additions and corrections. Since Stowell's criteria largely excluded accidents on short bridges, his data should be compared to Cooper's estimates of bridges over 20 feet long. Assuming that bridges of unknown construction were wood, such a calculation implies an annual failure rate in 1888–1889 for iron bridges of one in 4,445, and for wooden bridges, one in 726.

Table 2
Number of Bridge Accidents by Cause, 1873–1889

	1873–1877			1878–1882			1883–1887			1888–1889		
Cause†	**Wood**	**Iron**	**Total‡**	**Wood**	**Iron**	**Total‡**	**Wood**	**Iron**	**Total‡**	**Wood**	**Iron**	**Total‡**
Square Fall	1	3	4	5	6	12	19	3	23	8	2	10
Fire	4	0	4	11	0	11	18	0	18	5	0	5
Freshet	5	2	19	0	0	14	1	4	20	5	0	13
Repair	1	1	7	0	0	0	4	0	4	2	1	4
Knocked Down	33	8	66	9	6	26	4	10	32	6	8	17
Unknown	2	3	26	24	2	52	5	1	43	1	0	5
Total	46	17	126	49	14	115	51	18	140	27	11	53

Source: Thomas Appleton, "Railroad Bridge Accidents," *Engineering News* 5 (21 February 1878): 59–61; "The Bridge Failures of Ten Years," *Engineering News* 5 (30 March 1889): 288–289; "The Bridge Failures of Eleven Years," *Engineering News* 23 (19 April 1890): 373–374.

† I have modified Appleton's data by adding his category "hurricane" to "freshet" and "floor broken by train" to "knocked down." Most of the bridges that Stowell classified as made of "unknown material" the editor of *Engineering News* claimed were wood.

‡The totals columns include bridges of unknown material.

Unfortunately these data cannot be compared to British experience; when Cooper tried to obtain data on English railroad bridges from the Board of Trade he was informed that no such figures existed. As the epigraph suggests, however, most contemporaries believed that bridge accidents were far more prevalent in the United States than in Europe.[6]

One obvious inference from Table 2 is that most bridge failures were not simply a collapse; that is, square falls—where the bridge went down from the weight of the train—were comparatively rare, even for wooden bridges. By implication, neither engineering errors nor rising train weight were the major sources of bridge disaster. Of greater importance were design choices, such as the widespread use of wood that traded safety for cost, and management procedures that made American railroad bridges disaster-prone.[7]

Square falls arose from three quite different causes. Some, like Ashtabula, were indeed the result of bad engineering. Since the 1840s, with the publication of works by Squire Whipple and Herman Haupt, competent engineers computed strain diagrams that calculated the load on each member, whether in tension or compression, from the dead load of the bridge and some assumed live (train) load. Experiments by William Fairbairn for the English Iron Commission published in 1850 and by the German engineer August Wöhler established the ultimate strength of wrought iron as around 50,000 pounds per square inch (psi) and its elastic limit at about half that level, although both might vary substantially with the quality of the iron. Similar calculations were done for cast iron and wood as well. Thus, by the time of the Civil War, a skilled engineer armed with such information could proportion all bridge members to be able to withstand the assumed strain with a safety factor of four or five (relative to the breaking strength) to allow for the uncertainties in the process. As will be seen, bridge engineers constantly refined and improved these techniques throughout the nineteenth century.[8]

But not all bridge builders pursued the path of science. Thomas Appleton told the Boston Society of Civil Engineers that "in view of the prevailing lack of system, or 'rule of thumb,'" he was surprised how few Howe trusses had collapsed. He had once computed the strains on some Howe truss bridges and found that the iron was too weak. He showed his calculations to one of the pioneer builders who dismissed them with the comment "we never use such heavy iron as that." Another writer told the British Institution of Civil Engineers of early American timber bridges in which the iron tension rods carried a strain of 23 tons psi when accepted procedures limited strains to 5 tons. As late as 1893 the Superintendent of Bridges and Buildings on the Big Four Railroad sent the *Railway Review* photographs of two trestles that he termed "death traps" because they lacked either lateral or diagonal bracing.[9]

The results of such practices were nicely illustrated in 1850 on the Erie when one of Rider's Patent Iron Bridges gave way, moving the company to abandon iron altogether for a time. Although Rider's bridge had been praised by the *American Railroad Journal* and won an award from a committee that included Horatio Allen and John B. Jervis, it was fatally flawed. Three years before the bridge fell, Squire Whipple had pointed out that Rider's design placed strains of 26,000 pounds psi on some of the wrought iron—when the then-accepted practice was to limit such strains to 10,000–15,000 pounds psi. John Roebling claimed that he too had denounced Rider's plan. To him it symbolized the "necessary consequence of that total want of scientific knowledge on the part of those who superintend these structures." He called upon the civil engineers of the United States "in view of their professional standing" to denounce the "wholesale veto" which the Erie had passed "*indiscriminately* upon *all* iron bridges."[10]

Square falls also resulted from overloading bridges and trestles beyond their rated capacity. Train and engine weight increased steadily throughout the nineteenth century. On the Baltimore & Ohio, for example, the early "Grasshoppers" of 1835 weighed about 10.5 tons, but by 1873 the company was employing Consolidations weighing 52.6 tons. By the 1890s their weight had increased to 80.4 tons. Since many bridges were, as one committee of American engineers put it, "cheap and nasty"— which is to say designed to carry a load only slightly greater than immediately necessary—they soon became overloaded.

The *Railroad Gazette* thought this the result of economic, if not engineering design errors, and in 1886 it denounced the policy of "sailing so close to the wind" that was not only uneconomic but introduced a "constant element of danger" as well. The editor pointed out that the carrying capacity of a bridge rose more than proportionately with its weight, while costs rose less than proportionately. Under such circumstances, he argued, investing in a heavier bridge was both safer and more economic, as it postponed the costs of replacement.[11]

Several years later, Albert Robinson, bridge engineer on the Rock Island, expanded on the *Gazette*'s claim. Robinson calculated that for spans of 100 feet or less, built about 1882, the extra cost of building them to withstand 1897 train loads, when compounded at 5 percent, would have been less than the cost of reinforcing the bridge in 1897 (Table 3). Yet given the apparently large number of lightly built bridges, it is hard to believe that such behavior was uneconomic. Robinson's own figures

Table 3
Extra Cost of Building 1882 Bridge to Meet 1897 Loads vs. Cost of Reinforcement in 1897

	Length of Span in Feet							
	40	**60**	**80**	**100**	**120**	**140**	**160**	**180**
Added Cost for Heavier Load	$86	$254	$531	$714	$1,377	$1,744	$2,148	$2,601
At 5% for 15 Years	$179	$528	$1,105	$1,485	$2,864	$2,628	$4,466	$5,410
At 8% for 15 Years	$273	$807	$1,684	$2,265	$4,368	$5,532	$6,814	$8,251
Cost of Reinforcement	$377	$713	$1,408	$1,926	$2,857	$3,574	$4,388	$5,159

Source: Albert Robinson, "Relative Cost of Heavy vs. Reinforced Bridges," *Engineering News* 30 (21 September 1893): 237–238, Table 1, and calculations by the author.

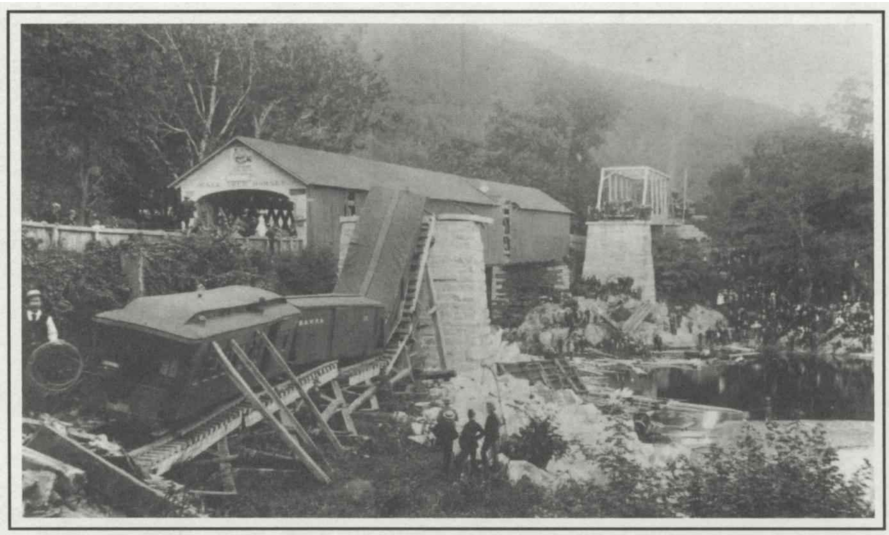


Fig. 2—This old bridge over the West River near Brattleboro, Vermont, was found to have been badly overloaded when it collapsed on August 18, 1886, killing the engineer and a station clerk. (Courtesy Vermont Historical Society)

demonstrated that if he had chosen an interest rate of 8 percent, most of the heavier bridges would not have paid off. For many railroads, the prospect of earning 5 to 7 percent on bridge investments must have paled in comparison with expected returns elsewhere, even when the additional safety was factored in. In short, overloading was probably the outcome of rational engineering and economic design choices.[12]

In any event, old bridges were routinely overstrained—sometimes by large amounts. In 1885 *Engineering News* reported a bridge on the Central Railroad of New Jersey in which tension bolts with an allowable strain of 10,000 pounds psi were subjected to loads of 22,000 pounds psi and another bridge with portions overstrained 200 percent. In 1890 that journal described some "old Fink and Bollman bridges" on the B&O that were "carrying heavier loads than they were ever designed for . . . and ought to be taken down before they fall down." Five years later a speaker to the American Society of Civil Engineers claimed that "of the bridges built during the past 15 years . . . the greater proportion are carrying loads in excess of their specification requirements." Not surprisingly, some of these overloaded bridges failed. One of many such disasters occurred on August 18, 1886, when a bridge on the Central Vermont near Brattleboro went down, wrecking ten cars and killing two people (Fig. 2). It had been designed for a moving load of 1,000 pounds per linear foot and was "badly overloaded."[13]

The final cause of square falls was poor maintenance, which constituted a peculiar problem for wooden bridges and, hence, a peculiar problem for American as opposed to British railroads. Here again, danger arose not from error, but from design choices that put a premium on continuous and careful inspection, for as the American engineer Zerah Colburn explained to the British Institution of Civil Engineers, "timber bridges were always rotting." Colburn claimed that when a wooden bridge collapsed on the New York Central killing nine passengers in 1858, some of the timbers were found to be so decayed that a walking stick could be pushed through them. But Howe trusses not only rotted, their design also used threaded iron rods as tension members and these required adjustment; if a nut on one rod loosened, all the load would be carried on those remaining.

To cope with such difficulties, some companies developed elaborate procedures for bridge inspection, with weekly and monthly checks by various officials. By the late 1880s, the Erie employed ten inspectors who went over bridges monthly, while roadmasters inspected bridges quarterly and the bridge engineer annually. The Buffalo, Rochester & Pittsburgh kept detailed records on the dates each bridge was inspected and its condition. For wooden bridges, inspectors were admonished to pay particular attention to "the condition of the chords . . . around the angle blocks . . . to see that . . . there are no evidences of decay in the timber."[14]

But if some companies developed careful procedures to inspect and maintain their bridges, as Table 2 suggests, many did not. Writing in 1891, one expert condemned the "pernicious" practice that some roads followed of letting bridges deteriorate to the point of collapse before undertaking any repair. Poor maintenance and inspection probably contributed to the collapse of the Tariffville, Connecticut, bridge, which occurred a little over a year after Ashtabula. The bridge over the Farmington River on the Connecticut Western Railroad was a double-span wooden Howe truss, about 333 feet long, with vertical iron tension rods. It had been built in 1870 and was uncovered and unpainted. An excursion train, returning from a Moody and Sankey meeting in Hartford, went through the bridge about 10:00 p.m. on January 15, 1878, killing thirteen people and injuring forty-six (Fig. 3). Mansfield Merriman, then an instructor of civil engineering at Yale and at the beginning of his long and distinguished career, investigated the disaster. He found that the upper chord of the bridge was rotten. But, like Ashtabula, the Tariffville bridge had so much else wrong with it that Merriman could not pinpoint the precise cause of failure. He calculated that the strain on the tension rods was 22,000 pounds psi, which he thought exceeded their elastic limit. Finally, both chords were also skimpy. Merriman calculated that the upper chord needed a cross section of 396

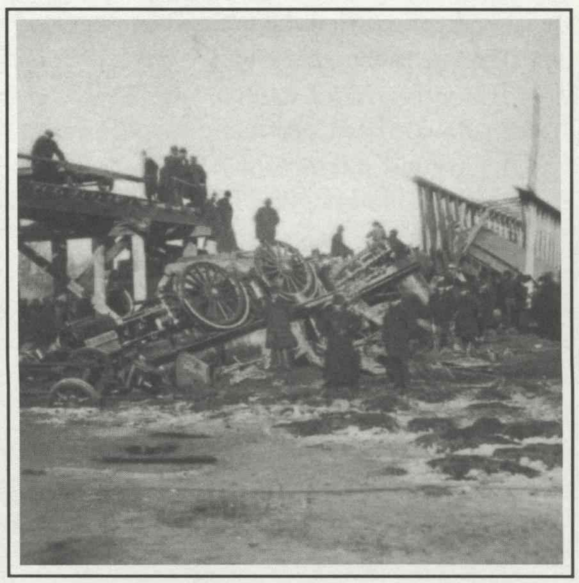


Fig. 3—The Tariffville disaster on the Connecticut Western. (Connecticut State Library)

inches but only contained 284. He concluded that the bridge "was not properly built, it was not properly kept in repair, and it was not properly inspected." As the *Railroad Gazette* put it, "eternal vigilance is the price of safety."[15]

Fire—like maintenance—was also a peculiar problem for wooden bridges. Howe trusses were always burning, the result of locomotive sparks, or lightning, or careless burning, or smoking, or arson. Many companies took extraordinary precautions to protect their bridges from fire, providing handy water pails (containing salt water in the winter) and requiring constant inspection from bridge watchmen or track-walkers, but fires continued to cause disasters at the rate of one or two a year. In 1887, a fire-weakened bridge brought on the Chatsworth, Illinois, disaster, which was one of the worst in American history. About midnight on August 10, a double-headed sixteen-car excursion train on the Toledo, Wabash & Western bound for Niagara Falls and carrying 600 people approached a tiny bridge over a culvert near Chatsworth. The bridge was only 15 feet long and 6 feet deep, but it was on fire. Unable to stop in time, the train broke the bridge, killing 73 and seriously injuring 374. Ironically, the bridge had been inspected by section men about 6:00 the previous night; they had been burning weeds and probably set the fire.

Chatsworth revealed another characteristic common to many disasters: operating practices were a contributing factor. The train was connected so that the air brakes were controlled in the *second* engine, which slowed their application. Had the brakes been applied when the first engine man saw the danger, the train might have stopped in time. In addition, the editor of *Engineering News* thought that Chatsworth revealed the dangers of running double headers. The first engine almost entirely escaped the wreck but the second engine and tender "were the true resisting force that telescoped the following cars causing most of the casualties," the journal reported.[16]

If fire did not get a bridge, flood often (in fact, more often) did. Charles Folsom of the Boston Society of Civil Engineers claimed that in two years of clipping the newspapers, he had assembled a list of eighty railroad bridges and 125 culverts that washed out, killing thirty-four people. Some of these were virtually unavoidable, but many were not, reflecting instead companies' efforts to economize on construction costs. On many of his consulting jobs, Folsom found the need to "increase the number and size of spaces for waterway," and stressed that in grading, "six feet above freshet mark is a great deal better than one." Culverts were an even worse problem than bridges; they were often too narrow, causing the stream to deepen the channel and wash out the abutments.[17]

Trestles were particularly prone to washouts because their supports were vulnerable to debris during high water. A washed out trestle bridge near Eden, Colorado, just north of Pueblo, caused the second-worst train accident in American history on August 7, 1904. Denver & Rio Grande Train No. 11, the Denver, Kansas City, and St. Louis Express carrying 162 passengers, broke through bridge 110-B into a rain-swollen creek, drowning ninety-seven people. The bridge was a simple timber frame trestle; it was "weak and in bad condition," and had been further weakened when a county bridge upstream let go, crashing into one of the bents.[18]

Bridges that collapsed while under repair provide yet another example of the role of management practices in contributing to bridge failures. On August 31, 1893, one of the worst of such disasters occurred near Chester, Massachusetts. At about 12:30 p.m. that day, Boston & Albany Train No. 16, the Chicago Express, consisting of seven cars hauled by a Ten-wheeler and carrying 135 passengers, plunged through Willcutt's bridge over the Westfield River, killing fourteen people and outraging the editors of *Engineering News*. It was, the journal fumed, "the least excusable bridge disaster of magnitude which has ever occurred." The investigation showed that the bridge was under repair at the time by an outside contracting firm, the R. F. Hawkins Iron Works, and under the immediate supervision of a foreman. The railroad, it appears, exercised no supervision over the project. The workmen were repairing one of the truss chords, which was built up from two beams with a riveted top plate that gave it lateral stability. At about noon, they quit for lunch, leaving the top plate off and the bridge in a fatally weakened condition when Train 16 arrived. Such an accident, the *News* concluded, reflected "not only merely gross individual carelessness but [also] certain radical underlying errors of practice and method . . . extending through quite a chain of officials from the president down."[19]

Knock-downs were the most common single reason why American railroad bridges failed. These also resulted from design choices that diverged sharply from European practice. In 1874 the *Railroad Gazette* printed a long exchange that highlighted the distinctions between British and American bridge-building techniques. The British engineer Ewing Matheson explained that the divergence in practice resulted in part from economic circumstances. "American [iron] bridges are lighter," he noted, thereby saving in material and also transportation, both of which—given the vast American distances—were far more important in the United States than in Britain where iron was cheaper and distances shorter.[20]

Differing contracting methods also encouraged contrasts in design. By the 1860s, American bridge companies were assuming responsibility for bridge design, thereby facilitating both standardization and mechanization. Faced with the demand for large numbers of small bridges, American producers turned to the mass production of standard designs. By contrast, in Britain even small bridges were custom made. As Matheson put it: "the builder gets his drawings from the railway engineer, who designs every rivet and bolt . . . A. B. wishes one style, C. D. an entirely different type." A later writer suggested that the American system, which located design with the contractor, generated strong incentives for economy, while in Britain design by the user emphasized safety.

American designers also used pins or bolts to connect the main members, while British engineers made such connections with rivets. Pin connections were ideally suited for American conditions, for they allowed all the bridge members to be factory-made and rapidly field-assembled. Such procedures speeded up construction, thereby allowing a railroad line to open quickly and earn revenue. One writer claimed that British methods would require ten or twelve days to erect a 160-foot riveted lattice span while the Phoenix Iron Works could put up a pin-connected bridge of similar size in 8½ hours. Factory construction was also a way of employing semi-skilled labor under close supervision "where skilled labor for erection is unobtainable or where, because of the lack of supervision, there is a risk that the riveting at the site would be carelessly or badly effected."[21]

American bridges also skimped on bridge floors, sometimes omitting them entirely, a practice unheard of in Britain, and they employed deeper trusses with fewer panels than did their British counterparts, which saved metal but required more lateral bracing. In the 1890s, the British journal *The Engineer* described American designs as "birdcage structures" (Fig. 4) and pointed out that they had "all the lateral stiffness of the side of a suburban garden fence." Matheson concluded that American practice was economical but very unsafe, claiming that "Fink trusses, and others of similar character . . . would not, in the interest of public safety, be allowed by the Government Inspectors in this country." He summarized the superiority of British practice by observing that nineteen bridges had failed in the United States in 1873, while in Great Britain, "not one accident per annum happens from any failure of a railroad bridge."[22]

American practices were defended by the civil engineer Charles Bender, who rested his case on economic and technical grounds and largely ignored the matter of safety. The *Gazette*'s distinguished editor Mathias Forney summarized the debate. Forney acknowledged the need for better floors on American bridges, laconically observing that "the American engineer seems to assume that derailment will never take place on a bridge," but he challenged Matheson's claim of superior safety for British practice. Forney asserted that "there is as yet no instance on record of an iron bridge designed by any of our leading engineers or engineering firms which has ever given way." As for the nineteen bridges cited by Matheson, all were wood. Forney then reviewed failures of six iron bridges built by "reputable firms." Three had been overloaded, while the other three "did not give way under a load but . . . were knocked down by a train." Clearly by Forney's lights a bridge that collapsed from a train accident did not constitute an engineering failure.[23]

In fact, the very techniques that made American iron bridges distinctive also made them peculiarly susceptible to knock-down—a point implicit in Forney's argument but which he seems to have ignored. Others did not, however. In 1878 Thomas Appleton concluded: "by far the most frequent causes of accidents are derailed trains." The solutions, he thought, were simple. Echoing Forney, Appleton noted that "an all important point in any bridge, and one that has been sadly neglected, is the floor. If we can make a floor that a derailed train will not break through . . . we shall have gained a great desideratum."

The second problem was that, unlike riveted bridges, pin-connected bridges were non-redundant structures in which the integrity of each member was necessary for the integrity of the whole. Knock one single post or truss rod out and the bridge was liable to fold up like a hinge. The solution, Appleton claimed, was to "let your chords, tension members, posts, etc., all be properly proportioned . . . but *fasten them together* [with rivets]; let your structure be one integral bridge, not a conglomeration of

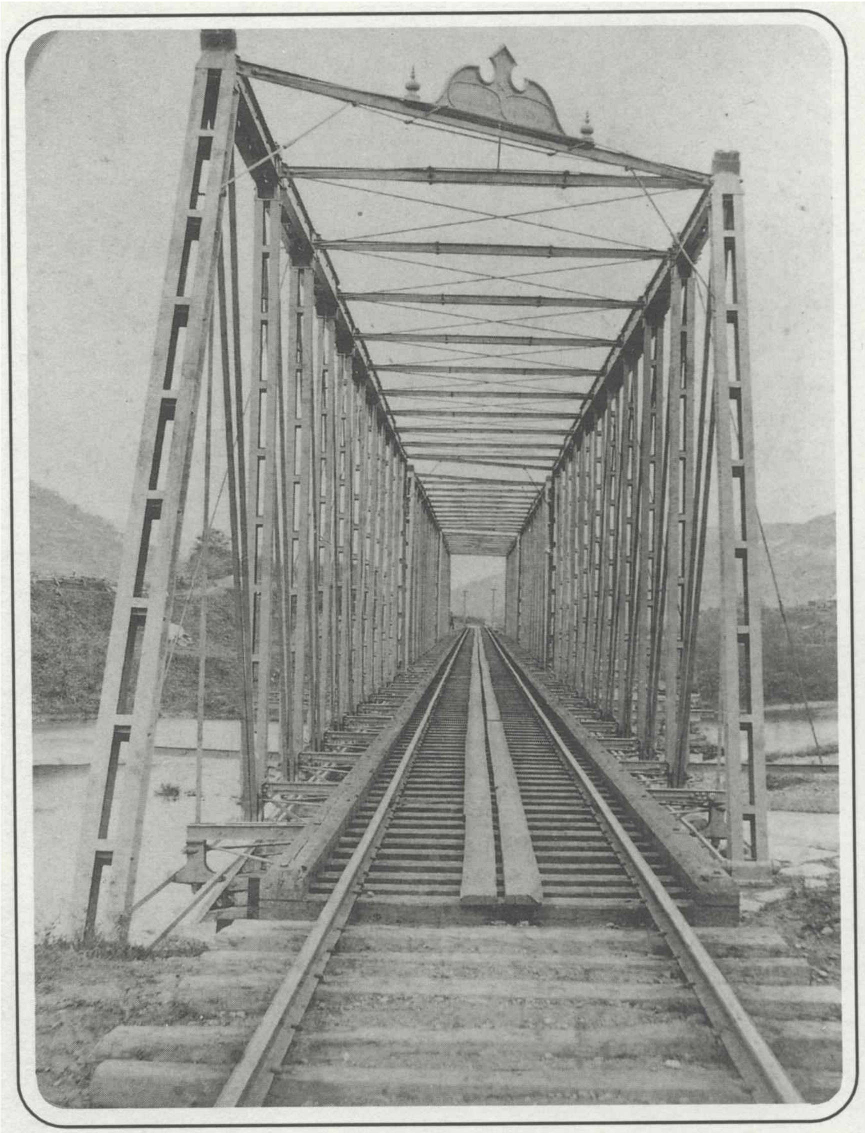
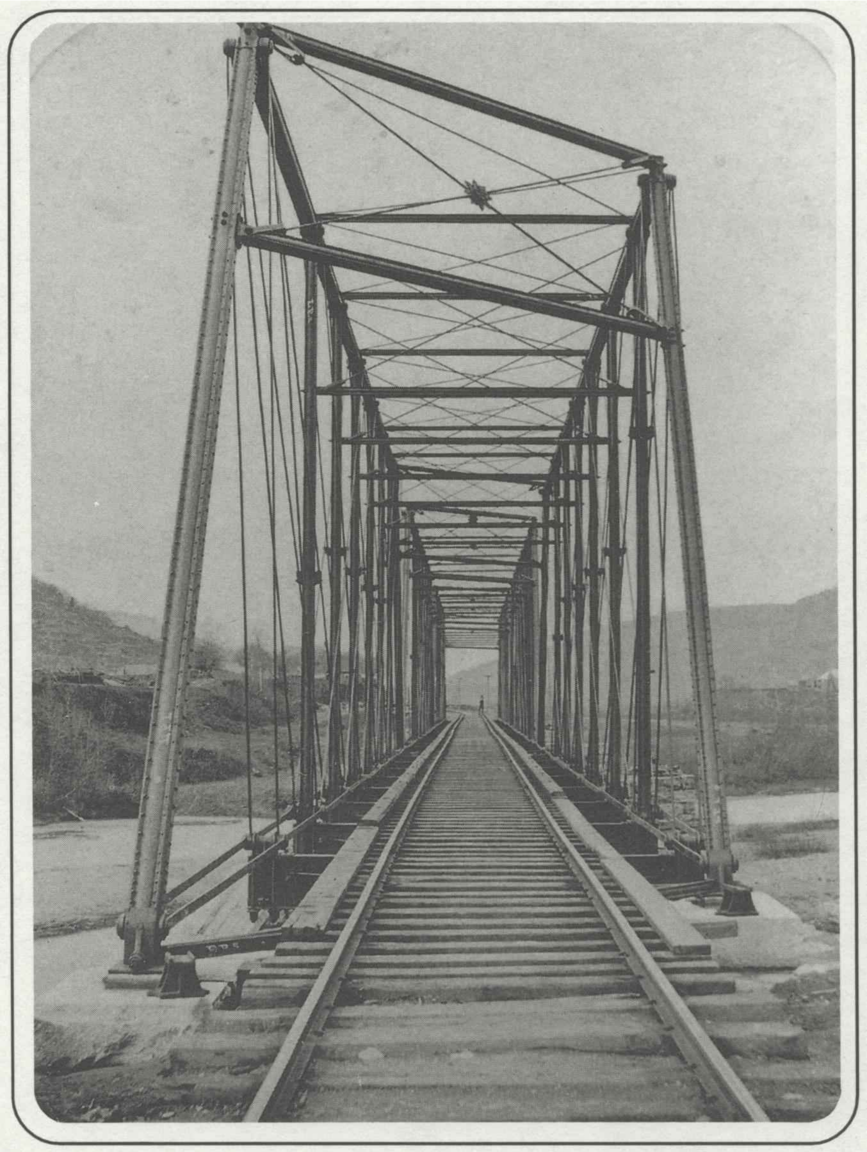


Fig. 4—Typical "birdcage structures"—as *The Engineer* termed them— from the first generation of pin-connected iron railroad bridges. Notice the almost complete lack of lateral bracing. These photographs show that both inside and outside wooden guardrails were used on the Central Vermont in the 1880s. (Courtesy Vermont Historical Society)



disconnected parts." Appleton confessed that it was a mystery to him "why the American pin and link bridge should be built in utter disregard of these essential principles as it almost invariably is." He then went on to describe a number of derailments on riveted lattice trusses on the New York Central that had broken various posts and braces but left the bridge standing.[24]

Nineteenth-century American railroad bridges failures, therefore, reflected not only engineering error but also the consequences of engineering-economic choices with respect to design, materials, and construction methods. Careful inspection and operation might offset some of the dangers resulting from such choices, but often did not. Most American bridges were designed with little margin for overloading, while the choice of wood made them susceptible to fire and rot. Trestles were inherently more dangerous than embankments, grading and waterway space were often inadequate, and floors were skimpy at best.

Finally, light link-and-pin metal bridges were prone to knock-down from derailments at a time when other engineering-economic characteristics of equipment and roadbed made American carriers derailment-prone. In the 1870s, the *Railroad Gazette's* statistics typically record twice as many derailments as collisions. Light rails, poor ballast, light cast-iron wheels, and flimsy axles combined with a wholesale rush toward heavier equipment all contributed to the derailment total. Most were minor affairs; a broken rail or wheel where the roadbed was flat might tip a few cars over but otherwise do little damage. But the same accident on a bridge designed according to approved American methods could lead to catastrophe.[25]

The Campaign Against Bridge Accidents

If American railroad bridges were disaster prone, these same disasters also generated powerful impulses toward reform. Beginning in the 1870s, the railroads and bridge companies, the American Society of Civil Engineers, the technical press, and state regulatory commissions—all in varying degree—began to press for change. Their actions, along with largely independent changes in materials technology, brought about a gradual reduction in bridge failures.

State governments and railroad commissions began to exercise some jurisdiction over railroad bridges as early as the 1850s. When an engineer ran his train into an open drawbridge at Norwalk, Connecticut, on May 6, 1853, killing forty-six people, the state promptly passed a law requiring all trains to stop before crossing such bridges. Many state railroad commissions inspected bridges, but few had any special expertise for the job and most lacked powers of enforcement. In 1859, Vermont's single railroad commissioner unsuccessfully requested authority to require repair of bridges. Two years later he was complaining of bridges that lacked guards and others that were not "sufficient to afford the security which the public have a right to require."[26]

In 1872, Ohio's railroad commission employed the civil engineer William S. Williams to inspect railroad bridges and he found many "unsound and imperfect structures." The next year Williams reported that he had inspected all the important roads in the state and claimed that "in most cases" his suggestions were complied with. Given that Ohio then had nearly 1,700 railroad bridges and trestles, his inspections cannot have been very thorough; he seems to have found no fault with the Ashtabula bridge before it fell. Similarly, two months prior to the Tariffville disaster an engineer employed by the Connecticut Railroad Commissioners had examined that bridge and pronounced it safe. George Vose—then professor of civil engineering at Bowdoin College and already committed to the cause of better bridges—described one bridge that was "old, rotten, [and] worn-out," and had "been condemned for four years," that Maine's railroad commission termed "safe for present use." Vose was thunderstruck. How this bridge "has suddenly become safe," he sputtered, "would puzzle any one but a railroad commissioner."

With early state regulation largely ineffective, the technical press led by *Engineering News* and the *Railroad Gazette* began a campaign to improve bridge safety. These and other journals not only published the technical papers presented at engineering societies and railroad clubs, they also reported debates such as that between Matheson and Bender in which ideas about best practice were hashed out. The engineering journals also reported on and discussed the lessons to be learned from disasters at a time when few states undertook adequate accident investigations. Finally, they diffused the ideas of reformers and championed specific reforms and better regulation. Sometimes these activities yielded immediate, concrete results. In one instance, the *Gazette* published an article, complete with illustrations, describing a bridge on the Kansas City, Memphis & Birmingham Railroad. A reader noticed that some crucial members had been omitted from the trusses and promptly notified the railroad and the bridge companies, asking for copies of the strain sheets. The companies refused to provide these until he threatened to publish his conclusions, whereupon they then acknowledged the blunder and made the corrections.[28]

In 1873 the American Society of Civil Engineers evidenced its first concern with bridge safety. Responding to the collapse of a highway bridge in Dixon, Illinois, "and other casualties of a similar character that . . . are constantly occurring," the ASCE appointed a seven-member committee, including some of the leading bridge engineers of the day, to report "on the means of averting bridge accidents." In 1875 the committee delivered its report. In fact, it delivered four reports. The first, signed by the distinguished James B. Eads and C. Shaler Smith, developed a model bill that its authors thought could easily be embodied in a law. It included standards for minimum loads per linear foot of track for bridges of varying length as well as maximum stresses for wood, wrought iron, and cast iron. Noting that derailed trains knocked down many bridges, it proposed standards for floor construction. The report also provided that each state appoint a bridge expert subject to an examination by the society and that every railroad be required to inspect its bridges once a month. Other members objected to many of the technical details. Some also disliked the proposal that states appoint inspectors who, they thought, would be political hacks. Compromise failed and the committee was dissolved in November 1876, a little over a month before the Lake Shore's Pacific Express kept its appointment with the Ashtabula bridge.[29]

As noted, Ashtabula precipitated an investigation by a committee of the Ohio legislature. The committee drafted a bill to regulate bridge construction, but it never passed. The ripples of Ashtabula extended beyond Ohio's borders, however. Liability suits stemming from the tragedy cost the Lake Shore more than $600,000, enough to get the attention of railroad managers everywhere. Both the Erie and New York Central went over all bridges as a result of the accident. "I venture to say that there is hardly a railway in the country that has not been inspected in some way as to its bridges since 1st December," Alfred Boller told the ASCE in February 1877. Wisconsin's railroad commissioner reported that, as a result of Ashtabula, "numerous letters were received at this office inquiring as to the safety of certain bridges." In response, he circularized the carriers urging them to employ competent engineers to inspect their bridges. "As the result of my labors . . . the railroad bridges are in better condition by far than ever before," he crowed. On the national level Ashtabula, which was in the district of Representative James A. Garfield, led him to submit a bill that would have required railroad inspection by Army engineers, though it failed. The Tariffville disaster of 1878 did improve bridge inspection in Connecticut, at least for a time. The commission urged carriers to compute strain sheets while the state's engineer began to inspect tension members with more care.[30]

Engineering News opined that Ashtabula provided a good excuse for the ASCE to revive its committee to inspect bridges, complaining that "at the present time there is scarcely any hindrance to parties building any structure they see fit." At the April 1877 meeting, Eads's report was again debated, and a resolution to form a committee to draft a model law was submitted to letter ballot. This failed, however, and, as it turned out, it was the last effort of the ASCE to develop a code of bridge specifications.[31]

Nevertheless, the ASCE and the regional engineering societies did play an important role in developing and diffusing new knowledge on proper bridge design. Before the 1870s, engineers often employed cast iron in compression. They compared the tensile strain on wrought iron to its breaking weight to estimate the safety factor. (This was the procedure followed by those who investigated Ashtabula; in fact the comparison should be with the elastic limit, not the breaking strength of the metal.) Nor did designers always distinguish between live and dead loads or how the live load was distributed. Little was known about the effect of wind on structures or the actual behavior of full-size members under load.

The societies' papers and discussions clarified many of these matters. Cast iron was abandoned and in the 1880s the implications of Wöhler's experiments on metal fatigue were gradually digested, leading to an increased emphasis on the elastic limit of metal rather than its breaking strength. Various formulas were also developed to incorporate these insights into designs, and by 1900 engineers were actually measuring the impact of live loads. The need for materials testing—including that of full-sized members—was stressed while the procedure of overloading a new bridge to see if it held up was abandoned as unsound and unsafe. Such a demonstration might be spectacular (some companies loaded bridges with as many engines and tenders as their length permitted) but it proved nothing, for the bridge might collapse with one more pound (Fig. 5). Worse, such a test might exceed the elastic limit of the metal and thereby weaken the bridge. These and many other improvements in technique contributed to both safer design and a better understanding of maintenance and replacement needs.[32]

Changes in the methods of bridge contracting during the 1870s also contributed to improvements in design and construction. Prior to the Civil War, most bridges had been constructed either by itinerant self-trained builders or by the railroads themselves, and neither method ensured expertise in design nor accuracy in calculation. In 1849 Isaac Hinckley, superintendent of the Boston & Providence, complained that the bridges built by one contractor "are in some respects inferior in dimensions of material and quality of workmanship." Some of the piles were small and poorly driven and "some of them have settled six or eight inches, thus permitting the permanent roadbed to deflect in same degree."[33]

During the 1860s, as the rail network expanded, companies such as Keystone Bridge and Phoenix Iron Works arose that specialized in bridge construction. The carriers would contract with the bridge manufacturers,

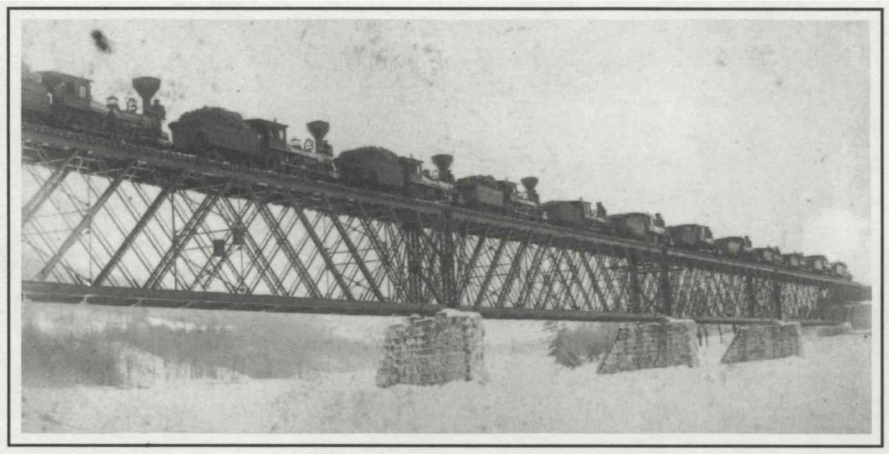


Fig. 5—Testing a new bridge the old-fashioned way. As civil engineers began to focus on the elastic limits of metal, they abandoned such methods, which could permanently weaken a structure. (Courtesy Vermont Historical Society)

leaving the design and construction to them. Again, such procedures provided no checks for either honesty or competence. During the 1870s, however, the railroads began to exercise much more control over the process, hiring their own or consulting bridge engineers. In 1873, George Morison of the Erie developed the first set of detailed printed bridge specifications. The Cincinnati Southern, the Milwaukee, and other large carriers soon followed. In the 1880s, prominent consulting engineers such as Theodore Cooper published their own specifications that were widely publicized and debated. Typically such specifications left design and construction details to the contractor, but they specified maximum strains for individual members; set out specific formulas to be used in computing loads and the concentration of load to be assumed; and required blueprints, strain sheets and materials testing. By this time, at least some bridge companies maintained materials testing equipment, and by the mid-1880s, Keystone Bridge and the Pennsylvania Railroad were performing compression tests on full-size members.[34]

These specifications came to define best practice. All were reported from time to time in the engineering press, thus ensuring that they would be widely known. They helped prevent shoddy construction and ensured that each bridge was independently checked at least twice. Despite such improvements, most critics continued to urge better public regulation of bridge safety and many, like *Engineering News,* had hoped that Ashtabula would bear more fruit. In 1880, George Vose penned two articles on bridge accidents in the *Railroad Gazette*. Vose had already established himself as a highly vocal critic of dangerous bridges. Not only had he denounced the Maine Railroad Commissioners in print, he had also publicly accused the King Bridge Company of constructing highway bridges with a safety factor of less than two. The *Gazette* articles included more of the same. In a scathing indictment, Vose blamed Ashtabula, Tariffville, and similar disasters on bad design, sloppy construction, and incompetent inspection both by the railroads and by state officials. Vose again urged states to begin inspection by ASCE-certified engineers. The *Gazette* itself went even further, urging states to compute sets of specifications that could become the basis for a law.[35]

In 1883, the New York State Railroad Commission instituted the first comprehensive program of railroad bridge inspection in the country. The commissioners investigated a bridge that collapsed on October 22, 1883, on the Rensselaer & Saratoga, killing three and injuring twenty-two people. It was the usual story of misfeasance and nonfeasance. The inquiry revealed that a truss rod had broken under a strain of about 25,000 pounds psi, and that no one in the company had clear responsibility for bridge inspection. Such management problems were by no means rare. Ohio's bridge inspector complained of the "division of responsibilities" between the engineer, superintendent, and general manager that allowed incompetent officials to meddle in engineering matters and left no one in charge. Somewhat later the Massachusetts Commission reported "the managements of most of the roads were not sufficiently familiar with the condition of their bridges."[36]

In January 1884 New York's commission requested drawings and strain sheets on every railroad bridge in the state, and it hired Charles T. Stowell as bridge inspector to assess the submissions and report needed changes to the companies. Stowell had graduated with a degree in civil engineering from Rensselaer Polytechnic Institute and had been a practicing bridge engineer. This was the first time any public authority had required the recording of accurate strain sheets on every member of every bridge and then employed an expert to verify the calculations. It was, *Engineering News* reported, a procedure that "well deserve[s] to be widely copied."[37]

New York's action had two results, the first being a very general upgrading in the state's railroad bridges. The engineering press reported that many companies reinforced their bridges before submitting plans in order to forestall bad publicity. Still, the final report, which ran to 1,600 pages, listed an astonishing number of unsafe bridges that had been revised only in the light of Stowell's criticisms. The second result was to provide Stowell with both the information and the bully pulpit that he would use to influence bridge design.[38]

Stowell's position made him familiar with bridge design on every railroad in New York, and he soon rediscovered the argument that Appleton and Matheson had made a decade before. The pin-connected truss bridges common on most railroads were subject to knock-down from derailed locomotives or cars, whereas the riveted lattice trusses used by the New York Central were not. To build his case, Stowell began to assemble failure statistics, ignoring trestles and simple stringer bridges since his concern was with trusses only. Stowell had powerful allies in the railroad press. His statistics came mostly from the *Railroad Gazette*'s annual compilation of train accidents. Both the *Gazette* and *Engineering News* also gave Stowell's statistics and views wide publicity and the *News* chimed in with editorial support as well.[39]

Stowell's first salvo appeared in the *Railroad Gazette* in November 1885. He presented his own and Appleton's statistics on bridge accidents from 1873 through 1885, pointing out that while knock-downs were the leading cause of failure of pin-connected iron bridges, there were *no* such accidents to lattice truss bridges. Stowell reminded the reader of the earlier debate over pin vs. riveted bridges and the *Gazette*'s claim that a knocked-down bridge did not really "fail." That "must be small consolation, either to the maimed survivors, the bereaved relatives, or the company which pays for the damage," he remarked.[40]

As soon as the figures for 1886 were available, Stowell struck again, this time in the pages of *Engineering News* where he was supported by its influential editors, David McNeely Stauffer and Arthur Mellen Wellington. Stauffer had been a construction and bridge engineer for several railroads, consulted, and worked for the Philadelphia Bridge Works, while Wellington also had broad experience in railway engineering and had authored the authoritative *Economic Theory of Railway Location*. Under their editorship the *News* virtually became a railroad journal. The editors had also concluded that the ease with which American bridges could be knocked down revealed a design flaw, but it was a different flaw than Stowell stressed. The problem was with the floor, not the truss.[41]

As Forney had observed a decade earlier, floors were a weak spot in many American bridges. Sometimes they had no floor at all, and the rails were laid on stringers that rested on the cross-braces. If ties were used, they were often unattached to the stringers, did not extend the width of the bridge, and were widely spaced (Fig. 6). In all such cases, derailment usually meant disaster. Without a floor, a derailed car might plunge into the cross-braces, carrying away the bridge; if ties were spaced more widely than 8 inches apart, the wheel would fall between them, causing them to bunch and leading to disaster. Even if the ties were properly spaced, however,

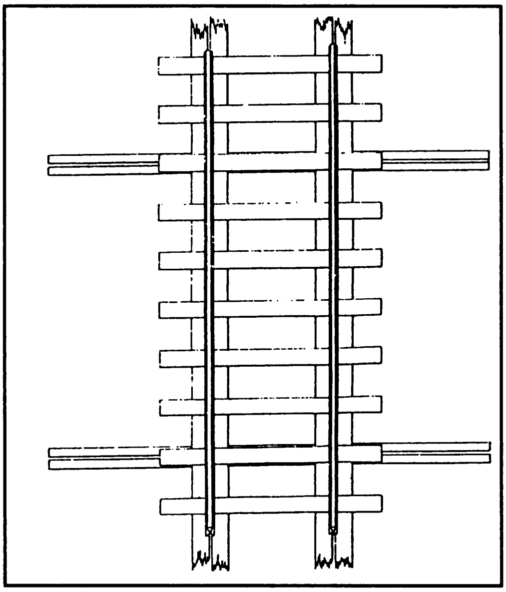


Fig. 6—A typical bridge floor with ties widely spaced over stringers. A derailment would bunch the ties and probably cause the car to plunge through the floor, collapsing the bridge. (American Society of Civil Engineers *Transactions*)

there was usually nothing to prevent a derailed car from plowing into the truss or going over the side of a deck truss bridge or trestle.[42]

The usual results of an accident with such flooring were nicely illustrated on Saturday, February 5, 1887, on the Woodstock bridge, near White River Junction, Vermont. The Central Vermont's Boston–Montreal express apparently hit a broken rail and derailed about 450 feet before the bridge, which was a deck truss. The last three cars pitched over the edge, falling about 42 feet to the ice below where one of the car stoves set them ablaze, incinerating 29 victims, injuring many more, and burning the bridge down (Fig. 7).

Woodstock illustrated the ambiguities inherent in the definition of bridge failures. To most engineers, Woodstock was a derailment—which was how the *Railroad Gazette* categorized it—for the bridge did not fail and its subsequent burning had nothing to do with the accident. Even Charles Stowell, concerned as he was with truss failures, did not include Woodstock in his list of bridge failures. But it was meat and drink for *Engineering News*, which saw such disasters as the predictable outcome of derailments on bridges with unsafe floors. In all events, it had lasting consequences, precipitating a nationwide campaign to banish the "deadly car stove" that ultimately resulted in the introduction of steam-heated passenger cars. It also led the Vermont legislature to pass a bill authorizing the annual inspection of railroads, by experts if necessary, and it led *Engineering News* to launch a crusade to improve bridge floors.[43]

Fig. 7—What remained of the Woodstock bridge after the wreck of February 5, 1887. Engineers disagreed whether or not this constituted a bridge failure, because the accident resulted from a derailment and the bridge burned as a consequence. Yet, an adequately guarded bridge would probably have averted the tragedy. (Courtesy Vermont Historical Society)

As soon as Vermont authorized inspections, the railroad commissioners promptly employed Hiram Hitchcock and Robert Fletcher, both of whom were civil engineers at Dartmouth, to inspect all bridges in the state. Their reports revealed the usual assortment of horrors and death traps. Hitchcock reported that many railroads were improving their bridge floors, but on others he noted "the absence of re-railing devices, improperly spaced ties, [and] inadequate guard timbers." In September 1889 he reported on the Bethel bridge, a Howe truss on the Central Vermont just then celebrating its forty-ninth birthday. The bridge had been "horsed up" (that is, turned into a trestle) without which Hitchcock thought it would have collapsed. He found some tension rods 100 percent overstrained and some wood posts with safety factors of 2.5.[44]

Such scrutiny got results, and several years later the commissioners reported much improvement as "the bridges of first construction on all the early built lines have almost wholly disappeared." Later it noted that the Central Vermont had adopted a standard bridge floor consisting of long ties, outside guardrails, and sometimes inside guards as well. Yet Vermont's inspection system remained inferior to that of New York. Companies were not required to file bridge plans and strain sheets with the commission, and in 1896 the commissioners complained that, with few exceptions, they had no records that gave the condition, material, and safety factor of railroad bridges. When they requested such information, some companies claimed to be unable to give the safety factor on their bridges—"a confession of incompetency that merits criticism," the commissioners rather lamely concluded.[45]

Engineering News also tried to ensure that the lessons of Woodstock did not go unheeded. In February 1887, immediately after the tragedy, it launched a campaign for safe bridge flooring. An editorial reproduced a letter dated February 18, 1874, from the general manager of the Chicago & Michigan to Charles Latimer, inventor of a re-railing device, which described an accident it had prevented. Latimer's invention was exceedingly simple, consisting of two rails that came to a point in the center of the track and led back to a ramp up to the main rails. A derailed truck that hit the device would automatically be guided back to the ramp and up onto the rail. The editorial claimed that the device was not patented and was standard on many lines. "We could readily give a list of a dozen more similar occurrences in which trains were without doubt saved from running off bridges," it concluded.[46]

As the editorial noted, efforts to improve bridge flooring were not new. In 1881, the Massachusetts Railroad Commission had sent a circular to that state's carriers describing various safety systems and urging the adoption of one of them. In 1885, Ohio's commission published a letter from J. E. Childs, chief engineer on the New York, Lake Erie & Western, describing a derailment on a bridge that would have resulted in a "Second Ashtabula" but for the use of Latimer's guard. Childs also modified Latimer's device to make it part of a guard system that the *News* described in a second editorial. The system included, in addition to the re-railer, two sturdy timbers bolted or notched to the sleepers and flared at each end of the bridge that would prevent the ties from spreading and also act as outside guard rails to prevent a derailed car from hitting the truss. Finally, sturdy endposts also protected the truss (Fig. 8). The whole arrangement could be installed for $120 to $160 per bridge.[47]

Stowell promptly responded with a list of recent accidents, most of which involved some form of collision on the bridge, that would not have been prevented by the Childs–Latimer system. He admitted it was wise to provide all bridges with guards. "But is it not also a pretty good idea," he queried the *News,* "to build your bridge [so] that if all these safe-guards fail, and the truss does happen to get struck, it will not fall down?" Stowell, who managed to retain his sense of humor while reporting these tragedies, concluded with the story of an "old bridge builder" who always claimed to tremble when riding over some bridges lest an elderly lady inadvertently stick an umbrella out the window and hit the truss.[48]

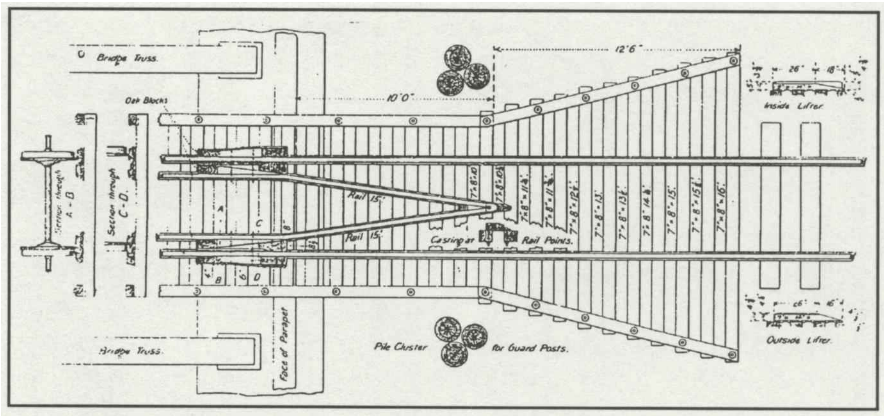


Fig. 8—An effective bridge guard (this one on the BR&P) included end posts to protect the truss, outside guard timbers that would both guide derailed car trucks and prevent the bunching of ties, an inside guard rail also intended to guide car wheels, and the Latimer re-railer. ***(Engineering News)***

For the next three years the pages of the *News* contained a lively debate among Stowell, the editors, and various other interested parties on whether pin-connected bridges or inadequate floors were the worst danger and which of the several sorts of guard rails were the best. The *News* emphasized disasters that resulted from bad flooring while Stowell bombarded the editors with examples, complete with photographs, of riveted bridges that had withstood the loss of endpost and webbing without collapsing, and of pin-connected bridges that had been knocked down under similar circumstances (Fig. 9). Stowell breezily suggested that all such bridges carry a sign saying: "Warning: Don't Touch the Trusses Under Penalty of a Wreck."[49]

In 1888 George H. Thomson, bridge engineer on the New York Central, joined the fray with a paper titled "American Bridge Failures: Mechanical Pathology Considered in Its Relation to Bridge Design." Since the 1860s, the Central had been constructing riveted lattice truss iron bridges, a type frowned on by the engineering establishment, and his paper constituted a self-justification as well as a critique of common practices. He delivered the paper to the British Association for the Advancement of Science and later published it in the British journal *Engineering,* both of which the American technical press considered little short of treason. His argument, like that of Stowell's, was that pin-connected spans were easily knocked down—a kind of mechanical pathology. "As long as reputable bridge practice is satisfied in making no provision for the contingencies of railroad operation—catastrophes due to broken axles, etc.—just so long must we expect to hear of railroad bridge failures," Thomson lectured.[50]

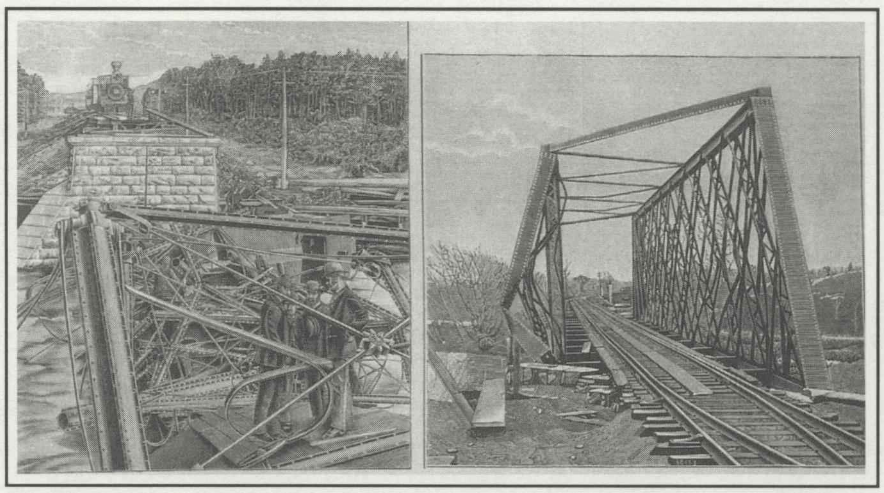


Fig. 9—As these illustrations from *Engineering* indicate, riveted bridges were hard to knock down even if several supports were broken, whereas pin-and-eye-bar bridges would usually collapse if any single member were broken.

Such arguments by Stowell and Thomson amounted to a direct attack on engineers' conception of their responsibility for safe bridge design. In his famous "American Railroad Bridges," Theodore Cooper rather testily gave the response to such critics. "Does anyone advocate the designing and building of bridges to withstand the impact of a railroad train or the bursting effect of piling two trains on one another inside of the trusses? Are such accidents to be classed as bridge failures or as failures of management?" Cooper asked rhetorically.[51]

In the long discussion that followed Cooper's paper, no one took the bait except Charles Stowell, who responded simply: "as long as trains run into bridges or cars pile up inside the trusses, a bridge to be safe must be designed and built to withstand just those things. I believe . . . that the time will come," Stowell concluded, "when the failure of an iron bridge from an ordinary accident of train service will be regarded as discreditable to its builder and not excused as a fault of the management." Another discussant, the respected J. A. L. Waddell, defended Cooper. The shift to riveted lattice-truss design that Stowell advocated "would be retrograde," Waddell claimed. Like the *News,* he, too, favored stronger floor systems instead and concluded that "general managers and superintendents are much to blame for the improper styles of floor system used on many American lines." Thus, Cooper and Waddell, and apparently most of the others present (for no one disagreed), saw knock-downs not as problems of engineering design but as the result of managerial choices and blunders that resulted in bad floors, collisions, and derailments.[52]

Fig. 10—When a B&O locomotive hit a cow on this pin-connected bridge on April 30, 1887, throwing her into the truss, the bridge collapsed.

The editors of *Engineering News* were also reluctant to follow Stowell in condemning pin-connected bridges, and in response to his claims they usually pointed out that most bridges that failed had widely spaced ties and lacked any system of guards. Sometimes, however, the facts pushed them into Stowell's camp. The *News* reported a knock-down on the B&O on April 30, 1887, that resulted when the locomotive hit a cow on a bridge (Fig 10). "Whether the cow was actually . . . flung against one of the posts, or whether the cow just happened to swing her tail against one of the compression members just as it was taking strain from the locomotive we cannot say, but the internal evidence rather favors the latter theory," the journal observed. "The day is near at hand," the editors hoped, "when it will ruin a man's professional reputation to have either designed or accepted such a bridge." By 1888 the *News* admitted that "a riveted structure of the same span and strength [as a pin-connected bridge] would . . . [be] much more likely to escape collapse."[53]

As this debate was proceeding, disaster gave the cause of reform another nudge. Forty days after White River Junction, on March 14, 1887, the Boston & Providence 7:00 a.m. train out of Dedham, Massachusetts, with nine cars and about 275 passengers and crew plunged through the Bussey Bridge, killing twenty-three people (Fig. 11). "The Second Ashtabula," the *News* called it, although compared to the Bussey Bridge "the Ashtabula Bridge was a masterpiece of engineering." If anything, this was an understatement. The bridge had started life as a wooden Howe truss. It had been tinned to prevent rot, thereby winning it the title "the tin bridge," and had been rebuilt with one iron truss in 1869. A second one of different design was added in 1876. It was not the trusses that had broken, however, but the hangers for the floor beams that held the track. The offending hangers were "of far from good iron . . . bad design . . . imperfectly welded . . . with old, deeply rusted breaks." Subsequent analysis revealed that normal train loads placed a strain on them of 48,000 pounds psi, roughly equal to their breaking strength.

But while the hangers caused the bridge to fail, as the *News* and the official investigation pointed out, the disaster also revealed a potpourri of defective management and operating practices. The railroad had exercised no supervision over the contractor, who built the bridge under what may

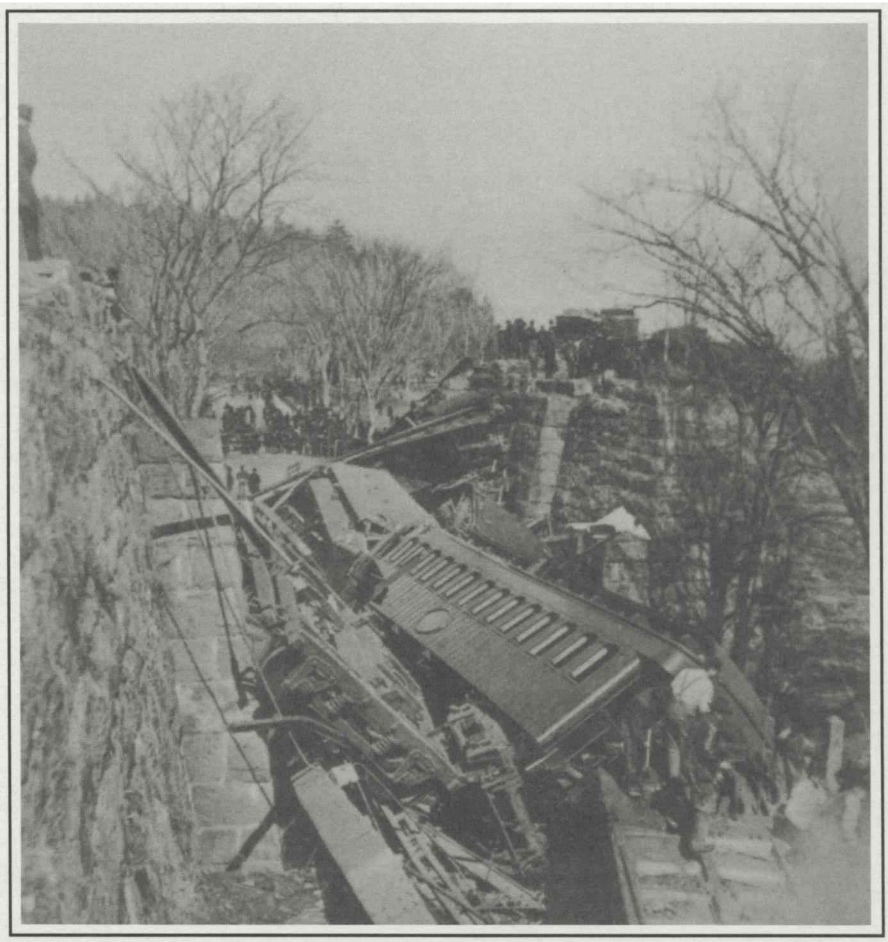


Fig. 11—The accident at the B&P's Bussey Bridge, March 14, 1887. This disaster—the result of bad design and poor maintenance in addition to obsolete brakes on the train—moved the Massachusetts legislature to require bridge inspection. (Massachusetts Board of Railroad Commissioners)

have been fraudulent conditions. It had never been tested, nor had a trained engineer ever inspected it. Moreover, the train that broke through was equipped with old-style Westinghouse straight air brakes that lost pressure when the train parted. These had been obsolete since 1874, when Westinghouse introduced the automatic brake that applied the brakes in such a situation. The *News* estimated that the train was traveling no more than 25 miles per hour when the bridge broke. Assuming standard braking efficiency, the editor calculated that with automatic brakes the train would have stopped before the last three cars went over the edge, while those that preceded would have settled with the truss rather than crashing into the abutment, thereby causing many fewer casualties.[54]

In its investigation, the Massachusetts Railroad Commission heard testimony from George Vose, now at MIT. Perhaps as a result, it recommended that the railroads be required to have all bridges inspected biennially by a competent engineer with the reports, including plans and strain sheets, going to both the railroad and the commission, which was empowered to employ its own engineer. The legislature promptly obliged and the commission employed George Swain, another MIT engineer, to inspect bridges and go over the carriers' plans and strain sheets. In addition, the board again sent out a circular, urging the carriers to choose one of the various systems of bridge floors and guards that it described. As in New York and Vermont, the new procedures apparently generated some spectacular results, although Massachusetts, in a gesture the carriers no doubt appreciated, did not publish individual inspection reports. However, in his yearly statements to the board, Swain reported a sharp increase in the number and quality of bridge guards and a very general upgrading in many bridges. In the early 1880s, Massachusetts carriers spent an average of about $1.1 million a year on bridge repair and renewal; in 1888, the year after the Bussey Bridge fell in, they spent $1.8 million.[55]

The Decline in Bridge Failures

These efforts by engineers, regulators, and reformers to improve bridge safety gradually bore fruit. With the technical press and the state commissions in Massachusetts, Vermont, and Ohio strongly advocating better flooring, companies increasingly addressed the problem. Shortly after the disasters at Chatsworth, White River Junction, and Bussey, the *Railway Review* reported that "guard rails and re-railing devices are being more extensively employed." In 1893 *Engineering News* claimed "within the last few years there has been a decided tendency on the part of some of our larger railways to adopt solid floors, the ballast and roadways being continued on the bridge itself." By 1899 that journal claimed—with some overstatement— that "it is the exception to find a steam railway bridge or trestle which is not thoroughly protected by guard rails." In fact, reports to *Engineering News* in 1909 and to the American Railway Engineering Association from 1912 to 1914 reveal that use of guardrails, while widespread, was by no means universal. As usual, the reason was economic, as C. E. Smith, bridge engineer on the Missouri Pacific explained. That carrier had about 10,000 bridges and to guard all of them would cost $1,350,000, which at 6 percent resulted in an annual cost of $80,000, he calculated. Even if guard rails were to eliminate all wrecks, "the saving to the railway would not have equaled the increased interest charge and the Company would still be away behind on the investment," Smith claimed.[56]

Fire protection for wooden structures also improved as railroads experimented with fire-retardant paint and graveled floors. In this century, some carriers also experimented with signals that would warn if a bridge had burned or washed out, while others installed sprinkler systems on their trestles.[57]

In the 1890s, engineers abandoned light pin-connected truss bridges for short spans in favor of more heavily built, riveted structures. In 1904 one engineer admitted that "there can now be no question that the English engineers were pretty much in the right in their old contention in favor of riveted bridges—at least for spans of less than 200 feet, which cover the bulk of ordinary railroad structures." In part this reflected an acknowledgment that Stowell and other critics of American practice had been right: such bridges were inherently less safe than riveted structures. Another engineer writing in 1907 admitted "the pin-connected truss is ranked last [in degree of safety] . . . because of its greater flexibility . . . and the greater chance of failure through rupture of a single member."

But the exit of the bridges that Stowell decried was also hastened by largely independent changes in technology. The arrival of compressed-air field rivet guns sharply raised labor productivity and reduced the need for skilled riveters. And as iron and then steel prices fell, companies increasingly began to use steel-plate girders, which had become cheaper for spans of less than 100 feet and were nearly indestructible. Reinforced concrete also made its appearance and it, too, yielded safety gains. Many companies also simply replaced bridges and trestles with embankments. In 1901 A. S. Markley of the Chicago & Eastern Illinois recalled that fifteen years before washouts had been common, but that "we have been continuously renewing our trestles with permanent structures and ... in the past ten years I cannot call to mind that we have had a single washout." In addition, the spread of steam heat, better brakes, and steel passenger cars also pared the casualty list from disasters.[58]

Technological change also gradually reduced the domain of the old wooden Howe truss. Statistics for Illinois, Ohio, and Iowa reveal that from the 1870s to 1900, the number of wooden bridges declined slightly while iron and steel structures increased sharply. If the figures in Tables 1 and 2 are to be believed, metal bridges had about one-seventh the failure rate of wood. Thus it was not the introduction of steel, but rather the substitution of metal (and later concrete) for wood that was probably the most important improvement in bridge safety. Such a conclusion also throws the debate between Stowell and the advocates of pin-connected iron bridges in a different light. Stowell was surely right: pin-connected metal bridges were less safe than those that were riveted. But to the cost-conscious, light-traffic carriers of the 1870s, the alternative to pin-connected iron bridges was not a more expensive metal bridge, it was wood. Seen that way, pin-connected bridges improved safety because they speeded up the transition from wood to metal.

Management and operating practices also improved in response to disaster. In the late 1880s, one journal reported that "the railways have taken hold of the matter of inspection in a manner that is not generally appreciated." By this century, most large carriers ensured that each bridge received two separate types of inspection. They required "current inspections" quarterly or monthly by foremen or section hands to look out for routine maintenance and repair. A bridge engineer or someone with similar qualifications also conducted a "general inspection" of all bridges at least annually to check on maintenance and mark bridges that needed major upgrades or renewal. On the Northern Pacific, these reports employed forms containing forty questions covering all aspects of the structure.[59]

Beginning in the 1890s, these efforts contained the problem of bridge failures. Many companies described instances of derailments that did not become disasters due to improvements in floors and trusses, but the only available statistical evidence derives from the *Railroad Gazette*'s compilation, for the Interstate Commerce Commission accident statistics did not allow separate tabulation of bridge failures. The *Gazette*'s data, while providing an undercount, can be used to spot trends. They reveal an annual average of twenty-four bridge accidents during the five years between 1873 and 1877, rising to thirty-eight per year in the half decade 1888–1892, and then declining to twenty-five from 1896 to 1900, even as the number of train miles and bridges was sharply increasing. In this century these trends continued, and bridge disasters slowly faded from public consciousness (Fig. 12).

Conclusion

These efforts to improve bridge safety reveal much about both nineteenth-century American railroads and about engineering problems and their solution. In fact, the rise and decline of bridge failures as a "problem" was partly an outcome of the particular form in which the *Railroad Gazette* collected accident statistics, for they provided Stowell and other critics with ammunition. In this century, as the gathering of accident statistics shifted to the ICC, hard evidence on bridge disasters simply disappeared. The commission did collect information on collisions, however, and these were rising sharply. As a result, both the engineering press and public outrage shifted to these more pressing problems. Concern with bridge failures thus declined much more sharply than the failures themselves.

The failure statistics also demonstrate that it was not simply engineering error or rising train weight that caused bridges to fail. The decline in disasters, in turn, cannot simply be attributed to the professionalization of bridge engineering or to the use of steel or any other small set of causes. In fact, improvements in floors and inspection, the shift from wood to metal-riveted trusses and girders, and to reinforced concrete, all reduced the incidence of disaster, while better brakes and safer heating reduced the magnitude of the ensuing carnage.[60]

Fig. 12—Although bridge failures continued to plague railroad travel early in this century, their number declined. This 1912 collapse of an old wooden bridge killed at least one man. (Courtesy Vermont Historical Society)

The problem of bridge safety also demonstrates that while failure can be instructive, its teachings depend on how it is interpreted. The dominant concern of the ASCE was with engineering errors as a cause of bridge failures, and while some members strayed beyond this self-defined boundary, most refused to take responsibility for bridges that burned, rotted, or were knocked down. As George Thomson perceptively noted, their designs assumed that the worst would never happen. Such a construction of failure was, of course, professionally valuable to the newly emerging engineering community, for it focused on the errors of outsiders rather than their own design choices.[61]

Critics of established practice such as Stowell, Stauffer, Thomson, and Wellington took a somewhat broader view of failure and responsibility, arguing that pin-connected bridges with poor floor systems were in fact "pathological" design choices for which engineers bore responsibility. Yet the critics too constructed failure in a peculiar fashion. Stowell's focus led him to define both bridges and failures in such a way that he ignored Chatsworth, which was the "wrong" kind of bridge and White River Junction, which was the "wrong" kind of failure. Stauffer and Wellington, while willing to indict American practice with respect to bridge floors, never showed much enthusiasm for Stowell and Thompson's campaign against the pin bridge. Nor did any of the critics conclude that the lesson to be garnered from bridge fires was that wood made poor bridge material. Such failures were not seen as design flaws but as the result of inadequate inspection and maintenance.

Finally, virtually all contemporaries perceived bridge failures as the result of some form of error, no doubt from the need to see disaster as unplanned and to apportion blame. Such a focus obscures rather than illuminates. Unlike Ashtabula, most bridge disasters were not the result of blunders but rather the outcome of conscious choices that implicitly traded safety for economy. These involved wood vs. metal, reinforcement vs. greater initial strength, weak vs. heavy floors and approaches, complete vs. partial guarding, and pin vs. riveted connections. Such choices were not necessarily bad designs; rather, they reflected the economic forces that shaped nineteenth-century American railroading and were, as George Morison put it, "good engineering." □

Notes

[1]Based on Report of the Joint Committee of the Ohio Legislature, *Concerning the Ashtabula Bridge Disaster* (Columbus, 1877); Stephen Peet, *The Ashtabula Disaster* (Chicago, 1877); Ohio Railroad Commission, *Annual Report, 1877,* p. 22, lists the death toll as eighty-nine. Charles MacDonald, "The Failure of the Ashtabula Bridge," American Society of Civil Engineers (ASCE) *Transactions* 6 (1877): 74–87; "A Terrible Disaster," *New York Times*, 30 December 1876; "The

Lake Shore Disaster," *New York Times*, 31 December 1876; "The Ashtabula Calamity," *New York Times*, 1 January 1877. "The Ashtabula Bridge," *Railroad Gazette* 9 (23 February1877): 86–87. "Committee Report of the Ohio Assembly on the Ashtabula Bridge," *Engineering News* 4 (26 May 1877): 133. Cooper's remarks are in "On the Failure of the Ashtabula Bridge," *Engineering News* 4 (9 September1877): 240–241. For biographical information on Cooper, see *National Cyclopedia of American Biography*, vol. 19, and *Dictionary of American Biography*, vol. 3. A modern assessment concludes that the bridge collapsed due to fatigue failure in an angle block; see Jacob Feld and Kenneth Carper, *Construction Failure* (New York, 1997), pp. 136–137.

[2]"The Ashtabula Bridge," *Engineering News* 4 (20 January 1877): 19; "Wooden Trestles," *Engineering News* 18 (13 August 1887): 113; George S. Morison, "Advance in the Design of Bridge Superstructure," *Engineering News* 30 (27 July 1893): 80–81. On the evolution of American railroad bridges, see the following: Carl Condit, *American Building Art, the Nineteenth Century* (New York, 1960), chaps. 3–4; George Danko, "The Evolution of the Simple Truss Bridge 1790–1860: From Empiricism to Scientific Construction," Ph.D. diss., University of Pennsylvania, 1979; Llewellyn Edwards, *A Record of History and Evolution of Early American Bridges* (Orono, Maine, 1959); Henry Grattan Tyrrell, *Bridge Engineering*, 4th ed. (1911); J. A. L. Waddell, *Bridge Engineering* (New York, 1916), vol. 1; Charles Schneider, "The Evolution and Practice of American Bridge Building," ASCE *Transactions* 54 (1905): 213–234; Theodore Cooper, "American Railroad Bridges," ASCE *Transactions* 21 (1889): 1–59; Larry Kline and Anthony Thompson, "The Evolution of American Railroad Bridges, 1830–1994," in Anthony Thompson, ed., *Symposium on Railroad History* 3 (1994): 71–93.

[3]Morison (n. 2 above). For further comparisons of British and American bridge construction techniques, see also "Bridge Building in England and the United States," *Engineering News* 29 (15 December 1892): 572, and "Some Fundamentals of American Bridge Building," *Railroad Gazette* 31 (14 July 1899): 508.

[4]Cooper (n. 2 above). Cooper's contacts are revealed in box 1, file 1, of the Theodore Cooper Papers, Cornell University (hereinafter CPCU).

[5]J. Parker Snow, "Wooden Bridge Construction on the Boston & Maine Railroad," Association of Engineering Societies *Journal* 15 (July 1895): 31–39; Massachusetts Railroad Commission, *Twenty-Ninth Annual Report, 1897* (Boston, 1898), pp. 16–18.

[6]In "The Bridge Failures of Eleven Years," *Engineering News* calculated that there were 24,450 iron and 15,250 wooden bridges over 20 feet long in 1889. It excluded shorter spans as likely to be culverts, which were omitted from the accident statistics. Over the two years 1888–1889, there were eleven failures of iron bridges and forty-two failures of wood and unknown materials, which the *News* assumed to be wood. The implied annual failure rates are [11/24,450]/2 and [42/15,250]/2 or about one in 4,445 for iron and one in 726 for wood. In "Bridge Accidents in the United States and Canada in 1896," *Engineering News* 37 (11 February 1897): 93, Stowell estimated that for 1896, inclusion of trestles increased the number of failing wood structures by 36 percent. If these proportions held true in 1888–1889, the implied failure rate for wooden structures would be one in 534. Cooper's efforts are from Courney Boyle [Board of Trade] to Theodore Cooper, 12 January 1889, box 1, file 1, CPCU.

[7]Robert C. Reed, *Train Wrecks, A Pictorial History of Accidents on the Main Line* (New York, 1982), chap. 7, stresses collapses, although he also notes the range of ways in which bridges failed. Robert Shaw, *Down Brakes: A History of Railroad Accidents, Safety Precautions, and Operating Practices* (London, 1961), also stresses square falls. Henry Petroski, *Engineers of Dreams* (New York, 1995), emphasizes design errors in bridge failures.

[8]"Wooden Trestles," *Engineering News* 18 (13 August 1887): 113; Squire Whipple, *Bridge-Building; Being the Author's Original Work, Published in 1847, with an Appendix* ... (Albany, 1869); Herman Haupt, *General Theory of Bridge Construction* (New York, 1853?). For the metallurgical investigations of Fairbairn, Wöhler, and others, see Stephen Timoshenko, *History of the Strength of Materials* (New York, 1953), and Nathan Rosenberg and Walter Vincenti, *The Britannia Bridge: The Generation and Diffusion of Technological Knowledge* (Cambridge, Mass., 1978).

[9]Appleton, "Railroad Bridge Accidents," *Engineering News* 5 (21 February 1878): 59–61; W. H. Barlow, commenting on Thomas Clarke, "The Design Generally of Iron Bridges of Very Large Span for Railway Traffic," Institution of Civil Engineers *Proceedings* 54 (1877–1878): 179–247,

on 218; "A Criminal Structure," *Railway Review* 33 (4 March 1893): 130.

[10]"Rider's Iron Bridge," *American Railroad Journal* 21 (2 December 1848): 769, 775–776, contains the testimonial from Allen and Jervis. "Accident on the Erie Railroad," *American Railroad Journal* 23 (24 August 1850): 534; Squire Whipple, "Iron Bridges," *American Railroad Journal* 20 (27 November 1847): 754–755; Whipple, "The Breaking of the Iron Bridge on the New York and Erie Railroad," *American Railroad Journal* 23 (21 September 1850): 594–595; John A. Roebling, "The Breaking of Rider's Iron Bridge on the New York and Erie Railroad," *American Railroad Journal* 23 (28 September 1850): 609–610, emphasis in original. For a modern discussion, see Victor Darnell, "The Pioneering Iron Trusses of Nathanial Rider," *Construction History* 7 (1991): 69–81.

[11]Engine weight from J. E. Greiner, "What Is the Life of an Iron Bridge?" ASCE *Transactions* 34 (1895): 294–307. "Cheap and nasty" is from "Report of Committee Appointed by Western Society of Engineers [on Bridge Legislation] March 5, 1890," Association of Engineering Societies *Journal* 10 (November 1891): 517–525; "Heavy Bridges and Economy," *Railroad Gazette* 18 (1 December 1886): 674–675. See also C. M. Barber, "Old Bridges Under New Loads," Association of Engineering Societies *Journal* 5 (March 1886): 159–163.

[12]Albert Robinson,"Relative Cost of Heavy vs. Re-Inforced Bridges," *Engineering News* 30 (21 September 1893): 237–238.

[13]Central Railroad bridge from "Dangerous Railroad Bridges," *Engineering News* 14 (12 December 1885): 276–377. "Old Fink and Bollman . . ." from "Knocked Down," *Engineering News* 24 (22 August 1890): 173. The speaker to the ASCE is Greiner (n. 11 above), p. 296. The wreck is from "Bridge Failures in 1886," *Engineering News* 17 (30 April 1887): 287–288.

[14]Colburn's remarks are in the discussion of James Mosse, "American Timber Bridges," Institution of Civil Engineers *Proceedings* 22 (1862–1863): 305–326, on 319. For a bridge that collapsed as a result of poorly adjusted tension rods, see New York State Railroad Commission, *Second Annual Report, 1884* (Albany, 1885), pp. 207–210. For the Erie, see Wolcott C. Foster, *A Treatise on Wooden Trestle Bridges According to the Present Practice on American Railroads* (New York, 1891), pp. 80–82. "Form for Reports of Bridge Inspectors on the Buffalo, Rochester & Pittsburgh Railway," *Engineering News* 19 (12 May 1888): 380–381.

[15]Foster (n. 14 above), p. 4. Mansfield Merriman, "The Farmington Bridge Disaster," *Engineering News* 5 (31 January 1878): 39. For biographical details see *National Cyclopedia of American Biography*, vol. 23. For a more similar assessment, see also the reports of the civil engineer Albert Hill, "The Tariffville Disaster," *Railroad Gazette* 10 (25 January 1878): 41, and 10 (February 1, 1878): 52. The quotation is from "Verdict of the Coroner's Jury on the Tariffville Bridge Accident," *Railroad Gazette* 10 (1 March 1878): 109. See also Connecticut Railroad Commission, *Twenty-Sixth Annual Report, 1879* (Hartford, 1879), pp. 1–17.

[16]"The Chatsworth Disaster," *Engineering News* 18 (20 August 1887): 126–128, and "The Lesson of the Chatsworth Disaster," p. 131. For similar views about double-headers, see the untitled editorial *Railway Review* 27 (29 October 1887): 624–625. Air brakes are discussed in "The Chatsworth Disaster," *Railroad Gazette* 19 (August 10, 1887): 544–545.

[17]Charles Folsom, "Railroad Washouts," Association of Engineering Societies *Journal* 5 (June 1886): 304–309. Donald Jackson, "Nineteenth Century American Bridge Failures: A Professional Perspective," *Proceedings of the Second Historic Bridges Conference,* March 1988 (Columbus, 1988), pp. 113–125, states (p. 117): "Failures resulting from washouts could certainly be categorized as bridge collapses but they did not relate to the design or construction of the truss proper."

[18]This recounting is based on Dow Helmers, *Tragedy at Eden* (Pueblo, 1971).

[19]"The Chester Bridge Disaster," *Engineering News* 30 (7 September 1893): 192; quotations from "The Last Great Bridge Disaster," *Engineering News* 30 (7 September 1893): 195–196. Testimony at hearings to the Massachusetts Railroad Commission is in "The Chester Bridge Disaster," *Engineering News* 30 (14 September 1894): 219–221. See also "The Chester Bridge Disaster Finding," *Engineering News* 30 (28 September 1983): 255–256, and Massachusetts Board of Railroad Commissioners, *Twenty-Fifth Annual Report, 1893* (Boston, 1894), Appendix B.

[20]Ewing Matheson, "English vs. American Bridges," *Railroad Gazette* 6 (4 April 1874): 119–120. Of course, British railroad bridges did fall down occasionally; see, for example, Marion Pinsdorf, "Engineering Dreams into Disaster: History of the Tay Bridge," *Railroad History* 179 (autumn 1998): 89–116.

[21]Matheson (n. 20 above). The discussion of design is by W. Shelford and A. H. Shield, "On Some Points for the Consideration of English Engineers with Reference to the Design of Girder Bridges," British Association for the Advancement of Science *Report* 56 (1886): 472–482. The time of erection is from Edward Howland, "Iron Bridges and Their Construction," *Lippincott's Magazine of Popular Literature and Science* 11 (January 1873): 9–26.

[22]Matheson (n. 20 above). The quotation from *The Engineer* is from "A Lesson for American Bridge Engineers," *Engineering News* 31 (15 February 1894): 134.

[23]Charles Bender, "Comparison of the Merits of the Mode of Building Iron Truss Bridges in America with the System Used in Europe," *Railroad Gazette* 6 (11 April 1874): 129–130, 6 (18 April 1874): 139–140, and 6 (25 April 1874): 149–151. Forney's assessment is in "English Versus American Iron Bridges," *Railroad Gazette* 6 (25 April 1874): 152–153.

[24]Appleton (n. 9 above), emphasis in original.

[25]Donald Jackson (n. 17 above), blames knock-downs on the lack of guardrails and ignores the matter of pin vs. rivet construction, claiming that "the lack of these guardrails can certainly be considered a major engineering deficiency, but it does not relate to structural problems with the design" (p. 116).

[26]For the Norwalk disaster, see Charles Francis Adams, *Notes on Railroad Accidents* (New York, 1879); Vermont Railroad Commissioner, *Fourth Annual Report, 1859* (Rutland , 1859), p. 4; *Sixth Annual Report, 1861* (Rutland, 1861), pp. 6–9.

[27]Ohio Commissioner of Railroads, *Sixth Annual Report, 1872* (Columbus, 1873), pp. 34–36; *Seventh Annual Report, 1873* (Columbus, 1874), Appendix A. The Connecticut Commissioners are reported in "The Framingham [sic] Bridge Disaster," *Engineering News* 5 (24 January 1878): 26. The engineer's report is in "Field Notebook, 1877–1881," Records of the Railroad Commission, Record Group 41, Connecticut State Library. Vose's remarks from "Testing Railroad Bridges," *American Railroad Journal* 51 (2 March 1878): 302. For biographical information on Vose, see *Dictionary of American Biography,* vol. 19.

[28]The exchange of correspondence took place in 1888 at the time the bridge was built. It was later published in "A Remarkable Blunder in Bridge Construction," *Engineering News* 58 (19 September 1907): 317–318, the occasion being the collapse of the Quebec bridge, also a result of poor design.

[29]"On the Means of Averting Bridge Accidents," ASCE *Transactions* 4 (1875): 123–135, and "Discussion," pp. 208–222. The committee originally had ten members, but only seven signed the final reports. The committee's demise is recounted in "Minutes of the Twenty-Fourth Annual Meeting, November 1, 1876," ASCE *Proceedings* 2 (1877): 146–147.

[30]The cost to the Lake Shore is from an untitled editorial, *Engineering News* 17 (19 March 1887): 181. Boller is quoted in "On the Failure of the Ashtabula Bridge," *Engineering News* 4 (25 August 1877): 225–226. For the Ohio investigation, see note 1 above. Railroad Commissioner of the State of Wisconsin, *Fourth Annual Report, 1877* (Madison, 1878), pp. 14–23. Garfield's bill, H. R. 4538, was introduced in February 1877 and is noted in "On the Failure of the Ashtabula Bridge," ASCE *Transactions* 6 (1877): 202. "Field Notebook," Records of the Railroad Commission, Record Group 41, Connecticut State Archives.

[31]"The Ashtabula Bridge," *Engineering News* 4 (20 January 1877): 19; "Minutes of the Ninth Annual Convention, April 24–30, 1877," ASCE *Proceedings* 3 (1877): 45–46, and "Minutes of the Meeting of October 3, 1877," ASCE *Proceedings* 3 (1877): 86–88.

[32]The interaction between engineering journals and the technical press is revealed in Thomas C. Clarke, "Lowthorp on the Role of Cast and Wrought Iron in Bridge Construction," *American Railroad Journal* 43 (17 December 1870): 1405–1406, which is a critique of a paper presented to the ASCE. John Griffin and Thomas Clarke, "Loads and Strains on Bridges," ASCE *Transactions* 1 (1872): 93–105, note that many engineers still focused on the breaking strength of metal rather than the elastic limit. See also Octave Chanute, "Factors of Safety," *Engineering News* 7 (31 January 1880): 41–42. For a discussion of ways to treat live loads, see Henry Seaman, "The Launhardt Formula, and Railroad Bridge Specifications," ASCE *Transactions* 41 (1899): 140–165, and "Working Stresses for Railroad Bridges," *Railroad Gazette* 30 (4 November 1898): 797–798, which discusses Seaman's paper. See also E. Herbert Stone, "The Determination of the Safe Working Stress for Railway Bridges of Wrought Iron and Steel," ASCE *Transactions* 41 (1899): 466–502. For tests of impact, see "Report of Committee 15—Iron and Steel Structures," American Railway

Engineering Association (AREA) *Proceedings* 12 (1911): 12–300. On the use of standard train loads to proportion bridges, see Theodore Cooper, "Train Loadings for Railroad Bridges," ASCE *Transactions* 31 (1894): 174–219. Testing is discussed in B. L. Marsteller, "Inspection of Iron Bridges and Viaducts," Association of Engineering Societies *Journal* 8 (January 1889): 7–12.

[33]Isaac Hinckley to President, May 3, 1849, box 19, superintendent's letters, Providence and Worcester Railroad Collection, Dodd Research Center, University of Connecticut.

[34]For the early history of bridge contracting, see note 2 above. For some typical specifications, see "Western Union Railroad," *Engineering News* 5 (31 January 1878): 40, 47; "General Specifications for a Wrought Iron Railway Draw-Bridge . . . for the Chicago, Milwaukee & St. Paul Railway . . . ." *Engineering News* 6 (18 January 1879): 21–22; "General Specifications for Iron Bridges [on the Erie]," *Engineering News* 6 (31 May 1879): 174–175. Clarke (n. 32 above) contains specifications for the Cincinnati Southern and reports from consulting engineers on tests. Theodore Cooper, *General Specifications for Iron Railroad Bridges and Viaducts* (1884). For the influence of Cooper's specifications, see "Working Stresses for Railroad Bridges," *Railroad Gazette* 30 (4 November 1898): 797–798. "A Series of Failure Tests of Full-Sized Compression Members Made for the Pennsylvania Lines West of Pittsburgh," *Engineering News* 58 (26 December 1907): 685–695.

[35]George Vose, "Bridge Disasters in America—the Causes and the Remedy," *Railroad Gazette* 12 (25 June 1880): 339–341 and 12 (2 July 1880): 355–357; these later formed the basis of his *Bridge Disasters in America* (Boston, 1887). For Vose's attack on King's highway bridges, see his "Dangerous Highway Bridges," *Engineering News* 6 (18 January 1879): 20–21, 6 (1 February 1879): 37–38, and 6 (February 8, 1879): 45–46; and "Factors of Safety, Danger, and Ignorance," *Engineering News* 7 (17 January 1880): 23–24. See also David Simmons, "Bridge Building on a National Scale: the King Iron Bridge and Manufacturing Company," *IA: The Journal of the Society forIndustrial Archeology* 15 (January 1989): 23–39.

[36]New York Board of Railroad Commissioners, *First Annual Report, 1883* (Albany, 1884), pp. 296–301; *Second Annual Report, 1884* (Albany, 1885), pp. xix-xxi; "State Bridge Inspection in New York," *Engineering News* 17 (30 April 1887): 284–285; Ohio Commissioner of Railroads, *Twelfth Annual Report, 1878* (Columbus, 1879), 21; Massachusetts Board of Railroad Commissioners, *Nineteenth Annual Report, 1887* (Boston, 1888), p. 38.

[37]For biographical information on Stowell, see *Who Was Who*, vol. 1. The quotation is from "State Bridge Inspection in New York," *Engineering News* 17 (30 April 1887): 284–285.

[38]*Report of the Railroad Commissioners of the State of New York on Strains on Railroad Bridges of the State* (Albany, 1891).

[39]For New York Central bridges, see George Gray, "Notes on Early Practice in Bridge Building," ASCE *Transactions* 37 (1897): 1–15. The *Gazette* began collecting such statistics in 1873. Howard Miller, "Truss Failures Reconsidered," *Technology and Culture* 22 (October 1981): 849–850, argues that it missed many bridge failures, basing his claim on the criticisms contained in several articles in *Engineering News*. Miller apparently failed to note "The Railroad Gazette Accident Record," *Engineering News* 17 (7 May 1887): 303, in which Stowell claimed to have "found the *Gazette's* tables to be generally reliable," and the journal's editors apologized to the *Gazette* for their erroneous criticism. In fact, users of the *Gazette's* statistics often missed bridge failures because they were listed by cause of train accident. For a comparison with Interstate Commerce Commission accident statistics, see "Our Accident Statistics," *Railroad Gazette* 22 (13 June 1890): 419–420.

[40]"Light Bridges and Bridge Accidents," *Railroad Gazette* 18 (5 November 1886): 755.

[41]For Wellington's career, see *National Cyclopedia of American Biography*, 11:168–170, and "Arthur Mellen Wellington," *Engineering News* 33 (23 May 1895): 337–338.

[42]A deck truss carries the tracks on the top chord.

[43]"The Facts in Regard to the Woodstock Disaster," *Engineering News* 17 (12 February 1887): 105–106; Vermont Board of Railroad Commissioners, *First Biennial Report, December 1, 1886–June 30, 1888* (Boston, 1888), pp. 91–100. The campaign to ban stoves may be followed in the pages of the railroad and engineering press and in reports of state railroad commissions.

[44]*Second Biennial Report, June 30, 1888 to June 30, 1890* (Burlington, 1890), pp. 105–121, quotation on 106.

[45]*Third Biennial Report, June 30, 1890 to June 30, 1892* (Burlington, 1892). The Central Vermont is noted in *Fourth Biennial Report, June 30, 1892 to June 30, 1894* (Rutland, 1894), pp. 40–41.

The quotation is from *Fifth Biennial Report, June 30, 1894 to June 30, 1896* (Rutland, 1896), pp. 13–15.

[46]Untitled editorial, *Engineering News* 17 (12 February 1887): 108. Indeed, Latimer had patented the device ("The Latimer Safety-Guard Patent," *Engineering News* 17 [May 7, 1887]: 199), but, as the editors pointed out, the same result could be easily achieved without fear of infringement.

[47]For early evidence of concern with inadequate flooring, see "Railroad Bridges," *American Railroad Journal* 26 (10 September 1853): 582, which complains about the "want of side protection." Massachusetts Board of Railroad Commissioners, *Thirteenth Annual Report, 1881* (Boston, 1882), Appendix F; Ohio Commissioner of Railroads, *Annual Report, 1884* (Columbus, 1885), pp. 182–183; "The Best Safeguard Against Woodstock Disasters," *Engineering News 17* (12 February 1887): 112–113.

[48]"Some Strong and Weak Points in Railroad Bridges," *Engineering News* 17 (12 March 1887): 170–171.

[49]For a partial listing, see "All at Once and Nothing First," *Engineering News* 18 (3 November 1887) 171; "Inside and Outside Guard Rails," *Engineering News* 19 (28 January 1888): 60–61, 64–65; "Fall of the Apple River Bridge," *Engineering News* 19 (31 March 1888): 248 (which contains the quotation); "A Riveted Bridge in a Collision," *Engineering News* 19 (14 April 1888): 298; "The Flat Creek Trestle Disaster," *Engineering News* 22 (31 August 1889): 198–199; "Knocked Down," *Engineering News* 24 (23 August 1890).

[50]George H. Thomson, "American Bridge Failures: Mechanical Pathology Considered in Relation to Bridge Design," *Engineering* 48 (14 September 1888): 252–253, 294.

[51]Cooper (n. 2 above), pp. 50–51.

[52]Discussion of Cooper (n. 2 above), pp. 589, 592, and 598.

[53]"The Consequences of a Cow," *Engineering News* 17 (11 June 1887): 377. The second quotation is from "Fall of the Apple River Bridge" (n. 49 above).

[54]Untitled editorial, *Engineering News* 17 (19 March 1887): 188; "The Second Ashtabula Disaster," *Engineering News* (19 March 1887): 189–192. The strain on the hanger is from A .G. Robbins, "The Bussey Bridge," *Technology Quarterly* 1 (September 1888): 68–72. "The Second Contributing Cause to the Bussey Bridge Disaster," *Engineering News* 17 (30 April 1887): 285–287. "The Testimony as to the Brakes at the Fall of the Bussey Bridge," *Engineering News* 17 (30 April 1887): 289. Massachusetts Board of Railroad Commissioners, *Nineteenth Annual Report, 1887* (Boston, 1889), 26–28, 38–52, and Appendix C.

[55]"Precaution Against Accident," *Railway Review* 54 (8 October 1887): 583; "Trenton Falls Bridge, Adirondack and St. Lawrence Railroad," *Engineering News* 29 (13 April 1893): 344; untitled editorial, *Engineering News* 42 (10 August 1899): 88; "Guard Rails and Deck Construction for Railway Bridges," *Engineering News* 62 (9 September 1909): 270–276. The surveys are in "Report of Committee 7—On Wooden Bridges and Trestles," AREA *Proceedings* 14 (1913): 652–676; 1136–1143, quotation on 1138, and 15 (1914): 402–405.

[56]For a well-documented instance where a bridge guard averted disaster see "Report of Committee 7—On Wooden Bridges and Trestles," AREA *Proceedings* 14 (1913): Appendix H. "Train Accidents in 1900," *Railroad Gazette* 33 (15 February 1901): 112–113. In 1896, Stowell (n. 6 above) found twenty-nine bridge accidents, or about as many as occurred in the mid-1880s; but, with more bridges in 1896, the rate of failure must have been lower. ICC *Accident Bulletins* do not separate bridge failures from other forms of accident until 1917.

[57]"Special Signal to Indicate Fires or Washouts at Railway Trestles," *Engineering News* 59 (9 April 1908): 398–399. For use of sprinkler systems, see "The 'Practical' in Conflict with the 'School' Idea and an Illustration from a 24-Mile Mountain Railway," *Engineering News* 62 (16 September 1909): 311–312, and "How the Southern Pacific Protects Timber Bridges From Fire," *Railway Maintenance Engineer* 22 (February 1926): 54–55.

[58]"Progress in Bridge Building," *Railway Review* 44 (June 30, 1904): 556–557. A. J. Himes, "On Classification of Existing Bridges," AREA *Proceedings* (1907): 361–375, on 364. "Two Large Plate Girder Railway Bridges," *Engineering News* 51 (18 February 1904): 166–167. For bridge building techniques at the turn of the century, see Charles Fowler, "Some American Bridge Shop Methods," and "Machinery in Bridge Erection," *Cassier's Magazine* 17 (January and February 1900): 200–215 and 327–344. Markley's remarks are in "Report of Committee 7—Bridges and Trestles," AREA *Proceedings* 2 (1901): 172–173.

[59]Quotation from "Precaution Against Accident," *Railway Review* 27 (8 October 1887): 583. "Methods of Making Annual Inspections of Bridges and Culverts," *Engineering News* 50 (29 October 1903): 394–395. See also B. W. Guppy, "On Maintenance of Existing Metal Bridges," AREA *Proceedings* 8 (1907): 369–375, and E. H. McHenry, *Engineering Rules and Instructions, Northern Pacific Railway* (New York, 1899), chap. 5.

[60]Jackson (n. 17 above), also notes that improvements in bridge safety were not simply the result of engineering professionalization or the shift to steel.

[61]That failure is instructive is argued by Henry Petroski, *To Engineer Is Human: The Role of Failure in Successful Design* (New York, 1992).