National Transportation Safety Board
Washington, DC 20594

Highway Accident Brief

Accident No.:	HWY-04-MH-023
Accident Type:	Passenger vehicle collision with a fallen overhead girder
Location:	Eastbound on Interstate 70 at the Colorado State Route 470 overpass, Golden, Colorado
Date and Time:	May 15, 2004; 10:04 a.m., mountain daylight time
Vehicle:	2002 Dodge Durango
Injuries:	3 fatal

Accident Description

On May 15, 2004, about 10:04 a.m., mountain daylight time,[1] a 2002 Dodge Durango sport utility vehicle (SUV) driven by a 34-year-old man eastbound on Interstate 70 (I–70) approached the Colorado State Route 470 (C–470) overpass.[2] The driver's 37-year-old wife and their 2-year-old child were also in the SUV. The interchange of I–70 and C–470 was in a temporary traffic control zone for a highway construction project, during which an additional entry ramp and two additional lanes were being constructed for the overpass.

As the SUV approached the overpass, a fabricated steel girder line composed of two joined sections, which had been erected during the evening of May 11 through the early morning hours of May 12, 2004, parallel to the existing overpass, as a part of the bridge-widening project, rotated toward the overpass and sagged into the I–70 eastbound lanes. The girder struck the SUV about half the distance between the vehicle's front end and its windshield and sheared off the vehicle's top. The lower portion of the SUV continued east for 818 feet, coming to rest in the grassy median of I–70. All three vehicle occupants were killed. (See figures 1 and 2.)

[1] Unless otherwise noted, all times in this document are mountain daylight time.

[2] Structurally, an overpass is a bridge.

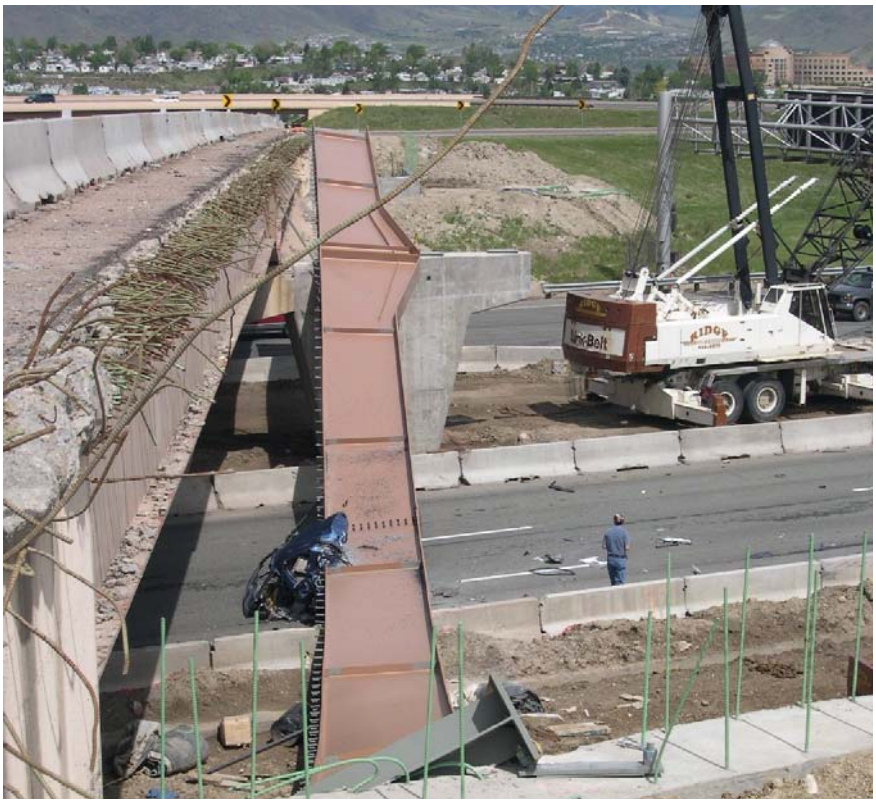

Figure 1. Fallen girder and top portion of the accident vehicle on I–70 (looking north). The C–470 bridge/overpass being widened is to the left of the fallen girder in this photograph.

Figure 2. Overhead view of the accident scene, showing the C–470 bridge and fallen girder. (Photo source: Jefferson County Sheriff's Office)

Construction Project

Before May 11, 2004

The Federal Highway Administration (FHWA) and the State of Colorado funded the I–70/C–470 interchange construction project, which was intended to improve traffic capacity and safety at the interchange of these two routes and to make additional improvements along I–70 in this area. As a part of the project, the overpass of I–70 by C–470 was to be widened by adding two lanes. An additional loop ramp was also to be constructed. Under the terms of the stewardship agreement between the FHWA and the Colorado Department of Transportation (CDOT), CDOT was managing the project[3] and had contracted with Asphalt Specialties, Inc., to perform the actual construction work. Asphalt Specialties had been the general contractor for numerous projects in Colorado for CDOT and other agencies.

CDOT prequalified Asphalt Specialties as the prime contractor[4] for this project. The prequalification process is governed by the Colorado rules of prequalification and can be found in the *Rules for Prequalification, Debarment, Bidding, and Work on Colorado Department of Highways' Road, Highway, and Bridge Public Projects*.[5] In these rules, prequalification is defined as follows:

> The process of review by CDOT of a contractor's fiscal and workmanship qualifications to perform work on public projects through which CDOT determines whether the contractor will be permitted to submit bids as provided in these rules. (See 2 *Code of Colorado Regulations* 601-10, Section 1.03(ff).)

These Colorado rules require the potential prime contractor to file a prequalification application and questionnaire with the CDOT staff construction engineer or designee. To complete the prequalification application, the prime contractor must (among other requirements) indicate its previous experience in highway construction work, detail the number of years' experience in various types of highway work, and list all construction contracts, both highway and nonhighway, performed in the past 3 years.

One of the purposes of prequalification is to ensure that the contractor is technically proficient in performing highway construction. Proficiency entails the contractor having had recent relevant experience and being familiar with standard highway construction regulations, specifications, and guidelines, such as those issued by

[3] The purpose of the stewardship document was to set forth an agreement between CDOT and the FHWA Colorado Division Office regarding their respective roles and responsibilities in administering the Federal-aid highway program in Colorado. This stewardship agreement outlined the project approval authorities that CDOT and the FHWA agreed upon in accordance with 23 *United States Code* 106. Under the agreement, CDOT project-level oversight included its taking over FHWA responsibilities for all reviews and approvals associated with the design and construction, including final inspection, of Federal-aid projects.

[4] CDOT refers to the contractor responsible for engaging and monitoring subcontractors as the "prime" contractor.

[5] Additional information may be accessed at <http://www.dot.state.co.us/Bidding/index.htm>.

the FHWA, CDOT, and the American Association of State Highway and Transportation Officials (AASHTO).[6]

Asphalt Specialties subcontracted with steel erection firm Ridge Erection Company, Inc., (Ridge) to erect the three new girders needed to widen the C–470 bridge. The FHWA and CDOT permit up to 70 percent of a project's work to be done by subcontractors, pursuant to 23 *Code of Federal Regulations* (CFR) 635.116. According to the Colorado prequalification rules, CDOT is not required to prequalify subcontractors on its projects,[7] and CDOT did not prequalify Ridge. CDOT records show that between 1987 and 1990, Ridge erected bridge girders on nine CDOT projects. According to Ridge records, in the 14 years preceding the accident, Ridge had not worked on any highway bridge projects.

For the bridge-widening project, three complete girders, each composed of three separate sections, were to be installed east of the existing C–470 bridge deck. Initially, only the first two sections were to be set for each of the first two girders. The third sections, completing these girders, were to be installed and spliced to these two-section girder lines at a later date. Each two-section girder line was to be cantilevered over the center pier for the bridge expansion.

The girder installation work that ultimately led to this accident was the subject of a March 24, 2004, planning meeting, which was attended by representatives from CDOT, Asphalt Specialties, and Ridge.[8] According to Ridge representatives,[9] at this meeting, Ridge officials said they planned to set 2 two-section girder lines to the east side of the C–470 bridge during the evening of May 11 through the early morning hours of May 12, 2004. (The two-section girder lines will henceforth be referred to as "girders.")

According to Ridge, to install the two girders, workers were to use cranes to pick up the first girder's two sections, splice them together while they were held in the air by the cranes, and then set the first girder in place parallel to the C–470 bridge deck. Next, while being held by the cranes, the first girder was to be braced to the existing C–470 bridge deck with angle-shaped steel braces ("angle irons") bolted to the new girder and attached to the paved bridge deck with expansion bolts. (See figure 3 for a photograph of an angle-shaped steel brace.) Once it was temporarily braced in this manner, the first girder would be released from the cranes. Then, the second girder would be installed the same way, and, once it was in place, the two girders would be cross-braced with diaphragms[10] to stabilize them. Ridge said that if only the first girder could be erected

[6] AASHTO is a nonprofit, nonpartisan association representing highway and transportation departments in the 50 States, the District of Columbia, and Puerto Rico. AASHTO documents are used as reference and guidance materials by State highway and transportation departments.

[7] Safety Board staff contacted 15 randomly selected State departments of transportation or highways to determine how other States address the qualifications and competence of subcontractors. Of the 15 States contacted, 5 required prequalification of subcontractors.

[8] No written documentation was made of the meeting. All information is based on Safety Board investigators' postaccident interviews with meeting participants.

[9] Including Ridge's vice president.

[10] A *diaphragm* in this usage is a system of cross braces between two or more parallel girders.

that night, it intended to stabilize the single girder by connecting it to the existing C–470 bridge deck with the angle braces, in the manner described above for the temporary bracing to keep one girder in place, and erection of the second girder would continue the following night.

Figure 3. Postaccident photograph of one of the angle-shaped steel braces used to brace the accident girder.

Ridge officials stated that the Ridge safety officer developed the bracing plan for a single girder and made a non-scale, hand-drawn sketch of it. The Ridge safety officer had been a Ridge employee for more than 20 years, initially as an ironworker (holding positions that included foreman, general foreman, and superintendent), and eventually was named safety officer in 1998. He had no training or certification in engineering. No copy of his bracing plan sketch could be provided to the Safety Board after the accident.

Attendees recalled little discussion of the temporary bracing at the March 24 meeting.[11] The Ridge safety officer characterized the talk concerning the temporary

[11] After the accident, Ridge officials told Safety Board investigators that, in preparation for the erection, it had proposed three bracing methods, including using permanent diaphragms between the new girder and the existing C–470 bridge. Ridge stated that it also suggested using temporary cross braces bolted or welded to the existing bridge. Ridge stated that it was told that the diaphragms had not been designed and fabricated yet and that it could not attach cross braces to the existing bridge web with bolting or welding, even if they were temporary and later removed. Consequently, Ridge stated that it had to use its third alternative, bolting angle braces to the top deck of the C–470 bridge roadbed.

bracing as a brief discussion of 3 to 5 minutes' duration. The CDOT project engineer stated that he did not recall any specific discussion of the bracing, but he thought it might have been mentioned "in passing." The CDOT inspector said he did not recall any discussion of the temporary bracing but could not say that it was not discussed. Asphalt Specialties' general superintendent and traffic control supervisor said that few details were discussed with respect to the bracing plan. They recalled no drawings of any kind being presented. The Asphalt Specialties concrete structural superintendent recalled that angle braces were mentioned with respect to the temporary bracing. He had no recollection of any discussion concerning "X" bracing (cross bracing between two girders) or a plan to secure a single girder to the existing bridge structure. The Asphalt Specialties project manager stated that the temporary bracing was briefly discussed, and he recalled that CDOT officials told Ridge representatives that they could not weld to the existing structure. He said that a few ideas were discussed, but nothing was decided about how the bracing was to be accomplished.

The contract for the C–470 bridge-widening project did not require that the contractor or subcontractor submit plans for the erection of the girders or the girder bracing. CDOT did not request, and neither the contractor nor the subcontractor prepared, a formal design or plan for the erection of the girders or the girder bracing.

No Registered Professional Engineer[12] reviewed or was otherwise directly involved in Ridge's plans. A Registered Professional Engineer must be registered as a qualified engineer in the State. According to the Colorado State statute for registration of engineers,

> In order to safeguard life, health, and property and to promote the public welfare, the practice of engineering is declared to be subject to regulation in the public interest. It shall be deemed that the right to engage in the practice of engineering is a privilege granted by the state through the state board of licensure for professional engineers and professional land surveyors, created in section 12-25-106; that the profession involves personal skill and presupposes a period of intensive preparation, internship, due examination, and admission; and that a professional engineer's license is solely such professional engineer's own and is nontransferable. (12-25-101.)

On May 5, 2004, Ridge and Asphalt Specialties held a meeting at the construction site to discuss the placement of cranes. On May 10, they held a meeting to make a final check of the crane pads and cranes. According to CDOT, it was never notified of these meetings, and no one from CDOT attended either meeting.

May 11 to 12, 2004

The task of erecting the two girders over I–70 parallel to the C–470 bridge deck was scheduled to take place from 9:00 p.m. on Tuesday, May 11, until 5:00 a.m. on Wednesday, May 12. During this 8-hour period, I–70 was to be closed to allow the girder

[12] The terms "Professional Engineer," "Registered Engineer," and "Registered Professional Engineer" are used interchangeably in the construction industry.

erection equipment (including cranes) access to the east- and westbound lanes and median of I–70. This roadway had average traffic of about 76,000 vehicles per day. During the work period, traffic was to be routed onto a series of frontage and paralleling routes west of the work site. The Colorado State Patrol had a patrol car positioned near the I–70 closure area to slow traffic.

Work began about 9:00 p.m.,[13] as scheduled. Present at the work site were CDOT's project engineer, two inspectors, and a senior executive service engineer (this individual left about 12:30 a.m. and did not return that night). Four Asphalt Specialties supervisors and three workers were on scene, as were two Ridge supervisors and eight workers.

Between about 9:00 p.m. and 11:00 p.m., Ridge workers positioned the cranes and moved the girder sections into place for lifting with the cranes. The weight of one girder section was approximately 20,000 pounds or 10 tons, and two girder sections spliced together weighed approximately 40,000 pounds or 20 tons. With two sections spliced together, each girder was approximately 204 feet long. The distance from the south abutment to the center bridge pier for the expansion was approximately 154 feet, and a two-section girder would be cantilevered over the center bridge pier and extend beyond the pier by about 50 feet.

Between about 11:00 p.m. and 12:30 a.m., Ridge employees began raising the girder sections, and they encountered problems. Ridge did not have impact wrenches or similar tools to facilitate removal of the numerous shipping bolts[14] on the girder sections. Consequently, workers had to use hand tools to remove these bolts. A cutting torch was needed to remove some of the shipping bolts.

According to the CDOT lead inspector, after Ridge workers had lifted the two sections of the first girder with cranes and were attempting to splice them while the sections were suspended in air, he noticed that one of the two sections was backward. According to Ridge, the fabricator's drawing indicated that a piece mark was located on what was to be the north end of the girder section for the project. The permanent piece mark was stamped into the steel section, consistent with the fabricator's drawing; however, the fabricator had painted over[15] this stamped piece mark. When the Ridge workers checked the section, they found hand-applied alphanumeric characters, which are used to identify the section, on the end opposite from the piece mark. They mistakenly used these alphanumeric characters to position the section, and as a result, raised it backward.

[13] All times indicated as referring to tasks and events that took place the night of the girder erection are rough estimates, based on the sometimes conflicting recollections of witnesses, all of whom were recalling incidents that had taken place at least several days earlier. The sequence of events is generally not in dispute, but the times at which they took place sometimes differed from one witness's account to another's.

[14] Shipping bolts are used to attach the splice plates to the girder for shipment from the shop to the construction site. The shipping bolts had to be removed before the bolts needed to join the two sections could be inserted.

[15] It is standard industry practice to paint girders.

The CDOT lead inspector informed the workers of the mistake, which meant that the backward girder section had to be rotated 180 degrees before the two sections could be spliced. He said he had some difficulty persuading the Ridge workers that the section was backward, but they ultimately agreed and reversed the section. Sometime between midnight and 1:30 a.m. (witness accounts concerning the time vary considerably), the mid-air splicing process resumed. The CDOT lead inspector estimated that the splicing would take until about 4:00 a.m. to complete.

Those on the C–470 bridge work site realized that they would not have time to erect the second girder before I–70 was scheduled to reopen at 5:00 a.m.[16] Consequently, the Ridge crew had to postpone this task and intended to perform it on the next night.

During the approximately 4 hours that the girder sections were being bolted together, the CDOT lead inspector and project engineer left the C–470 bridge site and drove to another work site for this project to look at repairs being performed by another work crew. They also stopped by an area of the traffic detour where, between about 11:00 p.m. and 1:00 a.m., an eastbound tractor-semitrailer truck driver had mistakenly driven down an exit ramp from I–70 and then eastbound in the westbound lanes, where workers were in the roadway. (No accident resulted from the truck's incursion into the work zone.) According to the CDOT lead inspector, they returned to the C–470 bridge site about 4:00 a.m.

About 3:45 a.m. to 4:00 a.m., Ridge workers began installing bracing to temporarily stabilize the single girder. They intended to install five angle-shaped steel braces to connect the single girder with the edge of the deck on the existing C–470 bridge. (See figure 4.) The braces were fabricated on site. To bend the braces, workers used a cutting torch to cut one leg of each brace (except the third brace, which was not cut). They also used torches to cut circular holes in the braces for the expansion bolts that would connect them to the bridge deck. Postaccident examination showed that these cutting procedures reduced the cross section of the braces by about half.

[16] After the accident, CDOT and Asphalt Specialties personnel questioned whether it would have been feasible, even had time not been lost due to removing the shipping bolts with hand tools and repositioning the backward girder section, to have installed two girders in one night.

Figure 4. Diagram overlaid on photograph to show the accident girder and five braces in relation to the existing C–470 bridge deck. Note that this graphic is representative only of the approximate relative positions of the girder, bracing, and deck.

Bolts were to be used to connect the girder to the braces, and expansion bolts were to be used to connect the braces to the bridge deck. When Ridge's workers bored holes in the bridge deck and attempted to install expansion bolts in them, they found that the bolts they had on hand were too long for the bridge deck holes.[17]

The existing C–470 bridge deck was composed of Portland cement concrete. As originally designed and constructed, the bridge deck had an asphalt overlay that measured from 1.7 to 3 inches thick at the expansion bolt locations. The Portland cement concrete bridge deck was in good condition. Its thickness was about 8.25 inches. The asphalt

[17] The CDOT lead inspector stated that he watched Ridge's bolting activities from a position on I–70 and that he could "hear and see the drilling and hammering" of the bolts.

overlay was generally in poor condition at the edge of the bridge deck, near where the expansion bolts for the bracing were to be inserted. The overlay had deteriorated and had been damaged by prior construction activity to remove the existing bridge rail at the edge of the bridge deck, in preparation for the bridge widening.

After workers made several unsuccessful attempts to make the bolts connecting the braces to the deck work, an employee was dispatched to the Ridge shop[18] about 4:30 a.m. to acquire different expansion bolts. These new bolts were put in, completing the girder bracing, and I–70 was reopened a half hour later than planned, about 5:30 a.m.

In a postaccident interview, the CDOT project manager stated that he believed no one on the construction site thought the accident girder was unsafe when the crew left it. He said, "If there was a known safety problem, the road could have been closed longer." He also said they could have kept the cranes attached to the girder if it had been considered unsafe.

Aside from the CDOT lead inspector who pointed out that Ridge was attempting to splice two sections of girder with one section backward, the CDOT construction supervisors did not question the adequacy of the subcontractor's work on the C–470 bridge project during the night. No one from CDOT or Asphalt Specialties objected to the lack of a written bracing plan or to the means used to install the bracing.

See table 1 for a timeline of the activities that took place during the girder erection and bracing installation processes.

Table 1. Timeline of activities related to erection and bracing of the accident girder. (Note: All times and time ranges are estimates based on the majority of witness statements.)

Time	Actions
May 11, 2004	
9:00 p.m.	I–70 is closed and traffic is rerouted to accommodate highway bridge construction; work begins at C–470 bridge work site
9:00–11:00 p.m.	Ridge personnel position cranes and girder sections for raising the sections
Sometime between 11:00 p.m. and 1:00 a.m.	A tractor-semitrailer truck mistakenly enters the work zone (no accident occurs)
11:00 p.m.–1:30 a.m.	Ridge workers raise two girder sections, using cranes, and remove shipping bolts from them CDOT lead inspector notices that one girder section is backward; he notifies Ridge personnel of this problem; following discussion about this issue, Ridge eventually rotates the girder section 180 degrees

[18] The Ridge shop was about 10 miles away.

May 12, 2004	
12:00–1:30 a.m.	CDOT senior executive service engineer leaves the work site for the night; CDOT lead inspector and project engineer leave the C–470 bridge site to visit another project-related work site
12:30–4:00 a.m.	Ridge workers splice the two girder sections while the sections are suspended in mid-air
4:00 a.m.–5:15 a.m.	Ridge workers brace the single girder to the existing bridge deck—this process involves cutting and bending the angle braces and bolting the braces to the girder and the bridge deck
4:00–4:30 a.m.	CDOT lead inspector and project engineer return to the C–470 bridge site; Ridge workers have trouble bolting expansion bolts to deck
4:30–4:45 a.m.	A Ridge worker is sent to the Ridge shop to acquire different expansion bolts
5:00–5:30 a.m.	Ridge finishes installation of the temporary bracing for the accident girder; I–70 is reopened for normal traffic; CDOT construction supervisors leave site

From May 12, 2004, Until the Accident

The work crew intended to install the second girder on the following night. No one on scene in the early morning hours of May 12 checked the weather forecast to determine whether conditions would be favorable for such work that night. As of 4:11 a.m., May 12, the National Weather Service forecast for the area called for temperatures in the mid-30s° F, winds of 15 to 20 mph, and likely precipitation for the evening of May 12. This forecast indicated that expected weather conditions were not favorable for installation of the second girder that night. The extended weather forecast showed that precipitation and low temperatures in the 30s° F were expected for several nights to come. Winds of 15 to 20 mph were predicted for May 14. Ultimately, Asphalt Specialties and Ridge postponed the completion of the girder installation for more than 3 days.[19]

After work was concluded on the morning of May 12, an Asphalt Specialties project supervisor did check the weather forecast and became concerned about the possible effects of the wind on the temporarily braced single girder. He said he returned to the site about 8:45 p.m. on May 12 and inspected the girder and its bracing.[20] He found nothing wrong with the installation. (He later said that he may not have noticed a small angle of deflection of the girder.) No one involved with the project periodically inspected the girder or its bracing following the May 12 installation.

[19] Until the accident occurred on the morning of May 15.

[20] U.S. Naval Observatory data show that the end of "civil twilight" occurred at 8:36 p.m. on May 12, 2004. Civil twilight refers to the period during which twilight illumination is sufficient, under good weather conditions, for terrestrial objects to be clearly distinguished.

On May 13, a traveler driving westbound on I–70 incidentally made a digital image of the accident girder through the car's windshield. After the accident, Safety Board investigators examined this image and found that it indicated that at this time the accident girder appeared to be leaning toward the existing bridge deck by about 5 degrees between the south abutment and the center bridge pier for the extension and by about 1 degree beyond the center bridge pier. (See figure 5.)

Figure 5. Portion of photograph taken by driver on May 13, 2004, while accident girder was in place over I–70. Photo has been cropped and enlarged to show area of interest; guidelines indicating vertical alignment (yellow) and estimated angle of lean of girder (blue) have been added.

On May 14, two travelers westbound on I–70 separately noticed anomalies involving the girder but did not report them. The first, who passed under the C–470 overpass about 1:30 p.m., later stated that the girder appeared to have been "tilted." The second traveler, who made the observation about 8:30 p.m., indicated postaccident that the girder had been "leaning" toward the bridge.

On the morning of May 15, two I–70 travelers, one about 8:00 a.m. and the other about 8:30 a.m., noticed irregularities in the girder's position. Neither reported the observations until after the accident. The first traveler noted that the girder was leaning toward the bridge. The second saw a "wave" in the girder.

At 8:49 a.m. on May 15 (about 75 minutes before the accident), a traveler on I–70 called 911 to report that the girder was "twisted." The caller reached the Jefferson County Sheriff's Office, which transferred the call to the Colorado State Patrol dispatcher. The

dispatcher evidently misunderstood a term the caller used in his statement and, when repeating the message to the caller, indicated that a sign was involved. The caller confirmed the dispatcher's restatement of the message, including the erroneous information that a sign was involved. The report was misinterpreted to involve a "damaged sign" on I–70; this was the message CDOT received about 9:00 a.m. CDOT dispatched two highway maintenance workers (each in a separate truck) in response. They located a leaning sign on the C–470 overpass (adjacent to the new construction) and assessed its condition. They then notified the Colorado State Patrol that the problem sign had been found, that it was not interfering with traffic, and that it would be fixed in the next few days. They returned to the CDOT equipment shed and had been there for about 15 minutes when they were told that the accident had occurred.

About 9:00 a.m., a CDOT bridge engineer (not involved with this project) was exiting northbound C–470 onto eastbound I–70. While traveling roughly parallel to the accident girder, this CDOT employee observed that the girder was "buckled toward the existing bridge," but she did not notify anyone. She later said that she did not know whether the girder's condition was abnormal. At the time of the accident, CDOT had an emergency call list in place for use by its staff, and CDOT periodically updated this list. However, the bridge engineer said she did not know whom she should call.

Accident reconstruction[21] indicated that the Dodge Durango SUV was traveling approximately the posted speed limit of 65 mph as it approached the C–470 overpass about 10:04 a.m. About that time, the temporarily braced and unstable girder rotated toward the overpass and sagged into the path of the oncoming vehicle. The girder struck the SUV, killing the victims instantly.

Girder Collapse

Postaccident Examination and Testing

After the accident, investigators examined and measured the fallen girder, the braces, the south abutment, the C–470 bridge, and the center bridge pier for the extension. Evidence indicated that the girder had been installed 4.26 degrees out of plumb at the south abutment and 2.33 degrees out of plumb at the center bridge pier, leaning toward the existing bridge. The five lateral braces, which were fabricated on site, had been intended to connect to a correctly installed (fully plumb) girder and to be bolted flush with the existing bridge deck. None of the braces were flush with the deck.

The bracing's failure occurred at the bridge deck, when the lateral force from the girder's distortion placed loads on the expansion-bolted connections, separating the expansion bolts from the bridge. Postaccident examination indicated that the expansion bolts used to connect the braces to the bridge deck were, in various ways, not installed in accordance with manufacturers' requirements. In particular, the Safety Board Materials Laboratory found that the bolt hole diameters in the existing bridge deck measured

[21] Reconstruction efforts involved investigators from law enforcement agencies, the FHWA, the Safety Board, and CDOT.

0.90 inch while the diameters of the expansion bolts were only 0.75 inch. A 0.75-inch-diameter expansion bolt set in a 0.90-inch-diameter hole required the presence of a horizontal load to maintain some pullout resistance. The horizontal loads at the time of the girder erection levered (or cocked) the bolts in the holes. Once the horizontal load decreased in magnitude or changed direction, the pullout resistance was immediately lost. Over time, the varying cyclical loads on the bolts caused by lateral vibrations, thermal expansion and contraction loads, and wind loads would have resulted in variations to the horizontal loads on the bolts, which eventually would have led to the bolts pulling out of the holes.

In addition, all but one of the expansion bolts were not embedded in the concrete according to manufacturers' installation requirements. These requirements were that the bolts must be embedded to a minimum depth of 3.25 inches. Investigators determined that, with the exception of one bolt,[22] the expansion bolts were embedded in concrete to depths of from 1.25 to 2.50 inches.

Finite Element Analysis

After the accident, the FHWA Turner-Fairbank Highway Research Center conducted a finite element analysis of the girder collapse to identify likely scenarios and to assist in determining the likely or possible sequence of events between erection and collapse of the girder. The FHWA developed a finite element analysis model to simulate the response of the braced girder under 10 load scenarios; various combinations of braces were removed, and additional wind loading was applied. The addition of wind loading had minimal effect on the deflected shape of the girder. The second (from the south) of the five braces appeared to be the most critical to providing stability for the girder. Removal of this brace caused immediate instability for the out-of-plumb girder. The analysis found that cyclic forces on the braces due to lateral vibrations and wind loads from May 12 through 15, 2004, were primary factors in weakening the incorrectly installed expansion bolts over time.

Specifically, the FHWA Turner-Fairbank finite element analysis report contained the following conclusions:

1. The girder has low resistance to lateral bending and twisting. The girder is dependent on top flange lateral bracing for stability under most conditions.
2. Brace number 2 appears to be the most critical to providing stability to the girder. Removal of brace 2 caused immediate instability for the out-of-plumb girder model. The plumb girder model remained stable when brace 2 was removed but became unstable when either brace 3 or 5 was subsequently removed.
3. Braces 3 and 5 are redundant members and their removal would not be expected to result in collapse. The presence of braces 3 and 5 is insufficient to brace the girder in the event brace 2 is lost.

[22] This bolt was embedded to a depth of 4.75 inches.

4. The out-of-plumb girder model was more susceptible to instability compared to the plumb girder model. This indicates that erection of the girder in an out-of-plumb condition could be a significant factor in the girder failure.

5. Wind loading created modest increases in brace forces, but in no case did it push the model into instability. All model runs that were stable under gravity only were also stable under added wind load. Therefore, wind load can be eliminated a primary reason for failure. Cyclic forces on the braces due to wind load may be a factor in reducing anchor bolt[[23]] capacity over time.

6. The girder was susceptible to lateral vibration at a natural frequency between 1 and 2 Hz [hertz]. It is possible that wind loading and truck gust loading could have excited these lateral vibration modes. This could create a cyclic force on the brace members that could have caused degradation in capacity over time. However, results from static analysis under wind load indicates the cyclic force variation was probably low due to vibration.

7. The maximum force calculated on any of the brace members for any load case was less than 1/2 the allowable compressive force calculated by the AISC [American Institute of Steel Construction, Inc.] steel construction specifications. Therefore, brace capacity is not a significant factor in initiating this failure.

8. The maximum pull-out and shear forces on the anchor bolts were well below the manufacturer's allowable design loads for a correctly installed anchor bolt. Since examination of the evidence shows that the anchor bolts pulled out during the failure, this strongly suggests that the anchor bolts did not reach their design capacity.

9. Based on the cases investigated in this study, the most likely cause of final collapse was the failure of brace 2. Failure of other braces changes the lateral deflected shape of the girder but would not be expected to cause collapse.

Bracing Failure

Thus, Ridge's erection of the girder and installation of the temporary bracing were inadequate. Had the girder been installed in plumb or had the bracing been bolted effectively, the bracing might not have failed and the girder might not have lost stability, causing it to rotate toward the overpass and sag onto I–70 on the morning of May 15. But in combination, the out-of-plumb girder and improperly installed bolts resulted in an insecure bracing arrangement that was not adequate in the short or long term.

Moreover, the planning for the bracing lacked forethought and precaution. According to Ridge, its original intention was that this bracing arrangement was to be used to secure the single girder for a relatively brief period during the 8 hours of work beginning on the evening of May 11 while a second girder was set in place. Thereafter, the permanent cross bracing with diaphragms would have secured the two girders to each other. But planning for the bracing apparently did not take into consideration the possibility that only one girder might be installed and that the bracing might need to secure a girder for longer than a few hours. Because no contingency plan had been

[23] The finite element analysis used the term "anchor bolt" to refer to the expansion bolts.

developed for securing a single girder, Ridge used this temporary bracing system, originally intended to stabilize the girder for a few hours, for more than 3 days, during which it was vulnerable to stresses caused by temperature variations, winds,[24] and vibrations from passing traffic.

State Oversight of Highway Construction Projects

According to postaccident interviews with CDOT engineers and managers, the department's construction management practice was not to tell a contractor how to accomplish contracted work and not to interfere as the contractor carried out the work. CDOT project managers were to ensure that the work was fulfilled according to the project plans and specifications and within the budget and timeline, but they were not to conduct more active oversight. They said the reasons for this policy were to reduce additional costs that a change in the contractor's plans, caused by a CDOT objection, might generate and to minimize the possibility of tort liability claims.

To determine how widespread such oversight practices may be among the States, Safety Board investigators asked the construction supervision managers of 15 randomly selected State departments of transportation whether their oversight policies were similar to CDOT's. They responded that allowing a contractor to work without significant State intervention is a common practice and cited the same reasons that CDOT did.

According to the AASHTO *Construction Manual for Highway Construction*, "the [State] Project Engineer shall in no way attempt to supervise work for the Contractor." In the section concerning "Duties and Authority of Inspectors," the manual states the following:[25]

> The [State] Inspector shall always bear in mind that the management of the work is the Contractor's business; however, if any methods are employed which the Inspector has reason to believe will impair the quality of the finished job, the Contractor shall be advised accordingly and the Project Engineer notified immediately. The inspector shall in no way attempt to supervise work for the Contractor.

CDOT has provided written guidance to its personnel concerning interaction with contractors. The CDOT *Standard Specifications for Road and Bridge Construction* describe the duties and authority of its construction supervision staff. Section 105.10, "Duties of the Inspector," states that "the inspector is not authorized to issue instructions contrary to the provisions of the Contract or to act as foreman for the Contractor."[26] Several pages of the CDOT design plans for the C–470 bridge-widening project

[24] Winds had been relatively strong during the night preceding the accident, and temperatures had begun to rise gradually during the day of May 14. Both these factors may have stressed the girder's bracing.

[25] American Association of State Highway and Transportation Officials, *Construction Manual for Highway Construction* (AASHTO: 2001) 4–5.

[26] Colorado Department of Transportation, *Standard Specifications for Road and Bridge Construction*, Section 105.10, "Duties of the Inspector" (Denver, CO: CDOT, 1999) 60.

displayed the notation, "The contractor shall be responsible for the stability of the structure during construction."

In both the CDOT *Standard Specifications for Road and Bridge Construction* and the *CDOT Construction Manual*, the guidance concerning the erection of steel structures recommends that falsework[27] for steel structures conform to Section 601, "Structural Concrete," Subsection 601.11, "Falsework," of the CDOT *Standard Specifications for Road and Bridge Construction*.[28] The *CDOT Construction Manual* states, in Section 601, "Structural Concrete," at Subsection 601.2, "Formwork and Falsework," that "Falsework design and construction are the Contractor's responsibility." At Subsection 601.2.2, "Bracing Considerations," the manual states, "The Contractor is responsible for providing adequate bracing of all formwork, and CDOT personnel cannot dictate construction methods."[29]

OSHA Steel Girder Erection Regulations

In 29 CFR Part 1926, "Safety Standards for Steel Erection," the Occupational Safety and Health Administration (OSHA) has regulations relating specifically to the erection of steel structures. After the accident, the Ridge vice president told Safety Board investigators that he believed he should follow the OSHA steel girder erection regulations and that he considered Ridge had fulfilled the OSHA requirements on the C–470 bridge project. CDOT told Safety Board investigators that it was unaware of the OSHA rules relating to the steel erection process. Safety Board communication with AASHTO and American Society of Civil Engineers representatives indicated that these organizations were also unaware of the OSHA rules.

The summary information at 29 CFR Part 1926, "Safety Standards for Steel Erection; Final Rule," dated January 18, 2001, states the following:

> By this notice the Occupational Safety and Health Administration (OSHA) revises the construction industry safety standards which regulate steel erection. The final rule enhances protections provided to workers engaged in steel erection and updates the general provisions that address steel erection. The final rule sets performance-oriented criteria, where possible, to protect employees from steel erection related hazards such as working under loads; hoisting, landing and placing decking; column stability; double connections; hoisting, landing and placing steel joists; and falls to lower levels. To effectuate this, the final rule contains requirements for hoisting and rigging, structural steel assembly, beam and column connections, joist erection, systems engineered metal building erection, fall protection and training.

[27] In the construction industry, *falsework* is generally considered to be a structure or frame that supports something temporarily, while it is being built.

[28] See CDOT *Standard Specifications for Road and Bridge Construction*, Section 509, "Field Construction Requirements," Subsection 509.27, "Erection of Steel Structures," 461; and Colorado Department of Transportation, *CDOT Construction Manual* (Denver, CO: CDOT, 2002), Section 509, "Steel Structures," Subsection 509.2.2 (2) "During Construction—Falsework Considerations," 500–29.

[29] *CDOT Construction Manual*, 600–2.

Title 29 CFR 1926.752, "Site layout, site-specific erection plan and construction sequence," states that OSHA requires that the contractor adhere to the following requirements (in addition to others) before construction may begin:

> (d) Pre-planning of overhead hoisting operations. All hoisting operations in steel erection shall be pre-planned to ensure that the requirements of § 1926.753(d) are met.
>
> (e) Site-specific erection plan. Where employers elect, due to conditions specific to the site, to develop alternate means and methods that provide employee protection in accordance with § 1926.753(c)(5), § 1926.757(a)(4) or § 1926.757(e)(4), a site-specific erection plan shall be developed by a qualified person and be available at the work site.

OSHA defines a "qualified person," as indicated in section (e) above, as

> One who, by possession of a recognized degree, certificate, or professional standing, or who by extensive knowledge, training, and experience, has successfully demonstrated the ability to solve or resolve problems relating to the subject matter, the work, or the project.

The definition does not require that this person be a Registered Professional Engineer. In the case of this accident, Ridge considered its safety officer to be a "qualified person" in accordance with OSHA regulations because, according to Ridge, he had knowledge, training, and experience, and he had on prior projects demonstrated his ability to solve and resolve problems. The safety officer had no engineering credentials, and Ridge had not worked on a highway bridge project for 14 years.

At 29 CFR 1926.754(a), "Structural steel assembly," OSHA further requires that "Structural stability shall be maintained at all times during the erection process."

OSHA was a party to this investigation and was asked to review its regulations and determine their applicability to the steel erection activity affecting this accident. The Denver OSHA office furnished the following evaluation of "potential"[30] violations of OSHA regulations that may have existed during the attempted erection of the accident girder:

- Failure to maintain stability of the girder at all times during erection of the steel structure. (See OSHA 1926.754(a).)
- Lack of an erection plan by the steel erector that provided a method and means for bracing the girder.
- Improper proportioning of the lateral braces and their anchorage by the steel erector. (Braces are engineered, whether temporary or permanent, with due regard to the cross section and end conditions of the girder, in accordance with the design standards of the industry.)

[30] OSHA did not conduct an official evaluation of this work site and took no official action concerning it. This informal evaluation, conducted postaccident at the Safety Board's request, indicates areas in which the Denver OSHA office believes that OSHA regulations may not have been fulfilled.

- A reduction in the cross sectional area of the braces by 50 percent or more by arbitrarily flame-cutting one of the legs to facilitate field bending the braces, without any engineering evaluation.
- Improper installation of the braces by the steel erector, without engineering evaluation, before the girder had undergone dead load deflection. (Note that the girder was still being held by at least one crane while the braces were installed.)
- Lack of professional diligence on the part of the Colorado Department of Transportation's site representative, who had control and authority over the construction site. The site representative reportedly permitted the contractor to proceed with the erection of the girder without any erection plan and without ensuring the lateral stability of the girder.
- Failure on the part of the steel erector to ensure the plumbness of the girder after the braces were installed and anchored to the concrete deck. Note that the girder was braced while at least one crane was still reportedly holding the load. Transits were not reportedly used at the site.

The OSHA steel erection regulations do not specifically define or discuss falsework.

Falsework Guidance

CDOT Specifications

As noted above, the guidance concerning the erection of steel structures in the CDOT *Standard Specifications for Road and Bridge Construction* recommends that falsework for steel structures conform to the guidance in the structural concrete section of the specifications. Section 601 of the CDOT *Standard Specifications for Road and Bridge Construction* is entitled "Structural Concrete." Subsection 601.11 defines falsework as "any temporary construction used to support vertical loads for a structure until it becomes self-supporting."[31]

After the accident, CDOT and the FHWA Colorado Division Office told Safety Board investigators that the temporary lateral braces that supported the girder were "braces" rather than "falsework." Both Ridge and Asphalt Specialties referred to the structure as "bracing." Because the contractor and subcontractor considered it bracing rather than falsework, they thought that this work did not need to follow the specific guidance for falsework provided in the CDOT specifications. Because CDOT did not consider the braces to be falsework, it did not require the contractor or subcontractor to follow such guidance.

[31] CDOT *Standard Specifications for Road and Bridge Construction*, 550.

Subsection 601.11 of the CDOT specifications[32] recommends the following for designing and constructing falsework:

> The Contractor shall be responsible for designing and constructing falsework which provides the necessary rigidity, supports the loads imposed, and produces in the finished structure the lines and grades indicated on the plans.
>
> The Contractor shall have a Professional Engineer determine whether falsework drawings are or are not necessary. When falsework drawings are determined to be unnecessary, the Contractor shall submit a written statement signed by the Contractor's Professional Engineer so stating.

Neither Asphalt Specialties nor Ridge had a Registered Professional Engineer determine whether falsework drawings were necessary for the C–470 bridge-widening project; neither submitted to CDOT a written statement, signed by a Registered Professional Engineer, indicating that falsework drawings were unnecessary. CDOT maintains that the CDOT specifications did not require falsework drawings for the erection of steel girders,[33] and CDOT did not request falsework drawings.

AASHTO and FHWA Guidance

The AASHTO *Standard Specifications for Highway Bridges*, Section 3, "Temporary Works," 3.2 "Falsework and Forms," 3.2.1 "General,"[34] define falsework as follows:

> Falsework is considered to be any temporary structure which supports structural elements of concrete, steel, masonry, or other materials during their construction or erection.

With respect to falsework over publicly traveled ways, the AASHTO *Standard Specifications for Highway Bridges*[35] recommend the following:

> Whenever the height of falsework exceeds 14 feet or whenever traffic, other than workmen involved in constructing the bridge, will travel under the bridge, the working drawings for the falsework shall be prepared and sealed by a Registered Engineer.

No Registered Professional Engineer prepared or reviewed working drawings for the five lateral braces that connected the girder to the existing bridge deck. The only drawing reportedly prepared was a hand-drawn sketch made by the Ridge safety officer, who had no engineering training or certification.

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[32] CDOT *Standard Specifications for Road and Bridge Construction*, 550–551.

[33] CDOT gave this information to the Safety Board in its May 4, 2006, postaccident technical review comments.

[34] American Association of State Highway and Transportation Officials, *Standard Specifications for Highway Bridges*, 17th ed. (AASHTO, 2002) 484.

[35] AASHTO *Standard Specifications for Highway Bridges*, 484.

The FHWA *Guide Design Specification for Bridge Temporary Works* recommends the following for falsework over publicly traveled ways:[36]

> Where temporary bracing is to be used during erection and removal of falsework over or adjacent to public traffic, the falsework drawings shall show the sequence of erection and removal and details of the temporary bracing system to be used.

Aside from the single non-scale, hand-drawn sketch reportedly made by the Ridge safety officer, Ridge apparently did not prepare drawings showing the sequence of erection and removal or details of the temporary bracing system to be used.

CDOT Postaccident Actions

Following this accident, CDOT issued revisions to its *Standard Specifications for Road and Bridge Construction* on August 9, 2004. Among other changes, CDOT revised its specifications at Section 509, "Steel Structures," Subsection 509.27, "Erection of Steel Structures," to

- Require an erection plan to be developed at least 4 weeks prior to erection of a structural steel member. The contractor's Professional Engineer, registered in the State of Colorado, must approve the erection plan. (The details for any falsework, bracing, or other connection supporting the structural steel member should be shown on the erection plan.)

- Require a conference to be held at least 2 weeks before beginning an erection. At the meeting, the contractor and the contractor's Professional Engineer would review the erection plan with CDOT personnel.

- Require the contractor's Professional Engineer to provide written approval of each phase of the installation before allowing vehicles or pedestrians on or below the structure.

- Require the contractor to perform daily inspections of the erected girders until completion of the deck concrete. The contractor must also provide CDOT personnel with written documentation of the inspections within 24 hours.

Probable Cause

The Safety Board determines that the probable cause of the May 15, 2004, girder collapse in Golden, Colorado, during a highway bridge-widening project was the failure of the girder's temporary bracing system due to insufficient planning by Ridge Erection Company, Inc., Asphalt Specialties, Inc., and the Colorado Department of Transportation, which were responsible for putting the girder and its bracing in place, and due to

[36] Federal Highway Administration, *Guide Design Specification for Bridge Temporary Works*, FHWA-RD-93-032 (Washington, DC: FHWA, November 1993) 3.

deficiencies in the installation of the girder and the bracing, so that the bracing ultimately failed to adequately secure the out-of-plumb girder to the existing bridge deck. Contributing to the accident were the lack of uniform, consistent bracing standards and the Colorado Department of Transportation's narrow definition of falsework, which did not include lateral bracing. Also contributing to the accident was the failure of the Colorado Department of Transportation to effectively oversee safety-critical contract work for the project.

Recommendations

As a result of this accident investigation, the National Transportation Safety Board makes the following safety recommendations:

To the Federal Highway Administration:

Take the lead in working with the Occupational Safety and Health Administration and the American Association of State Highway and Transportation Officials to make consistent and compatible your organizations' regulatory requirements for and guidance to construction contractors concerning the design and certification of falsework, formwork, and bracing for the erection of highway structures, including the regulations and guidance concerning the need to have the designs prepared or approved by a Registered Professional Engineer. (H-06-22)

To the Occupational Safety and Health Administration:

Work with the Federal Highway Administration and the American Association of State Highway and Transportation Officials to make consistent and compatible your organizations' regulatory requirements for and guidance to construction contractors concerning the design and certification of falsework, formwork, and bracing for the erection of highway structures, including the regulations and guidance concerning the need to have the designs prepared or approved by a Registered Professional Engineer. (H-06-23)

To the Colorado Department of Transportation:

Require your State highway and transportation department supervisory construction personnel to actively supervise and monitor safety-critical work being accomplished by contract workers. At a minimum, State supervisory personnel should 1) prequalify all subcontractors performing safety-critical work on highway projects and 2) intervene when a contractor or subcontractor exhibits a lack of competence. (H-06-24)

To the American Association of State Highway and Transportation Officials:

Work with the Federal Highway Administration and the Occupational Safety and Health Administration to make consistent and compatible your organizations' regulatory requirements for and guidance to supervisory construction contractors concerning the design and certification of falsework, formwork, and bracing for the erection of highway structures, including the regulations and guidance concerning the need to have the designs prepared or approved by a Registered Professional Engineer. (H-06-25)

Revise the guidance in your *Construction Manual for Highway Construction* that pertains to the role of State highway and transportation departments' supervisory construction personnel to ensure active supervision and monitoring of safety-critical work being accomplished by contract workers. At a minimum, the guidance should call for State supervisory personnel to 1) prequalify all subcontractors performing safety-critical work on highway projects; 2) require the contractor or subcontractor to submit a written plan or design drawings for all construction, including temporary falsework and bracing, and to have these plans or drawings reviewed and approved by a Registered Professional Engineer; 3) intervene when the contractor or subcontractor exhibits a lack of competence; and 4) require the contractor or subcontractor to take reasonable precautions to monitor and ensure the continued stability of temporary bracing or falsework until permanent construction is completed. (H-06-26)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

MARK V. ROSENKER
Acting Chairman

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Member

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Adopted: May 31, 2006

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