National Transportation Safety Board
Washington, D.C. 20594

August 19, 2003

Mr. Matthew K. Rose, Burlington Northern Santa Fe Corporation, Petitioner
Railroad Accident
Kingman, Arizona
August 9, 1997
Accident No. DCA-97-MR-004
Railroad Accident Report NTSB/RAR-98/03

RESPONSE TO PETITION FOR RECONSIDERATION

In accordance with 49 *Code of Federal Regulations* (CFR) 845.41, the National Transportation Safety Board has reviewed the December 3, 1998, petition for reconsideration and modifications of certain findings and probable cause in the investigation of the derailment of Amtrak train 4, the *Southwest Chief*, on the Burlington Northern Santa Fe (BNSF) Railway near Kingman, Arizona, on August 9, 1997. To ensure a complete and thorough review, the Safety Board issued a contract (jointly funded by BNSF and the Safety Board) to Ayres Associates of Fort Collins, Colorado, a civil engineering consulting firm, to perform additional tests and research in support of the supplemental investigative effort. Ayres Associates performed a hydraulic analysis and a hydrology study.[1] This information was used to supplement the Safety Board's original investigation and provide additional information on the relationship between the Burlington Northern Santa Fe Corporation railroad bridge and the Arizona Department of Transportation (ADOT) highway bridge.

The Safety Board has reviewed the additional information provided by the petitioner[2] and Ayres Associates[3] and does not believe there is sufficient justification for modifying the probable cause adopted in the original accident report.[4] The Safety Board has deleted finding 8 from the original accident report and added 2 new findings based on the additional information developed during the supplemental investigation. This response to the petition explains the basis for these decisions.

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[1] Ayres Associates Final Report: *Hydraulic, Erosion, and Scour Analysis of the 1997 BNSF Bridge Failure Near Kingman, Arizona*. March 2001.

[2] Mussetter Engineering report: *Expert Report of Dr. Michael D. Harvey and Dr. Robert A. Mussetter Regarding Soil Conditions and Sediment Transport Processes in the Bridge 504.1 Wash and Adjacent Washes*. May 2000; Mussetter Engineering letter commenting on the final report by Ayres Associates dated May 31, 2001; and submission letters from BNSF dated June 1, 2001; July 27, 2001; and October 22, 2002.

[3] Ayres Associates' response to Mussetter Engineering's comments on the Ayres study, dated July 9, 2001.

[4] National Transportation Safety Board, *Derailment of Amtrak Train 4,* Southwest Chief*, on the Burlington Northern Santa Fe Railway, Near Kingman, Arizona, August 9, 1997*, Railroad Accident Report NTSB/RAR-98/03 (Washington, DC: NTSB, 1998).

Background Information

About 5:56 a.m., on August 9, 1997, National Railroad Passenger Corporation (Amtrak) train 4, the *Southwest Chief*, derailed on BNSF tracks about 5 miles northeast of Kingman, Arizona. Amtrak train 4 was en route from Los Angeles, California, to Chicago, Illinois, and had just left the Kingman station. The train was traveling about 89 mph on the eastbound track when both the engineer and the assistant engineer saw a "hump" in the tracks as they approached railroad bridge 504.1S. They applied the train's emergency brakes. The train derailed as it crossed the bridge. Of the 294 passengers and 18 Amtrak employees on the train, 173 passengers and 10 Amtrak employees were injured. No fatalities resulted from the accident. The damages were estimated to be about $7.2 million.

Investigation revealed that the severe flash flooding and additional streambed erosion on the day of the accident caused the failure of the unreinforced concrete crosswall downstream of the railroad bridge. The purpose of the crosswall was to maintain the elevation of the channel bed beneath the bridge by slowing the water so that sediments could settle out and fill in the area upstream of the wall. When the concrete crosswall failed, the erosion accelerated through the accumulated silt and quickly progressed upstream to the shallow foundation of the bridge. This process undermined the bridge's mud sills and timber blocking and compromised the bridge's ability to support Amtrak train 4. The Safety Board therefore concluded that the failure of bridge 504.1S was caused by scour and erosion affecting the inadequately protected shallow foundations that supported the bridge; the scour resulted because a poorly designed concrete crosswall was built instead of a new and better-engineered bridge.

On August 31, 1998, the Safety Board determined that the probable cause of this accident was as follows:

> ...displacement of the track due to the erosion and scouring of the inadequately protected shallow foundations supporting bridge 504.1S during a severe flash flood because the Burlington Northern Santa Fe management had not provided adequate protection, either by inspection or altering train speeds to fit conditions. Contributing to the accident was the failure of the Burlington Northern Santa Fe management to adequately address the erosion problems at bridge 504.1S.

BNSF was a party to the Safety Board's investigation in accordance with 49 CFR 831.12. In support of its petition, BNSF claimed that the report contained "...an erroneous conclusion regarding the probable cause of the accident that is not firmly supported by the investigation" and that BNSF was "...concerned that a nearby highway bridge and box culvert may well have been the source of the scouring." BNSF's petition went on to point out that "independent expert hydrologists identified the highway bridge as a critical factor...." An aerial photograph of the derailment site and bridges is shown in figure 1.

Although BNSF did not ask for specific wording changes to the accident report, the petition did specifically request

- "reconsideration of the probable cause finding" and
- "a fair and complete investigation of the highway bridge/box culvert issue before issuing a final statement as to the probable cause of the incident."

In response to the petition, the Safety Board agreed to order additional testing by an independent party acceptable to both the Safety Board and BNSF. The Safety Board, with the concurrence of BNSF, issued a contract to Ayres Associates of Fort Collins, Colorado, to perform tests and research in support of the investigation.

There were two objectives of the tests and research assigned to Ayres Associates:

1. Reanalyze the hydrology and hydraulics and conduct a detailed scour analysis of the failure of BNSF bridge 504.1S near Kingman, Arizona, on August 9, 1997.
2. Determine the relationship between the scour at the BNSF bridge and the ADOT reinforced concrete box (RCB) culvert located approximately 1,000 feet downstream.

A scope of work for Ayres Associates was developed that included surveys, tests, and research in several areas. The areas of work were selected based on the confidence that definitive results could be developed that would have a bearing on the accident.

Ayres Associates performed the following work:

- Developed a thorough history of the failed bridge.
- Characterized the attributes of the storm that occurred on August 9, 1997, and estimated its frequency by standard hydrologic analysis procedures.
- Conducted computer simulations to determine the effect of each bridge on the environment and on the other bridge.
- Conducted a bed profile and wash cross section survey in the area of the accident.
- Analyzed historical records, including historic aerial photographs, to determine the long-term migration of headcuts at dry washes in the area of the accident.
- Mapped and characterized the soil calcite horizons (caliche).
- Conducted a geotechnical survey based on borings conducted in the area of the accident.
- Conducted water flume tests to determine the erosion rate for caliche recovered from different areas near the accident site.
- Conducted a scour analysis to determine the method of failure for the bridge.
- Developed a hydraulic computer model of the area to determine the effect of each structure on the watershed.

Ayres' work was performed within the party process with the participation, concurrence, and review of the Safety Board, BNSF, ADOT, and the Federal Highway Administration (FHWA). Ayres conducted field, laboratory, and office investigations. The field and laboratory studies were monitored by Safety Board staff and made with the approval of all four organizations.

Ayres produced a final report in March 2001. All parties reviewed the final report for completeness and technical accuracy. The parties to the investigation were also offered the opportunity to provide a submission on the Ayres report. BNSF and its consultant, Mussetter Engineering, Inc., provided submissions on the Ayres report. No submissions were received from ADOT or the FHWA. Copies of the Ayres final report, and the BNSF and Mussetter Engineering, Inc., submissions were placed in the Safety Board's public docket of the accident investigation.

The Safety Board's response to BNSF's petition will first address the results of the Ayres Associates study and then address pertinent conclusions made and published in the Safety Board's accident report and the probable cause of the accident.

Results of the Ayres Study

The Ayres study consisted of work that the Safety Board and the parties to the investigation determined was necessary to conduct "a fair and complete investigation of the highway bridge/box culvert issue." A discussion of the work conducted and the significant results and conclusions are provided for each activity.

1. Background Information and Timeline:

BNSF bridge 504.1S is located on a desert alluvial fan northeast of Kingman, Arizona. The railroad and highway are parallel and cross the alluvial fan perpendicular to the direction of flow. There is very little precipitation in the area, and the channels that pass under the railroad and highway bridges are almost always dry. The streams are classified as ephemeral in that they flow only when it rains. The duration of flow in a flood event is usually less than 12 hours.

Ayres developed a timeline for the events associated with the failure of bridge 504.1S. The timeline also includes events and actions by the FHWA regarding its initiatives to make highway bridges safe from scour. The actions of the FHWA, which were prominent in published technical articles and the news media, predate the accident by 9 years. The FHWA and the Federal Railroad Administration (FRA), the agency responsible for railroad safety in the United States, are within the U.S. Department of Transportation.

The most significant result of this portion of the Ayres study is the following historical timeline:

BNSF Bridge 504.1 Historical Timeline	
Year	**Comment**
1883	Single main track constructed (now north track); consisted of 4 timber spans with total length of 37 feet.
1907	Bridge 504.1N replaced on driven timber piles, bridge length 37 feet.
1922	South track and bridge 504.1S constructed on mud sills on hardpan.
1934	Hwy 66 with box culvert constructed 1000 ± feet downstream of bridge 504.1N.
1940	Bridge 504.1N replaced; it is on driven timber pile bents; piles range from 19 to 22 feet from cutoff to pile bottom.
1940	ATSF records show a drainage area of 3.8 square miles draining to the bridge.
1954	Aerial photograph shows a headcut approximately 580 feet upstream of Hwy 66 culvert.
1958	ATSF replaces mud sills for bridge 504.1S.
1959	ATSF bridge inspector recommends putting grout and stone between spans 1 and 2. Work performed 1964.
1963	Stock tank constructed immediately upstream of bridge.
1964	Grout and stone placed between spans 1 and 2.
1966	Inspection records indicate riprap floor first placed in 1966.
1967	Aerial photograph shows a headcut approximately 690 feet upstream of Hwy 66 culvert.
1971	ADOT widens Route 66 and extends concrete box culvert 20 feet upstream.
1975	Bridge inspector first notices some erosion at the streambed under the railroad bridge.
1/2/1975	ATSF engineering department letter recommends replacing bridge 504.1 under 1977 CIP because of scouring at mud sills.
1975	ATSF bridge forces place grout and stone between spans 2 and 3.
12/9/1975	ATSF engineering calculates 19.09 square-mile drainage area.
1976	Aerial photograph shows a headcut approximately 760 feet upstream of Hwy 66 culvert.
1/13/1976	Hydraulic calculations, sketch of bridge opening, and flow line elevation with initials AAM made, flow line Elev. 3272.34 NAVD.
1/13/1976	ATSF management expresses concern about proposed concrete crosswall and removal of the bridge from the 1977 CIP.
5/18/1976	ATSF maintenance-of-way forces install concrete crosswall on downstream side of bridge.
1976	More riprap and grout placed in July; grouted riprap lined entire channel under bridge but upstream and downstream extent unknown.
5/1976	Bridge 504.1 removed from 1977 CIP.
7/24/1976	High water recorded over top rail.
7/29/1976	High water measured over 2 inches above base of bridge rail.
1978	Aerial photograph shows a headcut approximately 775 feet upstream of Hwy 66 culvert.
4/5/1987	I-90 bridge over Schoharie Cr., Albany, NY, fails, killing 10 people.
4/29/1988	NTSB determines probable cause of I-90 bridge failure was severe erosion in the soil beneath the spread footing; spread footings without piles had supported the piers.
9/1988	FHWA issues TA5140.20 and “Interim Procedures for Evaluating Scour at Bridges.” TA5140.20 requires the States to evaluate all their bridges over water for scour. The interim procedures and subsequent HEC-18 states: a. Spread Footing on Soil • Insure that top of the footing is below the sum of the long term degradation, contraction scour, and lateral migration. • Place the bottom of the footing below the total scour line from step 4. • Top of the footing can act as a local scour arrestor.
2/1991	FHWA issues HEC-18, “Evaluating Scour at Bridges,” which replaces “Interim Procedures for Evaluating Scour at Bridges.”
10/28/1991	FHWA issues TA51140.23, which supersedes TA5140.20.

BNSF Bridge 504.1 Historical Timeline	
Year	**Comment**
1992	Aerial photograph shows a headcut approximately 930 feet upstream of Hwy 66 culvert, within 50 feet of crosswall.
1993	FHWA issues second edition of HEC-18.
1995	FHWA issues third edition of HEC-18.
2/18/1997	BNSF bridge inspector performs programmed bridge inspection.
7/3/1997	Aerial photograph shows a headcut approximately 930 feet upstream of the Hwy 66 culvert.
7/9/1997	BNSF bridge inspector performs bridge inspection, noting no problems.
8/9/1997	BNSF track supervisor is at bridge for special high water inspection at 4:30 a.m.; water is "lapping against bottom of bridge."
8/9/1997	Amtrak Train 4 derails while crossing bridge at 5:56 a.m.

Notes pertaining to the Ayres Associates timeline:

1. The timeline contains the following acronyms: ADOT = Arizona Department of Transportation; ATSF = Atchison Topeka & Santa Fe Railway; BNSF = Burlington Northern Santa Fe Railway; CIP = capital improvement program; FHWA = Federal Highway Administration; NAVD = North American Vertical Datum; TA = technical advisory.
2. Full references for the information cited in the timeline are included in the Ayres Associates report.
3. The year 1883 is listed as the year of construction for the railroad. ADOT provided the study team with an Arizona map dated 1874, which shows the Atlantic & Pacific Railroad in place, apparently on the alignment of today's BNSF railroad. It is not clear whether 1883 or 1874 or some time earlier should be stated as the railroad's construction date.

2. Hydrology Study:

Ayres Associates conducted a hydrology study to estimate the peak discharge rates through bridge 504.1S for floods of various recurrence intervals and for the flood of August 1997 that resulted in the bridge failure. A secondary objective was to quantify the hydrologic impact of the construction of the railroad embankment in 1883. The peak discharge values developed were used to analyze potential bridge scour and as input in the hydraulic computer modeling study.

Rainfall-runoff models were produced to provide the estimated peak discharge rates for floods at recurrence intervals of 2, 5, 10, 25, 50, and 100 years. ADOT's 1993 publication, *Highway Drainage Design Manual—Hydrology* (HDDM), provided detailed and specific guidance on the development of the rainfall-runoff modeling. Ayres used the U.S. Army Corps of Engineers' (USACE's) program HEC-1 (HEC 1998a) to perform the modeling, following the HDDM's guidelines.

Railroad bridges 505.9, 505.6, 504.9, 503.7, and 503.1 are all in the area of the accident and are interconnected hydrologically. Some of the flow reaching bridge 505.9, for instance, can bypass that bridge and follow the upstream edge of the railroad embankment to bridge 505.6 during high-discharge floods. Flow reaching bridge 505.6 can likewise bypass that bridge and move toward bridge 504.1, and so on, down to bridge 503.1. These interbasin transfers of flow were simulated using the USACE program UNET (HEC 1997). The analysis ultimately showed that interbasin transfers do not affect the peak discharge at bridge 504.1.

High-water marks visible on the walls of ADOT's RCB culvert 4217, downstream of bridge 504.1, made it possible to estimate the peak discharge rate for the flood of August 1997.

The study team used the USACE program HEC-RAS (HEC 1998b), a 1-dimensional water surface profile program, to find the discharge rates that most closely matched the high-water marks.

The most significant results and conclusions of the hydrology study were as follows:

1. The flood-frequency relationship for bridge 504.1S was determined.
2. Construction of the railroad significantly increased the peak discharge rate at the upstream side of bridge 504.1S for every recurrence interval.
3. The range of plausible peak discharge values for the flood of August 1997 is from 450 cubic feet per second (cfs) to 875 cfs.
4. The most probable peak discharge rate is 875 cfs, based on the box culvert high-water marks.
5. The peak flow of 875 cfs is found to have a recurrence interval greater than 2 years but less than 5 years.

3. Channel Profiles and Cross Sections:

A bed profile and wash section survey was conducted on portions of seven channels in the vicinity of the accident site, including the channels associated with railroad bridges 501.5, 503.1, 503.7, 504.1, 505.6, 505.9, and 506.9. The purpose of the survey was to document the condition of the wash and to determine the location and extent of existing headcuts and knickpoints along the surveyed channels. Although the terms “knickpoint” and “headcut” are often used interchangeably in the literature on channel incision, for the purposes of the Ayres bed profile and wash section survey, knickpoint is used to represent an elevation change of less than 1.5 feet, and a headcut is defined as a scarp or vertical face in the channel bed that is more than 1.5 feet high. All seven channels, including the accident channel, were surveyed and documented in this manner.

In addition, aerial photographs taken between 1954 and 1997 were examined to determine changes in the channels and the migration of headcuts and other erosion features. For most of the years, photo enlargements were used in the analysis. In most cases, the channels have become incised and have enlarged and extended in the downstream direction as a result of degradation and incision over time. The upstream progression of headcutting in the channels over time is evident on most of the aerial photos.

All the channels examined exhibit some degree of incision and are deeply incised downstream of U.S. Highway 66. The channels contain features indicative of multiple episodes of incision. All channels have undergone episodes of incision between the railroad and highway bridges.

The presence of caliche, which are soil horizons cemented to varying degrees by calcium carbonate, has not halted the progression of incision and headcutting. The shallow caliche horizon found in the bed and banks of the channels is highly variable locally and among channels relative to grain size, cementation, and erodibility. In many places, incision has cut a small channel into or has incised through the caliche horizon where the caliche is not as competent. In places where a more erosion-resistant caliche is encountered, channel incision may skirt, undercut, or bypass the resistant caliche by eroding the less resistant material marginal to the resistant caliche. Where the caliche horizon is well cemented and erosion resistant, incision has progressed upstream much more slowly through the process of knickpoint or headcut migration.

The most significant results and conclusions of the channel profiles and cross sections survey were as follows:

1. Following the construction of the railroad in 1883, sheet and discontinuous channelized flows were concentrated at the railroad bridges.
2. In 1934, ADOT constructed Highway 66 downstream of the railroad and placed its box culverts directly downstream of the railroad bridges. In most places, the culvert inverts (bottoms) were constructed below the invert of the channel, thus requiring excavation of the channel bed. The presence of two bridges along each drainage way resulted in the concentration of flow in the reach between the bridges, causing general degradation of the channels. The placement of the Highway 66 culvert inverts below the channel bed probably produced short oversteepened reaches upstream of the culverts, causing small headcuts to form.
3. The headcuts migrated upstream as flood events occurred over 63 years and helped accelerate channel incision and degradation on all the channels.
4. The rate at which the headcuts progressed upstream and the rate of general degradation of the channel were dependent on the competence of the caliche. The caliche in the lower half of the reach between the bridge 504.1 and Highway 66 RCB culvert 4217 was less erosion resistant and allowed a relatively rapid progression of degradation and upstream headcut migration.
5. Channel incision, the upstream progression of headcuts, and the downstream extension of the channels below the highway were caused primarily by flow concentration at both the railroad and Highway 66.
6. It is likely that if the highway had not been built, flow concentration at the railroad bridge would still have resulted in the downstream extension of the channel, which was already evident in the 1939 railroad ravine section. The general degradation that produced the downstream extension of the channel below the railroad bridge would have eventually extended beyond the erosion-resistant caliche. Once the degrading channel extended beyond the erosion-resistant caliche, a headcut would have developed that would then have migrated upstream and caused bridge 504.1S to fail.
7. The stock tanks and grading activities in the watershed above bridge 504.1 had no significant effect on the incision of the channel or the failure of bridge 504.1.

4. Caliche Geotechnical Investigation:

The bed of channel 504.1 between the BNSF railroad bridge and the U.S. Highway 66 box culvert has a history of headcutting and degradation. Caliche or hardpan is observable in the channel banks and was thought to be a control in limiting erosion in the channel and the upstream migration of headcuts. However, the degree to which the caliche limits channel erosion and headcutting varies because the overall extent and physical properties of the caliche are highly variable. Therefore, a geotechnical investigation was conducted to determine the extent and variability of the caliche along channel 504.1.

The geotechnical investigation consisted of drilling and logging bore holes at 21 locations along the channel banks between the bridges of channel 504.1. Three blocks and one cylindrical sample of caliche were also collected for erodibility tests. Tests on the three blocks were conducted at Colorado State University, and tests on the cylindrical sample were conducted at Texas A&M University. Complete boring logs and blow counts were recorded for each of the 21 borings.

The bed material in the area of the accident is mostly fine sand with some gravel and cobbles. There are relatively thin layers of carbonate-cemented soils (hard pan or caliche) in these deposits. The carbonate-cemented strata are a common occurrence in deserts throughout the U.S. Southwest. The carbonate-cemented strata occur as a result of water penetrating the soil and leaching calcite from higher layers.

The degree of cementation and thickness of the cemented zones can vary throughout the full range of cementation across very short distances. The cementation layer may be much harder than the surrounding soils. Shallow foundation bridges, such as the one that failed in this accident, were often constructed using the caliche layer as the base.

The most significant results and conclusions of the caliche geotechnical investigation were as follows:

1. The caliche horizon within the study area is variable in extent, thickness, degree of cementation, and resistance to erosion by flowing water.
2. Based on the blow count data from the borings, there is a significant reduction in the hardness of the caliche near U.S. Highway 66. This is also verified by observations in the channel banks and in the pit and trench excavations, and by the results of the erodibility tests made at Texas A&M and Colorado State Universities.
3. The caliche horizon near the upstream end of the Highway 66 box culvert is neither hard nor uniform. It is highly erodible.
4. The caliche horizon is more resistant to erosion in the area upstream of and just downstream of the railroad bridge.
5. Erosion of the caliche horizon is by surface shear from flowing water, plunging flow, and the undermining of the competent portion by erosion of the weaker

underlying sediments. The undermined competent portion of the caliche horizon fails by gravity.

5. Scour Study:

Scour is the erosion by water of the soil around the piers and abutments that make up the foundations of a bridge. Total scour at a bridge is the combination of long-term degradation of the streambed, general scour of the stream channel under the bridge, and local scour at the piers and abutments. The measurements of the three components are added together to obtain the total scour at a pier or abutment.

Scour of the channel bed at the foundations caused the failure of railroad bridge 504.1S. This conclusion was stated in the Safety Board report of 1998, was implied in the HDR Engineering report of 1997, and was generally agreed upon by the participants at all of the meetings held after the Safety Board agreed to contract for additional research. The purpose of the scour study was to develop more specific findings related to the probable cause of the bridge failure. In particular:

- the relative importance and role of each of the three components of scour;
- the morphology of the channel and human impacts on the morphology;
- the significance of the type of bridge foundations used;
- the interaction between bridge 504.1 and the U.S. Highway 66 box culvert (RCB culvert 4217) downstream;
- the importance of the crosswall downstream of bridge 504.1, and the cause of the failure of the crosswall; and
- the importance of the stock tank just upstream of the bridge.

Scour depths were computed using the equations and methods given in the FHWA's HEC-18 procedures and other accepted methods. The results of the scour study were used to determine the most likely sequence of events that led to the bridge failure.

The most significant results and conclusions of the scour study were as follows:

1. The grouted riprap that was placed on the streambed under bridge 504.1N and 504.1S apparently had sufficient thickness, rock size, and binding to protect the piers from local scour.
2. Assuming that the grouted riprap covered the channel bed beneath the bridge, as indicated by BNSF personnel, there was no contraction scour beneath the bridge deck in the August 1997 flood because the area was protected by grouted riprap.
3. The August 1997 flood might have caused as much as 3.3 feet of local scour at the crosswall if the peak discharge rate was 450 cfs and as much as 5.6 feet if the peak discharge rate was 875 cfs. Either of these scour depths could have caused failure of the crosswall. The local scour downstream of the crosswall might not

have attained its full depth because of the underlying caliche. The caliche at the location of the crosswall was highly resistant to erosion but was still erodible.

4. A combination of long-term degradation and local scour downstream of the crosswall caused the crosswall to fail. Its failure allowed the long-term degradation of the streambed to undermine the grouted riprap, which was protecting the shallow mudsill foundations of the bents. The undermining of the grouted riprap allowed the foundations of bents 3, 4, and 5 to be undermined and to fail.
5. Incision of the channel crossed by bridge 504.1 was initiated when the railroad was constructed in 1883. The construction of RCB culvert 4217 probably accelerated the long-term degradation, but it also formed an elevation control, which will limit the ultimate depth of degradation at bridge 504.1. Long-term degradation in this channel has occurred by headcut migration in the upstream direction and by gradual channel lowering progressing in the downstream direction.
6. Without direct profile or photographic evidence from the late 1930s, it is difficult to conclusively determine the importance of the excavation of the channel at Highway 66 in the formation of the headcut that contributed to the failure of bridge 504.1.
7. The construction of the crosswall and the placing of grouted riprap up to 20 inches thick across the bed under bridge 504.1 reveals that ATSF/BNSF personnel knew the bridge was vulnerable to scour.
8. The stock tanks and grading activities in the watershed above bridge 504.1 had no significant effect on the incision of the channel or the failure of bridge 504.1.

6. Hydraulic Computer Modeling:

The Ayres Associates study team conducted one-dimensional hydraulic analyses in order to clarify the impacts and relative importance of the railroad and Highway 66 on the morphology of the channel downstream of bridge 504.1. Hydraulic modeling allowed the team to compare, for a range of conditions, the hydraulic conditions that produced the degradation.

A series of one-dimensional hydraulic models was created using the HEC-RAS computer program to make quantitative comparisons of the hydraulics of the channel under various physical scenarios from the past. Five models were developed to simulate each past condition: model 1 is a simulation of conditions just before the railroad was constructed that reflects an approximation of the undisturbed natural channels and overbanks; model 2 simulates the conditions after the railroad was constructed and just before the 1934 construction of Highway 66; model 3 represents conditions just after the highway construction; model 4 is a simulation of conditions just before the 1971 highway widening; and model 5 simulates the channel and overbank just after the 1971 widening.

The railroad embankment added significant drainage area to the channel. Discharge in the channel increased at the bridge as a result of the larger drainage area and the constriction of overbank flows into the channel. Downstream of the bridge, flow gradually re-expanded onto the overbanks; however, at Highway 66, flow was re-contracted to pass through the box culvert.

The channel was excavated about 2 feet at the Highway 66 box culvert in 1934 during construction. This is a common and accepted practice that allows the required drainage opening to fit beneath the roadway with adequate cover. The excavation of the channel may have been an important factor in the initial formation of the major headcut.

The five models help to clarify the relative roles of the railroad bridge and highway culvert on scour and degradation at the BNSF bridge. Observing changes in channel hydraulics between models allows comparative observations and conclusions to be made as to how hydraulic conditions affected scour at bridge 504.1.

The most significant results and conclusions of the hydraulic computer modeling study were as follows:

1. The construction of the railroad in 1883 increased the velocity and erosion potential in the channel downstream from bridge 504.1 by increasing the drainage area (relevant for 2-year and smaller floods) and by constricting the flow to the width of the bridge opening (relevant for all floods). Because of the gradual rate of re-expansion downstream of the bridge (an assumption whose validity can be verified only by site observation of flooding or by two-dimensional modeling), the increase in velocity extended downstream beyond the present-day location of Highway 66.

2. The construction of Highway 66 in 1934 caused an increase in velocity downstream of the box culvert for all discharge rates, leading to a markedly increased erosion potential downstream of the highway. Upstream of the box culvert, the highway embankment caused backwater, leading to reduced velocities and erosion potential, for discharges equal to and greater than the 5-year peak. For smaller flows, the excavation of the streambed, and the resulting oversteepened reach just upstream of the box culvert, led to locally increased velocities and a hydraulic jump. The higher velocities and hydraulic jump almost certainly led to significant scour upstream of the box culvert. If the conditions in the model are representative of the post-highway condition, they could definitely have led to the initiation of the headcut that is observable moving upstream toward the bridge in the historic aerial photographs.

3. The excavation to place the culvert was and is a common practice. When the invert of a culvert is depressed below the natural channel grade, it is now advisable to consider the possible need for erosion protection in the oversteepened reach just upstream of the culvert.

4. If the bottom of the box culvert had been placed at the existing channel grade, the potential for erosion upstream of the culvert would have been reduced, rather than increased, for all discharge rates. The maximum velocity downstream of the box culvert, however, would not have been any less under these alternative conditions than under the actual conditions.

5. There was little or no impact on the erosion or morphology of the channel imposed by the widening of Highway 66 in 1971.

The complete Ayres Associates report is available in the Safety Board's public docket for the Kingman accident. The six areas of work performed by Ayres Associates and summarized in this response represent the additional investigative work that was undertaken to fully understand the cause of the failure of BNSF bridge 504.1S.

National Transportation Safety Board Conclusions and Probable Cause

The Safety Board published 20 findings in the "Conclusions" section of its Kingman, Arizona, accident report adopted on August 31, 1998. Of the 20 findings, 1 was potentially affected by the additional research performed by Ayres.

Finding 8

The Safety Board concluded that:

> The relationship of the highway box culverts and the railroad bridges and their respective zone of influence is not fully understood.

The relationship between the Highway 66 box culvert and railroad bridge 504.1 is very complex. Bridge 504.1, built in 1883, concentrated overland sheet flow into a single drainage course. The concentrated flow had more sediment transport capacity than the upland sheet flow and began to erode a channel at the railroad bridge. With time, the channel increased in size and progressed downstream. In the early years, the flow partially re-expanded downstream of the railroad bridge.

Highway 66, built in 1934 about 1,000 feet downstream from the bridge, re-concentrated the flow that had re-expanded downstream of the railroad bridge. The concentrated flow through the box culvert accelerated channel incision downstream of the culvert. The bottom of the box culvert was set about 2 feet lower than the level of the existing swale.

The excavation to place the box culvert probably left a short, steep reach of streambed just upstream of the culvert. This could have initiated the headcut that the aerial photographs show moving upstream from 1954 to 1997 and that eventually contributed to the failure of the crosswall downstream of bridge 504.1.

Unfortunately, the available aerial photographs date back only to 1954, and no detailed channel bed profiles just upstream of the highway are available from the period just after the construction of the highway. Without direct profile and photographic evidence from the late 1930s, it is difficult to precisely determine the importance of the box culvert channel excavation in the formation of the headcut.

The box culvert also provided a positive benefit to the channel. The concrete floor of box culvert 4217 is now an elevation control point that will limit the ultimate depth of the long-term channel incision and degradation at the bridge. Had ADOT constructed a bridge on piles at this location instead of a box culvert, the ultimate degradation at the railroad bridge would have been deeper.

The channel formed downstream of bridge 503.7, the next bridge east of bridge 504.1, helps in understanding the development of the channel crossed by bridge 504.1 and the relationship between the railroad bridge and downstream box culvert. Compared to bridge 504.1, the drainage area upstream of bridge 503.7 is much smaller, and the discharge through bridge 503.7 is typically much lower in small to moderate floods. Consequently, the channel downstream from bridge 503.7 is smaller and is in an earlier stage of development. At this stage of development, channels have formed at bridge 503.7 and at the downstream box culvert. Neither channel extends very far downstream. Downstream of each structure, the flow spreads out and appears to occupy several smaller drainage courses.

Currently, the box culvert, by re-concentrating the flow, is accelerating the growth of the channel. It is not, however, affecting the erosion at bridge 503.7. In time, the channel can be expected to progress downstream from the railroad bridge and upstream from the box culvert. Eventually, the two processes will meet and form a continuous channel from the railroad bridge to the highway culvert.

The bottom of the box culvert downstream of bridge 503.7 was placed below the streambed elevation in 1934 in similar fashion to box culvert 4217. The associated excavation may have accelerated the channel formation, but it was not prerequisite to the process of erosion. The process is occurring at bridge 503.7, which has no floor and presumably was not excavated during construction. In the long term, the erosion of the channel will progress to the point that the box culvert will form a hard point. As long as the box culvert remains in place, it will limit the potential ultimate depth of scour at bridge 503.7. The alluvial fan is so steep (slope of about 0.013 foot per foot, or 69.9 feet per mile) that the erosion downstream of bridge 503.7 can be expected to continue, unless intervention is applied, until an equilibrium slope is achieved where bed material would be transported into the reach at a rate equal to the rate at which material would be transported out of the reach. The floor of the box culvert would provide a vertical control, and caliche layers would probably slow the erosion rate.

The above characterization of the relationship between two structures crossing the same stream in proximity to each other applies to an ephemeral stream on a steep alluvial fan. Structures crossing another stream in proximity to each other with different geologic, geomorphology, hydraulic, and hydrology conditions are likely to have different responses. The work of Ayres Associates has provided the Safety Board and the parties to the investigation with a much better understanding of the mutual impact between bridges occupying common channels. The Safety Board considers the additional research conducted by Ayres Associates in cooperation with the parties to the investigation to satisfy the petitioner's request for a fair and complete investigation of the highway bridge/box culvert issue.

The petitioner requested that the Safety Board complete an investigation of the highway bridge/box culvert issue and use the results in reconsidering the probable cause of this accident. On August 31, 1998, the Safety Board determined that the probable cause was as follows:

> ...displacement of the track due to the erosion and scouring of the inadequately protected shallow foundations supporting bridge 504.1S during a severe flash flood because the Burlington Northern Santa Fe management had not provided adequate protection, either by inspection or altering train speeds to fit conditions. Contributing to the accident was the failure of the Burlington Northern Santa Fe management to adequately address the erosion problems at bridge 504.1S.

The study by Ayres Associates showed that the original headcut that contributed to the undermining of the crosswall and BNSF railroad bridge may have initiated at the highway bridge soon after Highway 66 was built in 1934. However, there is no direct profile or photographic evidence from the 1930s to precisely determine what caused the original headcut to form.

The American Association of State Highway and Transportation Officials provides guidelines for highway bridge construction.[5] The association's 1931 guide, "Standard Specifications for Highway Bridges and Incidental Structures," advises that

> a careful study shall be made of local conditions, including flood height and flow, size and performance of other openings in the vicinity carrying the same stream, characteristics of the channel and of the watershed area, climatic conditions, available rainfall records and any other information pertinent to the problem and likely to affect the safety or economy of the structure.

However, ADOT reported that it did not have any hydrology studies or hydraulic design documents from the initial bridge construction in 1934 or from the widening project in 1971. The construction drawings do have annotations denoting drainage areas, but no calculation sheets or other evidence was provided to demonstrate how those numbers were derived. According to ADOT, the highway bridge was performing well in 1971 and there was no reason to change the size of the waterway opening;[6] therefore, no hydrologic or hydraulic studies were needed prior to the roadway-widening project in 1971. ADOT also reported that since the accident, it has completed studies confirming that the highway bridge culverts are adequately sized and designed. However, the Safety Board believes that an opportunity was missed in 1971 when ADOT did not carry out comprehensive studies that would have identified the already existing upstream channel deterioration and that could have prompted ADOT and ATSF efforts to assess the interaction between the bridges and develop strategies to address erosion problems.

In 1975, the ATSF engineering department recommended that the railroad bridge be replaced because of concerns about the bridge's ability to provide an adequate waterway opening and recurring erosion problems. Although the bridge was not replaced, records from 1976 indicate the addition of riprap along the streambed and a concrete crosswall downstream of the

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[5] Before the 1970s, this organization was known as the American Association of State Highway Officials.

[6] According to ADOT, the highway bridges along this stretch of highway were not designed to deal with heavy flooding and, in fact, water has crossed above the highway in the area of the subject bridge several times since 1934. The 1969 "Standard Specifications for Highway Bridges" published by the American Association of State Highway Officials states that, "On wide flood plains, the lowering of approach fills to provide overflow sections designed to pass unusual floods over the highway is a means of preventing loss of structures."

bridge. Therefore, the railroad also had an opportunity to communicate with ADOT and develop joint strategies to address erosion problems. Nevertheless, the railroad was aware of the vulnerability of the bridge, and it should have closely monitored erosion in the vicinity and taken whatever measures were necessary to ensure safe operations. According to the original accident report, a track supervisor conducted a track inspection during the severe weather and flooding on the morning of the accident. However, he was not qualified to conduct bridge inspections, and no restrictions were placed on train speeds.

The additional information developed by the Ayres Associates' study reinforces the finding that an adequate bridge inspection could have detected risk to the bridge. According to the historical photographs, at the time the crosswall was constructed, the headcut that threatened the bridge was about 240 feet away. For at least the 5 years preceding the south bridge failure (1992–1997), the headcut was about 80 feet from the bridge and less than 50 feet from the crosswall.

The ephemeral streambed between the railroad bridge and U.S. Highway 66 box culverts has a history of headcutting and degradation due to erosion. The railroad bridge concentrated the water flow to form a channel, which would erode and deepen over time even if the highway bridge/box culverts did not exist. Although both structures accelerated erosion of the streambed, it is the owner's responsibility to monitor and ensure a bridge's structural integrity against the effects of erosion, including headcuts or any other changes that may arise over time. Therefore, regardless of the cause of the headcut, BNSF, and its predecessors, had ample opportunity over the years to detect the headcut and take appropriate remedial action. The Safety Board has reviewed the additional information provided by the petitioner and the results of the Ayres Associates' study and does not believe there is sufficient justification for modifying the probable cause adopted in the original accident report.

Although the exact history and relationship between the Highway 66 bridge and railroad bridge 504.1S may never be completely understood, the results of the field investigations, the analysis and mapping of other channels in the region, and the results of the computer simulations provide much more insight than was available when the original accident report was adopted. Therefore, after evaluating the additional information developed during the research performed by Ayers Associates, the Safety Board has determined that finding 8 from the original report is no longer applicable and inserts the following two findings:[7]

8. Both the railroad construction in 1883 and highway construction in 1934 concentrated the overland flow of water and accelerated erosion of the ephemeral streambed. The headcut that contributed to the failure of the crosswall and railroad bridge may have originated at the highway bridge after construction of U.S. Highway 66 in 1934; the upstream progression of the headcut was primarily caused by flow concentration between the railroad bridge and the highway bridge.

[7] The Safety Board will delete finding 8 from the original report and insert the text shown as new findings 8 and 9. Finding 9 from the original report will become finding 10, with remaining findings renumbered accordingly.

9. Regardless of the cause of the headcut, Burlington Northern Santa Fe Railway and its predecessors were aware of the erosion problems affecting the railroad bridge and had ample opportunity over the years to detect the headcut and take appropriate remedial action. Moreover, the railroad decided not to replace the bridge in its 1977 Capital Improvement Program as recommended by its engineering department in 1975, reflecting that department's concern about the bridge's ability to provide an adequate waterway opening and recurring erosion problems.

Based on these findings, the Safety Board will add text to the factual and analysis sections of the Kingman, Arizona, accident report and will make the indicated changes to the findings. Those insertions and modifications are shown on the attached pages.

Chairman ENGLEMAN, Vice Chairman ROSENKER, and Members GOGLIA, CARMODY, and HEALING concurred in this response to petition for reconsideration.

John J. Goglia, Member, filed the following concurring statement on July 31, 2003. Richard F. Healing, Member, joined Member Goglia in this opinion.

Notation 6912E

Member GOGLIA, concurring:

> Based on the information in the docket, I believe we should have included in the contributing causes of this accident the Arizona Department of Transportation's (ADOT's) failure to react (for years) to the erosion that was progressing toward the railroad property. It is also interesting to note (and in contrast to ADOT's inaction, the BNSF's action) that on the upstream side of the railroad property the same type of erosion is occurring, yet the railroad (as a responsible landowner) has for some time taken actions to prevent this erosion from reaching the adjacent property.

Attachments

Attachment A: Amendments to Report Factual

[New text to be inserted at page 22, after line 28, of Railroad Accident Report NTSB/RAR-98/03, *Derailment of Amtrak 4,* Southwest Chief*, on the Burlington Northern Santa Fe Railway, August 9, 1997*.]

Results of Study by Ayres Associates

After the completion of its initial investigation of this accident, the Safety Board contracted with Ayres Associates of Fort Collins, Colorado, a civil engineering consulting firm, to perform additional tests and research, to include a hydraulic analysis and a hydrology study.[8] This information was used to supplement the original investigation and provide additional information on the relationship between the Burlington Northern Santa Fe Corporation railroad bridge and the ADOT highway bridge.

The tests and research assigned to Ayres Associates had two objectives:

- Reanalyze the hydrology and hydraulics and conduct a detailed scour analysis of the failure of BNSF bridge No. 504.1S near Kingman, Arizona, on August 9, 1997.
- Determine the relationship between the scour at the BNSF bridge and the ADOT reinforced concrete box (RCB) culvert located approximately 1,000 feet downstream.

As part of its work on this project, Ayers Associates developed the following timeline:

BNSF Bridge 504.1 Historical Timeline

Year	Comment
1883	Single main track constructed (now north track); consisted of 4 timber spans with total length of 37 feet.[a]
1907	Bridge 504.1N replaced on driven timber piles, bridge length 37 feet.
1922	South track and bridge 504.1S constructed on mud sills on hardpan.
1934	Hwy 66 with box culvert constructed 1,000 ± feet downstream of bridge 504.1N.
1940	Bridge 504.1N replaced; it is on driven timber pile bents; piles range from 19 to 22 feet from cutoff to pile bottom.
1940	ATSF records show a drainage area of 3.8 square miles draining to the bridge.
1954	Aerial photograph shows a headcut approximately 580 feet upstream of Hwy 66 culvert.
1958	ATSF replaces mud sills for bridge 504.1S.
1959	ATSF bridge inspector recommends putting grout and stone between spans 1 and 2. Work performed 1964.
1963	Stock tank constructed immediately upstream of bridge.
1964	Grout and stone placed between spans 1 and 2.

[8] Ayres Associates Final Report: *Hydraulic, Erosion, and Scour Analysis of the 1997 BNSF Bridge Failure Near Kingman, Arizona.* March 2001.

BNSF Bridge 504.1 Historical Timeline

Year	Comment
1966	Inspection records indicate riprap floor first placed in 1966.
1967	Aerial photograph shows a headcut approximately 690 feet upstream of Hwy 66 culvert.
1971	ADOT widens Route 66 and extends concrete box culvert 20 feet upstream.
1975	Bridge inspector first notices some erosion at the streambed under the railroad bridge.
1/2/1975	ATSF engineering department letter recommends replacing bridge 504.1 under 1977 CIP because of scouring at mud sills.
1975	ATSF bridge forces place grout and stone between spans 2 and 3.
12/9/1975	ATSF engineering calculates 19.09 square-mile drainage area.
1976	Aerial photograph shows a headcut approximately 760 feet upstream of Hwy 66 culvert.
1/13/1976	Hydraulic calculations, sketch of bridge opening, and flow line elevation with initials AAM made, flow line Elev. 3272.34 NAVD.
1/13/1976	ATSF management expresses concern about proposed concrete crosswall and removal of the bridge from the 1977 CIP.
5/18/1976	ATSF maintenance-of-way forces install concrete crosswall on downstream side of bridge.
1976	More riprap and grout placed in July; grouted riprap lined entire channel under bridge but upstream and downstream extent unknown.
5/1976	Bridge 504.1 removed from 1977 CIP.
7/24/1976	High water recorded over top rail.
7/29/1976	High water measured over 2 inches above base of bridge rail.
1978	Aerial photograph shows a headcut approximately 775 feet upstream of Hwy 66 culvert.
4/5/1987	I-90 bridge over Schoharie Cr., Albany, NY, fails killing 10 people.
4/29/1988	NTSB determines probable cause of I-90 bridge failure was severe erosion in the soil beneath the spread footing; spread footings without piles had supported the piers.
9/1988	FHWA issues TA5140.20 and "Interim Procedures for Evaluating Scour at Bridges." TA5140.20 requires the States to evaluate all their bridges over water for scour. The interim procedures and subsequent HEC-18 states: a. Spread Footing on Soil Insure that top of the footing is below the sum of the long term degradation, contraction scour, and lateral migration. Place the bottom of the footing below the total scour line from step 4. Top of the footing can act as a local scour arrestor.
2/1991	FHWA issues HEC-18, "Evaluating Scour at Bridges," which replaces "Interim Procedures for Evaluating Scour at Bridges."
10/28/1991	FHWA issues TA5140.23, which supersedes TA5140.20.
1992	Aerial photograph shows a headcut approximately 930 feet upstream of Hwy 66 culvert, within 50 feet of crosswall.
1993	FHWA issues second edition of HEC-18.
1995	FHWA issues third edition of HEC-18.

BNSF Bridge 504.1 Historical Timeline

Year	Comment
2/18/1997	BNSF bridge inspector performs programmed bridge inspection.
7/3/1997	Aerial photograph shows a headcut approximately 930 feet upstream of the Hwy 66 culvert.
7/9/1997	BNSF bridge inspector performs bridge inspection, noting no problems.
8/9/1997	BNSF track supervisor is at bridge for special high water inspection at 4:30 a.m.; water is "lapping against bottom of bridge."
8/9/1997	Amtrak Train 4 derails while crossing bridge at 5:56 a.m.

[a]The year 1883 is listed as the year of construction for the railroad. ADOT provided the study team with an Arizona map dated 1874 that shows the Atlantic & Pacific Railroad in place, apparently on the alignment of today's BNSF railroad. It is not clear whether 1883 or 1874 or some time earlier should be stated as the railroad's construction date.

Ayres Associates conducted a hydrology study to estimate the peak discharge rates through bridge 504.1S for floods of various recurrence intervals and for the flood of August 1997 that resulted in the bridge failure. A secondary objective was to quantify the hydrologic impact of the construction of the railroad embankment in 1883. The peak discharge values developed were used to analyze potential bridge scour and as input in the hydraulic computer modeling study.

The most significant results and conclusions of the hydrology study were as follows:

- The flood-frequency relationship for bridge 504.1S was determined.
- Construction of the railroad significantly increased the peak discharge rate at the upstream side of bridge 504.1S for every recurrence interval.
- The range of plausible peak discharge values for the flood of August 1997 is from 450 cubic feet per second (cfs) to 875 cfs.
- The most probable peak discharge rate is 875 cfs, based on the box culvert high-water marks.
- The peak flow of 875 cfs is found to have a recurrence interval greater than 2 years but less than 5 years.

A bed profile and wash section survey was conducted on portions of seven channels in the vicinity of the accident site, including the channels associated with railroad bridges 501.5, 503.1, 503.7, 504.1, 505.6, 505.9, and 506.9. The purpose of the survey was to document the condition of the wash and to determine the location and extent of existing headcuts and knickpoints along the surveyed channels.

The most significant results and conclusions of the channel profiles and cross sections survey were as follows:

- Following the construction of the railroad in 1883, sheet and discontinuous channelized flows were concentrated at the railroad bridges.

- In 1934, ADOT constructed Highway 66 downstream of the railroad and placed its box culverts directly downstream of the railroad bridges. In most places, the culvert inverts (bottoms) were constructed below the invert of the channel, thus requiring excavation of the channel bed. The presence of two bridges along each drainage way resulted in the concentration of flow in the reach between the bridges causing general degradation of the channels. The placement of the Highway 66 culvert inverts below the channel bed probably produced short oversteepened reaches upstream of the culverts, causing small headcuts to form.
- The headcuts migrated upstream as flood events occurred over 63 years and helped accelerate channel incision and degradation on all the channels.
- The rate at which the headcuts progressed upstream and the rate of general degradation of the channel were dependent on the competence of the caliche. The caliche in the lower half of the reach between the bridge 504.1 and Highway 66 RCB culvert 4217 was less erosion resistant and allowed a relatively rapid progression of degradation and upstream headcut migration.
- Channel incision, the upstream progression of headcuts, and the downstream extension of the channels below the highway were caused primarily by flow concentration at both the railroad and Highway 66.
- It is likely that if the highway had not been built, flow concentration at the railroad bridge would still have resulted in the downstream extension of the channel, which was already evident in the 1939 railroad ravine section. The general degradation that produced the downstream extension of the channel below the railroad bridge would have eventually extended beyond the erosion-resistant caliche. Once the degrading channel extended beyond the erosion-resistant caliche, a headcut would have developed that would then have migrated upstream and caused bridge 504.1S to fail.
- The stock tanks and grading activities in the watershed above bridge 504.1 had no significant effect on the incision of the channel or the failure of bridge 504.1.

A geotechnical investigation was conducted to determine the extent and variability of the caliche along channel 504.1. The most significant results and conclusions of the geotechnical investigation were as follows:

- The caliche horizon within the study area is variable in extent, thickness, degree of cementation, and resistance to erosion by flowing water.
- Based on the blow count data from the borings, there is a significant reduction in the hardness of the caliche near U.S. Highway 66. This is also verified by observations in the channel banks and in the pit and trench excavations, and by the results of the erodibility tests made at Texas A&M and Colorado State Universities.
- The caliche horizon near the upstream end of the Highway 66 box culvert is neither hard nor uniform. It is highly erodible.

- The caliche horizon is more resistant to erosion in the area upstream of and just downstream of the railroad bridge.
- Erosion of the caliche horizon is by surface shear from flowing water, plunging flow, and the undermining of the competent portion by erosion of the weaker underlying sediments. The undermined competent portion of the caliche horizon fails by gravity.

Total scour at a bridge is the combination of long-term degradation of the streambed, general scour of the stream channel under the bridge, and local scour at the piers and abutments. The measurements of the three components are added together to obtain the total scour at a pier or abutment. A scour study was conducted to determine:

- the relative importance and role of each of the three components of scour;
- the morphology of the channel, and human impacts on the morphology;
- the significance of the type of bridge foundations used;
- the interaction between bridge No. 504.1 and the U.S. Highway 66 box culvert (RCB culvert 4217) downstream;
- the importance of the crosswall downstream of bridge 504.1, and the cause of the failure of the crosswall; and
- the importance of the stock tank just upstream of the bridge.

The most significant results and conclusions of the scour study were as follows:

- The grouted riprap that was placed on the streambed under bridge 504.1N and 504.1S apparently had sufficient thickness, rock size, and binding to protect the piers from local scour.
- Assuming that the grouted riprap covered the channel bed beneath the bridge, as indicated by BNSF personnel, there was no contraction scour beneath the bridge deck in the August 1997 flood because the area was protected by grouted riprap.
- The August 1997 flood might have caused as much as 3.3 feet of local scour at the crosswall if the peak discharge rate was 450 cfs and as much as 5.6 feet if the peak discharge rate was 875 cfs. Either of these scour depths could have caused failure of the crosswall. The local scour downstream of the crosswall might not have attained its full depth because of the underlying caliche. The caliche at the location of the crosswall was highly resistant to erosion but was still erodible.
- A combination of long-term degradation and local scour downstream of the crosswall caused the crosswall to fail. Its failure allowed the long-term degradation of the streambed to undermine the grouted riprap, which was protecting the shallow mudsill foundations of the bents. The undermining of the grouted riprap allowed the foundations of bents 3, 4, and 5 to be undermined and to fail.

- Incision of the channel crossed by bridge 504.1 was initiated when the railroad was constructed in 1883. The construction of RCB culvert 4217 probably accelerated the long-term degradation, but it also formed an elevation control, which will limit the ultimate depth of degradation at bridge 504.1. Long-term degradation in this channel has occurred by headcut migration in the upstream direction and by gradual channel lowering progressing in the downstream direction.
- Without direct profile or photographic evidence from the late 1930s, it is difficult to conclusively determine the importance of the excavation of the channel at Highway 66 in the formation of the headcut that contributed to the failure of bridge 504.1.
- The construction of the crosswall and the placing of grouted riprap up to 20 inches thick across the bed under bridge 504.1 reveals that ATSF/BNSF personnel knew the bridge was vulnerable to scour.
- The stock tanks and grading activities in the watershed above bridge 504.1 had no significant effect on the incision of the channel or the failure of bridge 504.1.

The Ayres Associates study team conducted one-dimensional hydraulic analyses in order to clarify the impacts and relative importance of the railroad and Highway 66 on the morphology of the channel downstream of bridge 504.1.

The most significant results and conclusions of the hydraulic computer modeling study were as follows:

- The construction of the railroad in 1883 increased the velocity and erosion potential in the channel downstream from bridge 504.1 by increasing the drainage area (relevant for 2-year and smaller floods) and by constricting the flow to the width of the bridge opening (relevant for all floods). Because of the gradual rate of re-expansion downstream of the bridge (an assumption whose validity can be verified only by site observation of flooding or by two-dimensional modeling), the increase in velocity extended downstream beyond the present-day location of Highway 66.
- The construction of Highway 66 in 1934 caused an increase in velocity downstream of the box culvert for all discharge rates, leading to a markedly increased erosion potential downstream of the highway. Upstream of the box culvert, the highway embankment caused backwater, leading to reduced velocities and erosion potential, for discharges equal to and greater than the 5-year peak. For smaller flows, the excavation of the streambed, and the resulting oversteepened reach just upstream of the box culvert, led to locally increased velocities and a hydraulic jump. The higher velocities and hydraulic jump almost certainly led to significant scour upstream of the box culvert. If the conditions in the model are representative of the post-highway condition, they could definitely have led to the initiation of the headcut that is observable moving upstream toward the bridge in the historic aerial photographs.

- The excavation to place the culvert was and is a common practice. When the invert of a culvert is depressed below the natural channel grade, it is now advisable to consider the possible need for erosion protection in the oversteepened reach just upstream of the culvert.
- If the bottom of the box culvert had been placed at the existing channel grade, the potential for erosion upstream of the culvert would have been reduced, rather than increased, for all discharge rates. The maximum velocity downstream of the box culvert, however, would not have been any less under these alternative conditions than under the actual conditions.
- There was little or no impact on the erosion or morphology of the channel imposed by the widening of Highway 66 in 1971.

Attachment B: Amendments to Report Analysis

[The following revisions are to be made at page 60 of Railroad Accident Report NTSB/RAR-98/03, *Derailment of Amtrak 4,* Southwest Chief*, on the Burlington Northern Santa Fe Railway, August 9, 1997*.]

[Strikethroughs indicate deleted text; balance of text is new text to be inserted.]

~~However, the BNSF report did not include ADOT bridge inspection data or pictures of the streambed dating back to 1971, information that would have been helpful in determining the relationship between the box culverts and the railroad bridges. The Safety Board therefore concludes that the relationship of the two structures and their respective zones of influence is not fully understood.~~

The relationship between the U.S. Highway 66 box culvert and railroad bridge 504.1 is complex. Bridge 504.1, built in 1883, concentrated overland sheet flow into a single drainage course. The concentrated flow had more sediment transport capacity than the upland sheet flow and began to erode a channel at the railroad bridge. With time, the channel increased in size and progressed downstream. In the early years, the flow partially re-expanded downstream of the railroad bridge.

Highway 66, built in 1934, 1,000 feet downstream from the bridge, re-concentrated the flow that had re-expanded downstream of the railroad bridge. The concentrated flow through the box culvert accelerated channel incision downstream of the culvert. The bottom of the box culvert was set about 2 feet lower than the level of the existing swale.

The excavation to place the box culvert probably left a short, steep reach of streambed just upstream of the culvert. This could have initiated the headcut that the aerial photographs show moving upstream from 1954 to 1997 and that eventually contributed to the failure of the crosswall downstream of bridge 504.1.

Unfortunately, the available aerial photographs date back only to 1954, and no detailed channel bed profiles just upstream of the highway are available from the period just after the construction of the highway. Without direct profile and photographic evidence from the late 1930s, it is difficult to precisely determine the importance of the box culvert channel excavation in the formation of the headcut.

The box culvert also provided a positive benefit to the channel. The concrete floor of box culvert 4217 is now an elevation control point that will limit the ultimate depth of the long-term channel incision and degradation at the bridge. Had ADOT constructed a bridge on piles at this location instead of a box culvert, the ultimate degradation at the railroad bridge would have been deeper.

The Safety Board therefore concludes that both the railroad construction in 1883 and highway construction in 1934 concentrated the overland flow of water and accelerated erosion of the ephemeral streambed. The headcut that contributed to the failure of the crosswall and railroad bridge may have originated at the highway bridge after construction of U.S. Highway 66 in 1934; the upstream progression of the headcut was primarily caused by flow concentration between the railroad bridge and the highway bridge.

The American Association of State Highway and Transportation Officials provides guidelines for highway bridge construction.[9] The association's 1931 guide, "Standard Specifications for Highway Bridges and Incidental Structures," advises that

> a careful study shall be made of local conditions, including flood height and flow, size and performance of other openings in the vicinity carrying the same stream, characteristics of the channel and of the watershed area, climatic conditions, available rainfall records and any other information pertinent to the problem and likely to affect the safety or economy of the structure.

However, ADOT reported that it did not have any hydrology studies or hydraulic design documents from the initial bridge construction in 1934 or from the widening project in 1971. The construction drawings do have annotations denoting drainage areas, but no calculation sheets or other evidence was provided to demonstrate how those numbers were derived. According to ADOT, the highway bridge was performing well in 1971 and there was no reason to change the size of the waterway opening;[10] therefore, no hydrologic or hydraulic studies were needed prior to the roadway-widening project in 1971. ADOT also reported that since the accident, it has completed studies confirming that the highway bridge culverts are adequately sized and designed. However, the Safety Board believes that an opportunity was missed in 1971 when ADOT did not carry out comprehensive studies that would have identified the already existing upstream channel deterioration and that could have prompted ADOT and ATSF efforts to assess the interaction between the bridges and develop strategies to address erosion problems.

In 1975, the ATSF engineering department recommended that the railroad bridge be replaced because of concerns about the bridge's ability to provide an adequate waterway opening and recurring erosion problems. Although the bridge was not replaced, records in 1976 indicate the addition of riprap along the streambed and a concrete crosswall downstream of the bridge. Therefore, the railroad also had an opportunity to communicate with ADOT and develop joint strategies to address erosion problems. Nevertheless, the railroad was aware of the vulnerability of the bridge and should have closely monitored erosion in the vicinity and taken whatever measures were necessary to ensure safe operations. Although a track supervisor conducted a track inspection during

[9] Before the 1970s, this organization was known as the American Association of State Highway Officials.

[10] According to ADOT, the highway bridges along this stretch of highway were not designed to deal with heavy flooding and, in fact, water has crossed above the highway in the area of the subject bridge several times since 1934. The 1969 "Standard Specifications for Highway Bridges" published by the American Association of State Highway Officials states that, "On wide flood plains, the lowering of approach fills to provide overflow sections designed to pass unusual floods over the highway is a means of preventing loss of structures."

the severe weather and flooding on the morning of the accident, he was not qualified to conduct bridge inspections, and no restrictions were placed on train speeds.

The additional information developed by the Ayres Associates' study reinforces the finding that an adequate bridge inspection could have detected risk to the bridge. According to the historical photographs, at the time the crosswall was constructed, the headcut that threatened the bridges was about 240 feet away. For at least the 5 years preceding the south bridge failure (1992–1997), the headcut was about 80 feet from the bridge and less than 50 feet from the crosswall.

The railroad bridge concentrated the water flow to form a channel, which would erode and deepen over time even if the highway bridge/box culverts did not exist. Although both structures accelerated erosion of the streambed, it is the owner's responsibility to monitor and ensure a bridge's structural integrity against the effects of erosion, including headcuts or any other changes that may arise over time. Therefore, the Safety Board concludes that regardless of the cause of the headcut, Burlington Northern Santa Fe Railway and its predecessors were aware of the erosion problems affecting the railroad bridge and had ample opportunity over the years to detect the headcut and take appropriate remedial action. Moreover, the railroad decided not to replace the bridge in its 1977 Capital Improvement Program as recommended by its engineering department in 1975, reflecting that department's concern about the bridge's ability to provide an adequate waterway opening and recurring erosion problems.

[Return to original report text here]

The Safety Board believes….

Attachment C: Revisions to Report Findings

[The findings from Railroad Accident Report NTSB/RAR-98/03, *Derailment of Amtrak 4,* Southwest Chief*, on the Burlington Northern Santa Fe Railway, August 9, 1997*, are revised as follows.]

Conclusions

[*Strikethrough indicates deleted text. Underlined text is new text to be inserted.*]

Findings

1. The track did not cause or contribute to the accident.

2. The signal system was not a factor in the accident.

3. The weather warnings and alerts issued by WeatherData, Inc., were both timely and substantially correct.

4. The mechanical condition of the train was not a factor in the accident.

5. The health, rest, and qualifications of the train crew were not factors in the accident.

6. Although the track supervisor conducted a track inspection over his territory during the flooding, he was not qualified to conduct bridge inspections.

7. The failure of bridge 504.1S was caused by scour and erosion affecting the inadequately protected shallow foundations that supported the bridge; the scour resulted because a poorly designed concrete crosswall was built instead of a new and better-engineered bridge.

~~8.The relationship of the highway box culverts and the railroad bridges and their respective zones of influence is not fully understood.~~

8. Both the railroad construction in 1883 and highway construction in 1934 concentrated the overland flow of water and accelerated erosion of the ephemeral streambed. The headcut that contributed to the failure of the crosswall and railroad bridge may have originated at the highway bridge after construction of U.S. Highway 66 in 1934; the upstream progression of the headcut was primarily caused by flow concentration between the railroad bridge and the highway bridge.

9. Regardless of the cause of the headcut, Burlington Northern Santa Fe Railway and its predecessors were aware of the erosion problems affecting the railroad bridge and had ample opportunity over the years to detect the headcut and take appropriate remedial action. Moreover, the railroad decided not to replace the bridge in its 1977 Capital Improvement Program as recommended by its engineering department in 1975, reflecting that department's concern about the bridge's ability to provide an adequate waterway opening and recurring erosion problems.

~~9.~~10. Amtrak train 4 derailed when bridge 504.1S failed because the Burlington Northern Santa Fe maintenance-of-way managers lacked proper foresight and planning regarding the assignment or training or both of personnel designated to conduct bridge inspections during severe weather.

~~10.~~11. When, because of flash flooding conditions, the integrity of bridges has yet to be validated, it is critical that trains be operated at a reduced speed such as "restricted speed."

~~11.~~12. Had the Federal Railroad Administration issued minimum standards for special inspection procedures for bridges that would be at risk during severe weather, such as those standards recommended in its Safety Advisory 97-1, the Burlington Northern Santa Fe track supervisor would have had better guidance for making the special inspection.

~~12.~~13. Because an accurate passenger manifest was not provided by the Amtrak train 4 crew to the Incident Commander, the emergency response to evacuate and account for all passengers from the train could have been delayed, thus endangering passengers whose locations or circumstances were unknown to emergency responders.

~~13.~~14. Amtrak's current system for providing emergency training for train crews and on-board service personnel has not been effective, which has resulted in personnel being provided differing levels of emergency situation training.

~~14.~~ Passenger car interiors must have interior emergency lighting because a sufficient quantity of light sticks may not always be available, and light sticks may not be suitable for a large-scale evacuation such as the one that occurred in this accident.

Attachment D: Addition of Member Concurring Statement

[The following addition is to be made at page 79 of Railroad Accident Report NTSB/RAR-98/03, *Derailment of Amtrak 4,* Southwest Chief*, on the Burlington Northern Santa Fe Railway, August 9, 1997*. This text is to be inserted immediately following the report adoption date.]

On July 31, 2003, as part of the National Transportation Safety Board's response to a December 3, 1998, petition for reconsideration submitted by the Burlington Northern Santa Fe Corporation, John J. Goglia, Member, filed the following statement concurring with the Safety Board's response. Richard F. Healing, Member, joined Member Goglia in this opinion.

Notation 6912E

Member GOGLIA, concurring:

> Based on the information in the docket, I believe we should have included in the contributing causes of this accident the Arizona Department of Transportation's (ADOT's) failure to react (for years) to the erosion that was progressing toward the railroad property. It is also interesting to note (and in contrast to ADOT's inaction, the BNSF's action) that on the upstream side of the railroad property the same type of erosion is occurring, yet the railroad (as a responsible landowner) has for some time taken actions to prevent this erosion from reaching the adjacent property.