Ice Jams, Landslides, and the Northern Pacific Railway Bridge at Bismarck

by Ed Murphy

Ice Jams and the Bridge

Two ice jams on the Missouri River near Bismarck, one to the south and the other to the north, dominated local and national news in March of 2009 (fig. 1). The southern ice jam caused flood waters from the Missouri River to rise to 1,634 feet (above sea level). An elevation of 1,634.28 feet (a 16 foot-reading in the Bismarck stream gauge) is considered flood stage. This was the highest river level seen at Bismarck since 1952, one year prior to completion of Garrison Dam. The dam is located on the Missouri River 75 miles upstream from Bismarck. The northern ice jam, ten miles north of Bismarck, held water back and, in all likelihood, prevented the flood waters at Bismarck from rising to higher elevations.

Figure 1. Demolition crews set off a series of charges to weaken the southern ice jam on the Missouri River at Bismarck on March 25, 2009. A second series of charges and salt were used to further weaken the ice. Photo courtesy of the Bismarck Tribune.

The development of spring ice jams on the Missouri River would not have come as a surprise to George Shattuck Morison, the bridge engineer that designed and built the Northern Pacific Railway bridge on the Missouri River between Bismarck and Mandan in the early 1880s. Morison, a resident of New York City, came to Bismarck in the spring of 1880 to scout for a suitable bridge location and to obtain first hand knowledge of the Missouri River. After all, this was to be the first bridge to span the Upper Missouri River. While in Bismarck he witnessed a massive ice jam and noted that blocks of ice had piled up to a thickness of 20 feet in some places. An ice jam the following spring between Bismarck and Fort Abraham Lincoln caused flood waters to spill out over the bottomland to a height of 1,644.4 feet (fig. 2). These ice jams greatly concerned Morison and played a significant role in his bridge design. To minimize the chance that his bridge would be swept away by ice, Morison reduced the width of the Missouri River at the bridge site with a dike, permanently altering the river in the Bismarck area, and spaced the piers 400 feet apart. As a result, he only had to place two of his four massive granite bridge piers in the water where they would be vulnerable to ice. To protect these two middle piers, he designed them with 30-foot-high ice breaker sections on the upstream portion so that they could literally plow through the ice. In addition, he strengthened the ice breaker sections by doweling all of the granite stones into the underlying layer and plating the nose of the ice-breakers with ¾-inch steel. He also had the stonemasons smooth the stones around the ice cutters to promote downstream movement of the ice (fig. 3).

The Northern Pacific Railway Bridge at Bismarck was witness to many spring ice jams and floods between the years 1882 and 1953. Nine major flood events (above the 1,637.28 foot elevation) were

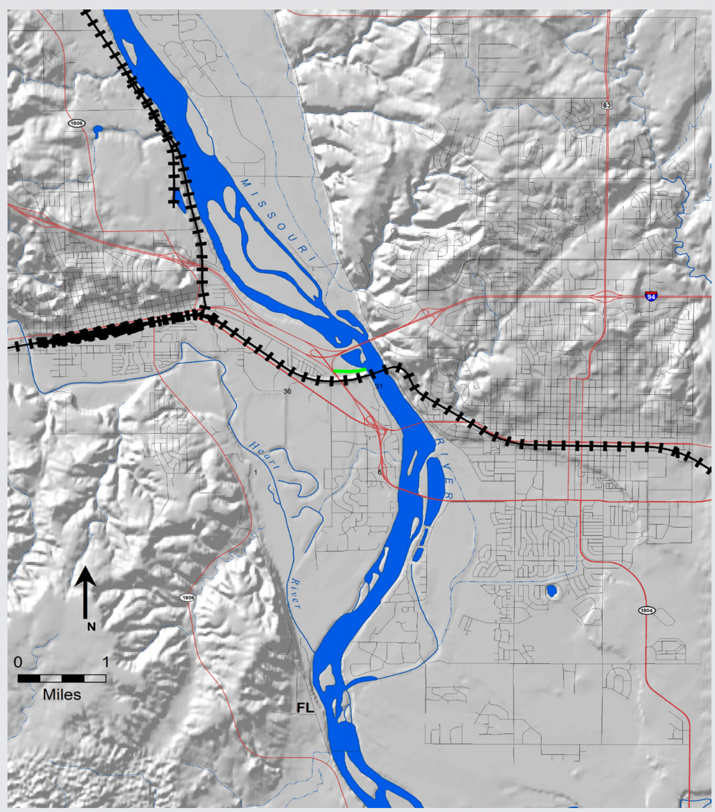

Figure 2. Shaded relief map of the Bismarck-Mandan area. George Morison's dike (green line) narrowed the Missouri River channel and constrained it against its east bank for more than one mile near the bridge site. The location of Fort Abraham Lincoln noted by FL.

Figure 3. Morison designed the two middle piers that stand in the river with a steel edge to "plow" through ice to reduce the chance of ice jams forming beneath the bridge. The granite blocks along either side of the metal edge were smoothed to encourage ice movement away from the pier. The photographs were taken in the fall of 2003 when the Missouri River was very low.

recorded in Bismarck during that time period (fig. 4). Morison did not have to wait long to see how his bridge would stand up against high water. The Missouri River reached a record high of 1649.88 feet in 1883 followed closely by a near-record level of 1,649.38 in 1887 (fig. 5).

Slope Stability and the Bridge

As time was to bear out, Morison properly designed his bridge to withstand the force of ice jams and high water. What he did not foresee was that slope instability would create decades of problems and almost lead to abandonment of his bridge. Shortly after the railroad bridge was completed, the east pier began sliding towards the river. For the next 68 years, Northern Pacific engineers applied a variety of slope stabilization techniques in an attempt to stop the pier from moving. As a result of their efforts, the bridge offers an interesting historical review of geotechnical theories and applications. These techniques included excavating a pit above the bridge site to isolate the pier from the sliding material, the keying of the rock above and below the sliding zone with blocks of concrete in an effort to lock the material together

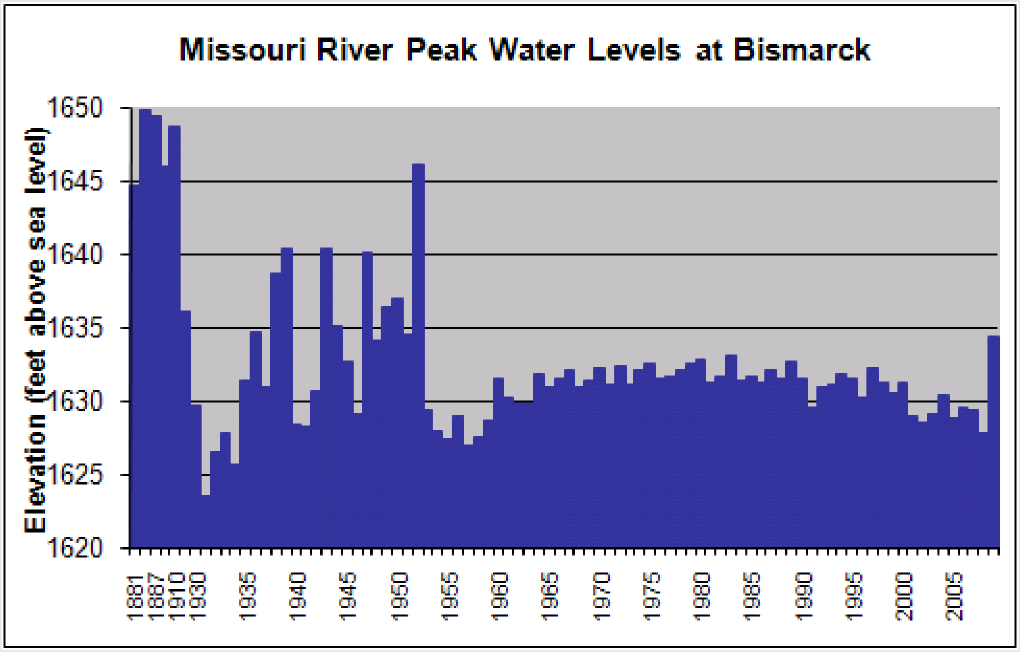

Figure 4. A graph of annual peak heights of the US Geological Survey gauging station on the Missouri River at Bismarck. Peak heights from 1929 - 2009 are from the US Geological Survey gauging station at B ismarck. Garrison Dam was completed in 1953.

Figure 5. The Missouri River flooding in the spring of 1884. Water extends all the way from the railroad bridge west to the present location of ND Highway 1806 south of Mandan. The ice breakers on the middle piers are under water indicating that the water level exceeded 1,644.4 feet. These original bridge spans were replaced in 1905 because they could no longer safely support the ever-increasing weight of locomotives. Photo courtesy of the State Historical Society of North Dakota.

and thus stabilize the slide, extending the east pier's foundation to a greater depth to get below the sliding zone, erecting a cofferdam around the pier to isolate it from the landslide, and construction of a groundwater intercept tunnel to stabilize the area by reducing pore water pressure. Ultimately, all of these attempts to stabilize the area failed.

It is appropriate that after nearly seven decades of confounding and frustrating engineers this slope stability problem would finally be solved by one of the most famous civil engineers that ever lived, Ralph B. Peck. By the late 1940s, the east approach to the bridge had to be straightened because the large locomotives of the 1930s and 1940s had difficulty negotiating it. At that time, the Association of American Railroads had a contract with the Engineering Department at the University of Illinois to investigate slope stability problems. Ralph Peck, an engineering professor at the University of Illinois and co-author of two of the most influential text books in geotechnical engineering, *Soil Mechanics in Engineering Practice* and *Foundation Engineering,* took over the project. Peck's first response was to initiate a subsurface boring investigation to identify the sediments in the problem area and to determine their soil properties (fig. 6). He used the results of that investigation to determine the factor of safety (the angle of a slope below which it should not fail) for the slope above the pier. Peck seized the opportunity that was afforded during the straightening of the railroad track to remove a considerable amount of the hillside above the east pier and reduce the remaining slope to within his desired factor of safety. Finally, after all of those years, his efforts resulted in relative stability of the slope above the east bridge pier (fig. 7).

Ralph Peck donated his papers regarding the Northern Pacific Railway Bridge to the North Dakota Geological Survey in 1993 (fig. 8). He mentioned that this project held special meaning to him because one of his father's first jobs had been to design the east tail span for this bridge. During his long and illustrious career, Dr. Peck was involved in more than 1,000 consulting projects and was the recipient of numerous accolades and awards including the prestigious National Medal of Science which was awarded by President Ford in 1974. Ralph Peck died in 2008 at the age of 95.

Figure 6. Several landslide scarps are visible along the east slopes of the Missouri River Valley above the Bismarck Railroad Bridge. The top of a City of Bismarck water reservoir is visible just below the largest tree at the top of the east slope. Photograph taken by Ralph Peck in 1951.