San Jacinto Monument Case History

Jean-Louis Briaud[1]; Jennifer Nicks[2]; Keunyoung Rhee[3]; and Gregory Stieben[4]

Abstract: The San Jacinto Monument was built in 1936 to commemorate the 100-year anniversary of the victory of the Texan army over the Mexican army. The victory at the battle of San Jacinto followed the defeat at the battle of the Alamo and secured the independence of Texas, as well as several other states along the Mexican border. The monument consists of a 176.5-m-high column resting on a large square mat with each side=37.8 m. The mat foundation was designed by Raymond Dawson who chose an average pressure of 223.8 kPa under the mat. Dawson had settlement points placed on the mat foundation together with benchmarks away from the monument. The settlement of the monument has been recorded over the last 70 years and shows a total settlement to date of 0.329 m. The settlement appears to be almost complete. This remarkable case history is used to evaluate current practice of calculating consolidation settlement and a best approach is suggested for such structures. Other issues addressed include the depth of influence, the time rate of settlement, the elastic-modulus approach, and the ultimate bearing capacity.

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Introduction

The San Jacinto Monument (Fig. 1) is in the *Guinness Book of World Records* as the tallest monument column in the world. It was built in 1936 to commemorate the victory at the battle of San Jacinto by the Texan Army over the Mexican Army in 1836 and the Texas independence that ensued. Raymond Dawson was the engineer who designed the foundation of the monument and had the vision of placing settlement points on the large mat and benchmarks away from the mat. The settlement of this very large structure has been recorded for the last 70 years; this record represents very valuable information from which many lessons can be learned. The data became available to the writers in 2004, courtesy of Philip King and Greg Stieben at Fugro Consultants where it had been archived. The writers proceeded to analyze the content of the two boxes of old papers and records. Their study and associated calculations are presented in this article.

History

On March 2, 1836, Texas unilaterally declared its independence from Mexico. The Mexicans did not want to allow such secession, and General Santa Anna and his army moved to suppress the insurgents. The battle at the Alamo Mission was the first notable battle between the Mexicans and the Texians, as they were known. The final assault on the Alamo came before daybreak on the morning of March 6, 1836 when Santa Anna and his Mexican army defeated the Texans. The Texas revolution took a step back, but on April 21, 1836, Mexican rule over Texas came to a dramatic close at the Battle of San Jacinto, southeast of present day Houston. This is where Sam Houston and his army defeated Santa Anna and his army. In commemoration of this historic event and to celebrate its 100-year anniversary, the San Jacinto Monument was built in 1936 (Fig. 1).

Raymond Dawson was professor at the University of Texas at Austin in 1936 and was asked to design the foundation for the tall column. He was aware of the work of K. Terzaghi and attended the First International Conference on Soil Mechanics and Foundation Engineering at Harvard in 1936. Dawson was the geotechnical engineer for the structure and worked with R. J. Cummins, the structural engineer, A. Finn, the architect, and C. A. Bullen, the contractor. The monument was completed in 1937, and settlement readings have been kept since that time.

Dawson kept the original data and read the settlement points 26 times from 1937 to 1966. Then in 1980, Walter P. Moore & Associates and McClelland Engineers were retained by the Texas Parks & Wildlife Department to assess the current condition of the monument. Cotton Surveying Company took the settlement measurements. In 1984, Dawson entrusted all his documents to McClelland Engineers, where Carl Fenske looked after the data. Later, McClelland Engineers became Fugro Consultants, the current steward of the data. In the Fall of 2004, Philip King and Greg Stieben of Fugro provided a copy of the data to Jean-Louis Briaud at Texas A&M University. The two boxes of data were studied; this study led to this article. In addition to these two boxes, the main historical references published on the San Jacinto Monument include Cummins (1937a,b), Bullen (1938), Dawson (1938, 1940, 1947, 1948), and Fenske and Dawson (1984).

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Fig. 1. San Jacinto Monument

Geometry, Weight, Construction, and Loading

The total height from the base of the foundation to the tip of the star is 176.5 m (Fig. 2). The foundation is a 37.8-m-square steel-reinforced mat beveled at the corners. This mat is 4.6 m thick at the center over a 14.3 m width tapering to 1.8 m thick at the edges. A set of terraces and a museum housing the artifacts of the Battle of San Jacinto are located around the base of the monument. The terraces are made of fill and represent additional loading on the soil over a wide area. Further dimensions can be found in Fig. 2.

The total weight of the monument including the column, the star, the foundation mat, and the museum structure resting on the mat is 312.7 MN (Cummins 1937a). The area of the mat is 1,397.3 m^2. The average pressure under the mat is, therefore, 223.8 kPa. The mat was founded at a depth of 4.6 m below the ground surface. Using a unit weight of 18 kN/m^3 (see the four sections on soil properties and modulus), this 4.6-m excavation corresponds to a weight of soil removed within the imprint of the foundation mat=115.7 MN and to a pressure of 82.8 kPa. Therefore, the net pressure for the monument is 141 kPa. The weight of the mat foundation itself is estimated at 133 MN (4,587 m^3 of concrete poured at 23.6 kN/m^3 in addition to the weight of the steel bars in the mat) for an average mat pressure of 95.2 kPa. Therefore, at the end of mat construction, net pressure on the soil was very small, 12.4 kPa (less than the pressure under your feet). This is when the benchmarks and the settlement points were installed, initiating the monitoring of the settlement of the structure (Dawson 1938). The two terraces surrounding the mat induce additional stress in the soil. The first terrace is 4.5 m high above the ground surface while the second terrace is 1.8 m high. The unit weight of the fill of the terrace was assumed to be 18.9 kN/m^3 and the corresponding terrace pressures are 85.1 kPa for the first terrace and 34 kPa for the second.

On September 19, 1936, the excavation for the foundation mat began. Immediately after the excavation, the soil was

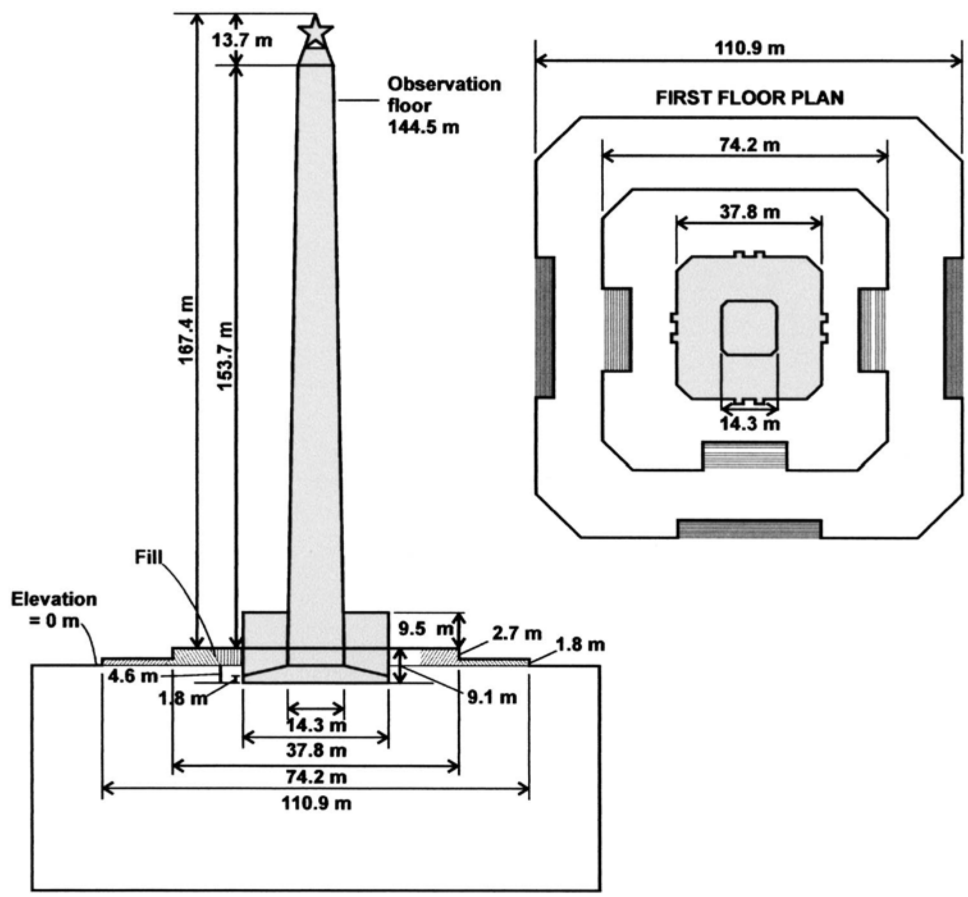

Fig. 2. Dimensions of the San Jacinto Monument

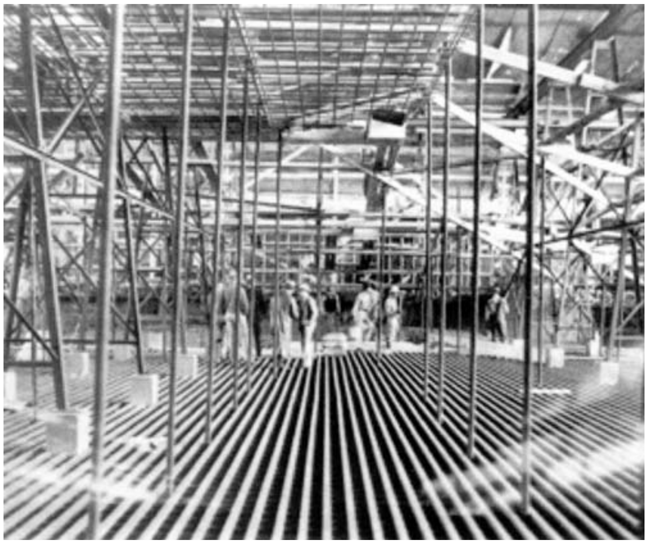

Fig. 3. Reinforcement in the foundation mat (Bullen 1938, with permission of American Concrete Institute)

hand-trimmed and leveled, and a 76.2-mm-thick, 17.2-MPa-compressive-strength concrete slab was poured as a work platform. This probably helped seal the moisture in the soil and reduced future shrinking or swelling of the soil below during construction. On October 26, 1936, workmen started to place the steel reinforcement, which consisted of 426 steel bars with a square cross section equal to 2581 mm^2, and a center-to-center spacing equal to 165 mm (Fig. 3). Then, approximately 4587 m^3 of concrete was poured in 57 to construct the slab. At the time, it was the largest single pouring of concrete ever reported. Construction ran from 1936 to 1939. It is not known when the terraces were constructed (best estimate is 1939).

The loading curve for the monument is shown on Fig. 4, and indicates that most of the monument weight was realized in late 1937. Winds of 120 mph were factored into the loading for the superstructure calculations. The maximum soil pressure on the leading edge of the mat for the combined dead load and wind load was 272.9 kPa. This pressure, however, was not used in settlement calculations. Instead, Dawson used the net pressure due to the dead load only (Dawson 1938).

Settlement Monitoring, Measured Settlement, and Tilt

In 1936, after the completion of the mat foundation, Dawson had 50 settlement-monitoring points installed. Most of them were bolts embedded into the concrete at the top of the mat, but some of them were steel rods connected to the base of the foundation.

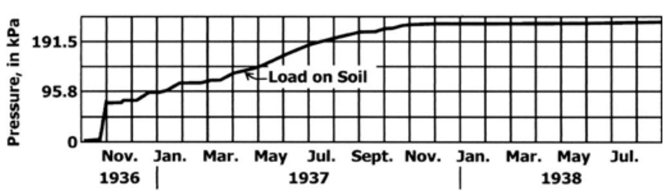

Fig. 4. Increase in pressure during construction (adapted from Dawson 1938)

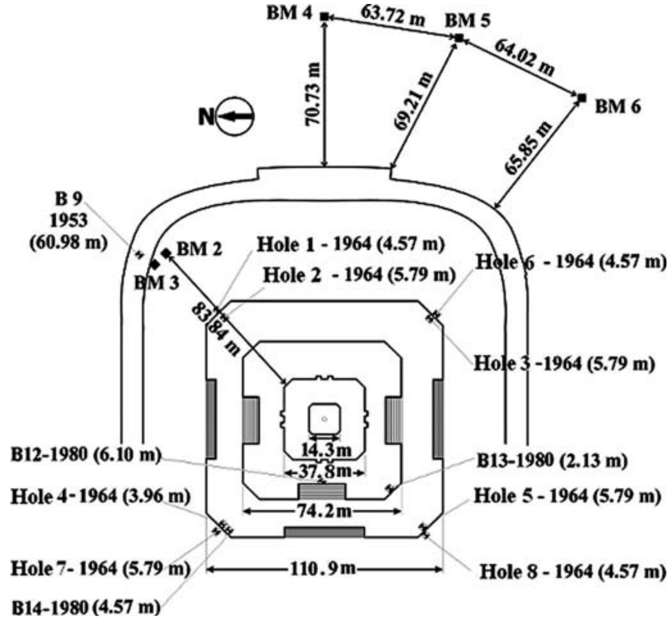

Fig. 5. Location of benchmarks and borings

According to Dawson, the purpose of the steel rods was to find out if the shrinkage of the concrete in the foundation would affect settlement readings. This was not the case, however.

Dawson designed the benchmarks which were placed away from the structure and set them at a depth of 6.7 m below the ground surface in an effort to get below the zone of seasonal moisture variation. Three benchmarks were installed in 1936, but one of them was destroyed during landscaping. The two that were left were BM2 and BM3 (Fig. 5). Dawson had three new benchmarks installed (BM4, BM5, and BM6 in Fig. 5) at an unknown date (best estimate is 1939). The settlement readings represent the difference between the average elevation of the settlement points on the mat (those that can be accessed) and Benchmark 3 (BM3 on Fig. 5).

The initial readings on the elevation of the benchmarks and settlement points were taken in Nov. 1936. The settlement-versus-time curve is shown in Fig. 6 over the 1936–2006 period; this likely represents one of the longest settlement records ever kept.

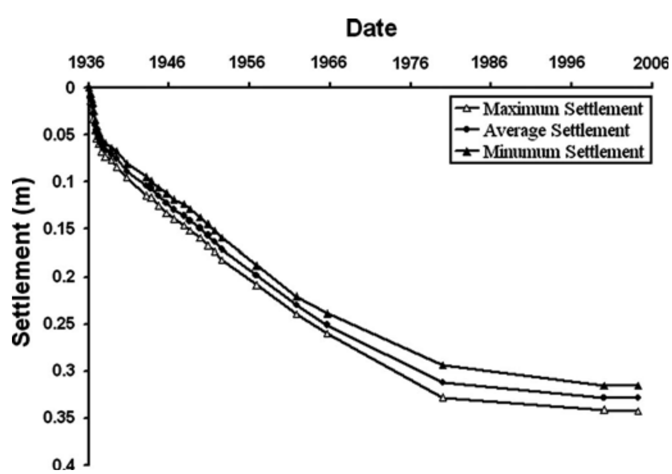

Fig. 6. Measured settlement-versus-time curve