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Preface

The study reported herein was conducted as part of the Monitoring Completed Navigation Projects (MCNP) Program (formerly Monitoring Completed Coastal Projects Program). Work was carried out under Work Unit 11M16, "Marseilles Dam, Illinois River, Illinois." Overall program management for MCNP is accomplished by the Hydraulic Design Section of Headquarters, U.S. Army Corps of Engineers (HQUSACE). The Coastal and Hydraulics Laboratory (CHL), U.S. Army Engineer Research and Development Center (ERDC), is responsible for technical and data management and support for HQUSACE review and technology transfer. Program Monitors for the MCNP Program are Messrs. Barry W. Holliday, David B. Wingerd, and Charles B. Chesnutt. The Program Manager is Mr. Ray Bottin (CHL).

The work was conducted during the period June 1999 through June 2001 under the general supervision of Dr. James R. Houston, Mr. Thomas W. Richardson, former Director and Acting Director, CHL, and under the direct supervision of Messrs. Phil Combs, Chief, Hydraulic Structures Division, James R. Leech, Chief, Spillways and Channels Branch, and Dr. Robert T. McAdory, Chief of the Tidal Hydraulics Branch, CHL. Principal investigators for the study were Ms. Deborah R. Cooper, research hydraulic engineer, and Messrs. Dave Wehrley and James Bartek, project engineers, U.S. Army Engineer District, Rock Island. The Life Cycle Cost (LCC) Analysis of the Marseilles Dam Remote Operating System was conducted by Mr. Bob Ward, electrical engineer, Rock Island District. Ice passage analysis was conducted by Mr. Andrew Tuthill, Cold Regions Research and Engineering Laboratory (CRREL). Model tests were conducted by Ms. Cooper and Mrs. Janice A. Flowers, and Mr. Earl Jefferson. Field data were obtained by Messrs. Timothy L. Fagerburg and Terry N. Waller of the Tidal Hydraulics Branch and by Messrs. S. Wallace Guy and Terry Warren of the Information Technology Laboratory. Mr. David Ray of the Information Technology Laboratory installed the time-lapse video camera and thermal equipment as well as photographed pertinent parts of the Marseilles Dam.

Ms. Cooper, Messrs. Fagerburg, Waller, Tuthill and Guy prepared this report. Acknowledgement is made to the personnel of the Rock Island District, especially Mr. James W. Hart and Rick Vesper, lock masters, and the staff at Marseilles Lock and Dam, for their assistance and information on ice operations in this investigation.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL John W. Morris III, EN, was Commander and Executive Director.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in figures and tables of this report can be converted to SI units as follows:

Multiply	By	To obtain
acres	4046.856	square meters
cubic feet	0.02831685	cubic meters
cubic feet	28.32	liters
cubic yards	0.7646	cubic meters
degrees (angle)	0.01745329	radians
feet	30.48	centimeters
feet	0.3048	meters
inches	2.54	centimeters
inches	25.4	millimeters
miles	1.609344	kilometers
pounds (force)	4.448222	newtons
pounds (mass)	0.45359	kilograms
square feet	0.9290304	square meters
square miles	2.589988	square kilometers
tons (2,000 pounds, mass)	907.1847	kilograms

1 Introduction

Objective

The objective of the monitoring plan was to determine if the Marseilles Dam remote operation system and the submersible tainter gates were performing efficiently and practically vibration-free, as predicted.

Monitoring Completed Navigation Projects Program

The goal of the Monitoring Completed Navigation Project (MCNP) Program (formerly Monitoring Completed Coastal Projects Program) is the advancement of coastal and inland waterways engineering technology. It is designed to determine how well projects are accomplishing their purposes and are resisting attacks of the physical environment. These determinations, combined with concepts and understanding already available, will lead to more credibility in predicting engineering solutions to coastal and inland waterways problems; to strengthening and improving design criteria and methodology; to improving operation and construction practices and cost-effectiveness; and to improving operation and maintenance techniques. Additionally, the monitoring program will identify where current technology is inadequate or where additional research is required.

To develop the direction for the program, the U.S. Army Corps of Engineers established an ad hoc committee of coastal engineers and scientists. The committee formulated the program's objectives, developed its operational philosophy, recommended funding levels, and established criteria and procedures for project selection. A significant result of their efforts was a prioritized listing of problem areas to be addressed, essentially a listing of the program's areas of interest.

Corps offices are invited to nominate projects for inclusion in the monitoring program as funds become available. A selection committee, comprised of members of the MCNP Program Field Review group (representatives from District and Division offices) and civilian members of the Coastal Engineering Research Board, reviews and prioritizes the projects nominated. The prioritized list is reviewed by the Program Monitors at Headquarters, U.S. Army Corps of Engineers (HQUSACE). Final selection is based on this prioritized list, national priorities, and the availability of funding.

The overall monitoring program is under the management of the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), with guidance from HQUSACE. Operation of individual monitoring projects is a cooperative effort between the submitting Districts/ Division office and CHL. Development of monitoring plans and the conduct of data collection and analyses are dependent upon the combined resources of CHL and the Districts/Division. Marseilles Dam, IL, was nominated and subsequently approved for inclusion in the monitoring program in 1998.

Project Location and History

Marseilles Dam was designed by the State of Illinois and constructed by the State and the Federal governments. The dam was completed in 1933 at a cost of $570,725. The Marseilles Canal was required because the rapids (downstream of the present dam) were being utilized as a source of hydropower. Hydropower generation has since been abandoned. Marseilles Dam maintains the navigation pool between Marseilles and Dresden Island locks on the Illinois Waterway. Major commodities shipped in this pool include coal, petroleum products, chemicals, and farm products.

Marseilles Dam is located near the upstream end of the Marseilles Canal at river mile 247.0 on the Illinois River, near the city of Marseilles, IL, approximately 9.6 km (6 miles)[1] southeast of the city of Ottawa, La Salle County, and 104.6 km (65 miles) southwest of Chicago, IL (Figure 1). Marseilles Lock is located at the mouth of Marseilles Canal, 3.9 km (2.4 miles) downstream of the dam at river mile 244.6. The lock and dam are connected by Bells Island, and maintain a 2.7-m-(9-ft-)deep channel in Marseilles Pool. Constructed between 1930-1933, the lock is 33.5 m (110 ft) wide by 182.9 m (600 ft) long with horizontally framed miter gates at both ends with a maximum lift of 6.4 m (21 ft). The lock concrete and mechanical and electrical systems were rehabilitated in 1977, and the lock miter gates were replaced in 1996.

Project Description

The main dam is a gated structure consisting of a 168.2-m-(552-ft-)wide section containing eight 18.3-m-(60-ft-)wide submersible tainter gates and a 14.2-m- (46.5-ft-)wide section containing an abandoned 9.1-m-(30-ft-)wide ice chute (Figures 2 and 3). The normal head on the main dam is about 4.0 m (13 ft) and the upper pool is maintained at el 483.17. The submersible tainter gates (Figure 4) replaced counter weighted nonsubmersible tainter gates (Figure 5) during the 1986-1987 major rehabilitation contract that also repaired deteriorated concrete and replaced the service bridge and machinery. The spillway submersible tainter gates are 18.3 m (60 ft) wide by 4.9 m (16 ft) high with a

[1] Units of measurement in the text of this report are shown in SI units, followed by non-SI units in parentheses. In addition, a table of factors for converting non-SI units of measurement used in figures and tables in this report to SI units is presented on page vii.

radius of 7.6 m (25 ft). Marseilles Pool has very tight tolerances (±6.1 cm (0.2 ft) "flat pool") requiring frequent gate adjustments to stay within the limits. The Marseilles pool must be maintained within these limits to prevent the overtopping of fully closed tainter gates and to maintain the 2.7-m-(9-ft-)deep navigation channel over a rock cut near Ballard's Island. Prior to the 1988-89 installation of a remote operation system, Marseilles Dam had to be attended 24 hr/day (amounting to four full-time operating positions) because the lock and dam are 3.9 km (2.4 miles) apart, too distant to reasonably work both sites in a single shift.

Project Operation

Automated gate operation

The existing operation of the gates at the dam is performed remotely from the lock operation room. The gate operations can also be operated in a manual-local mode of operation where all controls for gate operation are done from the machinery service bridge located on top of the dam. The gate controls are located on the machinery bridge above each gate. The pool level is continuously displayed and recorded at the control panel in the lock operation room as well as in the old boiler house at the dam. The digitally displayed readings are averaged over time to eliminate the variability of readings due to wind and boat waves. Devices that are attached to the pinion arms measure the gate positions. These devices measure the angular rotation of each gate and convert these values to actual gate openings. The gate-opening values are then displayed in the lock operation control room. All gate operations are recorded by the lock and dam operator and include the time of day, new settings of all of the gates operated, upper pool level, and tailwater level. The more trouble-free operation of submersible tainter gates helped make it possible to operate the dam from a remote location and alleviated the need for 24-hr staffing of the dam, which was required prior to the installation of a remote system in 1988-89. Displayed readings are averaged over a period long enough to give readings accurate to ± 0.3 cm (0.01 ft). This requirement prevents variable readings due to waves and manually overcompensating the gate openings.

The positions of all gates are monitored by measuring the angular rotation of the gates and converting the angular rotation to actual gate openings at the lock. The gate positions are displayed and recorded in feet. Whenever a gate adjustment is made, the time of day, amount of change, new settings of all of the gates, pool level, and tailwater stage are recorded.

As a security and safety measure, the project is equipped with three intensified low light video cameras. The cameras allow the lock and dam operator to survey the upper pool, the tailwater, the dam and the landing areas at each end of the dam prior to and immediately following all gate operations.

Gate operation schedule

The current gate operation schedule used at Marseilles Dam was developed from the combination of the experience of the operating personnel and rating curves from the physical model study. An added benefit of the current operating schedule is the improvement in the hydrodynamics in the upper pool that does not create a problem to the navigation of commercial vessels entering or exiting the lock structure. The schedule most favorable to navigation included opening the gates farthest from the Marseilles Canal first and working across the dam as flows increased.

With eight submersible tainter gates, Marseilles Dam affords a flexible gate-operating schedule. The constraints placed explicitly upon the gate operation schedule for the manual and remote operating modes were as follows:

a. The pool level is to be maintained within 6.1 cm (0.2 ft) of "flat pool" without excessive oscillations of the gates.

b. The gates should not be left in a position that could cause scour (e.g., one gate wide open while the remaining gates are closed).

c. The gates should not remain at settings in which they are vulnerable to damage from floating ice and debris (experience has shown 1.2-2.7 m (4-9 ft) of bottom opening results in water velocities that carry logs, ice, and debris with potentially gate damaging force)

d. The gate settings should minimize outdraft, which is a hazard to navigation.

e. The operation should result in approximately equal use of the gates.

Winter operations and ice problems

Prior to the installation of submersible tainter gates, winter operation was difficult due to ice buildup on the structural members of the gates. The gates often froze in place at the side and bottom seals. Ice removal required the application of steam produced from the boiler room at the dam. These deicing operations were hazardous, time consuming, and ineffective for thawing ice that was covered by water. The old tainter gates were not designed to pass ice without being raised nearly wide open and would result in dangerously low pool levels. To prevent this condition from occurring, the gates would be closed and the pool level allowed to build up, storing excess water. Then one or two of the gates were opened wide open to allow the ice to pass. The ice-passing problem was compounded by the low tailwater elevations that typically occurred during cold weather, low flow periods. The combination of the high discharge created from the wide-open gates and the low tailwater elevations resulted in considerable turbulence below the spillways and increased the potential for downstream scour to occur. The submersible tainter gates and the addition of the remotely operated system have enhanced the efficiency of the project operations for ice passage and pool regulation.

The old counter weighted nonsubmersible tainter gates needed to be raised a minimum of about 1.5 m (5 ft) in order to draw ice or debris beneath. Under conditions of heavy drifting ice, however, operators would open the gates to 3.4 m (11 ft), 0.6 m (2 ft) above the normal pool level, to prevent the floes from damaging the gate undersides. Under the right conditions, the large openings of one or two gates would create sufficient current to draw ice from the pool and canal entrance to the gates for passage. Also, when large ice slabs, 15.2 to 21.3 m (50 to 70 ft) in width would lodge against the dam piers, the large openings would draw down the water level in front of the gates sufficiently to break the floes in bending then pass the ice as smaller pieces.

Sometimes a free towboat or "light boat" would make a few passes in front of the dam to break the sheet into pieces small enough to pass the gates. According to Jim Hart,[1] lockmaster at Marseilles, before the gate rehab, passing heavy ice through fully raised tainter gates caused noticeable vibration of the dam. Because most of the winters since the rehab have been warmer than average, the new 18.3-m- (60-ft-)wide submersible tainter gates may have not yet experienced extreme ice conditions similar to those in the mid-1970s to mid-1980s period.

The downstream sides of the old tainter gates had a lot of exposed structural members that tended to accumulate ice, either from spray from the fast water moving beneath or from leaks along the side seals. In addition, the clearance between the gate trunnion arms and the concrete pier walls was only a few inches, so a small amount of ice buildup would freeze the gate in place. The ice along the "j" seals and trunnion arms had to be steam-melted or chiseled off, before the gates could be moved. This work was labor intensive, slow, and at times, hazardous to personnel working out and around the gates in all weather and river conditions. Figure 10 shows an ice-encrusted gate similar to the old Marseilles gates being steamed at Dresden Island Dam in 1998.

The new submergible gates are fully enclosed front and back and therefore less prone to ice buildup than the old gates. Also the gate arms are angled away from the pier walls with the clearance distance increasing moving away from the trunnions and towards the gate face. Running in submerged mode, spray icing and seal leakage do not result in ice buildup. During periods of extreme cold, the gates are moved or cycled every 2 hr to prevent freezing. Figure 11 shows one of the new gates at Marseilles Dam.

In the winter of 2000, the gates ran submerged from 20 January to 3 March, with typical openings in the 0.2 to 0.3-m-(0.5 to 1.0-ft-) range. To minimize outdraft on tow traffic at the canal entrance, the gate schedule favors openings on the right (north) side of the dam and moving progressively to the left as discharge increases. Figure 12 shows rating curves for the gates in underflow mode and submerged mode, based on approximate data from the Rock Island District,

[1] Personal Communication, August 2000, J. W. Hart, lockmaster, Marseilles, Lock and Dam.

showing that 0.3 m (1 ft) of underflow is equal to about 0.6 to 0.9 m (2 to 3 ft) of overflow in terms of gate discharge.

According to Jim Hart,[1] if drifting ice is light, it will pass the gates at even submerged openings in 0.2-0.3-m-(0.5-1-ft-) range. To pass light-to-moderate loose brash, from the canal and navigation channel, Gates 1, 2 and 3 need to be submerged 0.6 to 0.9 m (2 to 3 ft). To pass heavy brash, or large floes, several gates must be raised to a position 0.6 m (2 ft) clear of the water surface, as was done with the old gates. This practice concentrates the flow towards the gates and develops enough water velocity to prevent arching and avoid damage due to ice impacts. Ice congestion of the canal plagues winter operations at Marseilles Lock. With a good west wind and above-freezing air temperatures, it is possible to draw ice out of the canal and through fully opened Gates 1 and 2. Unfortunately no ice was passed in this manner during the winter of 2000, so there is no video or accelerometer data for what is probably the most extreme case.

Hydrometeorologic Conditions, Winter 2000 Compared to Long-Term Averages

Although winters are often severe enough to form significant ice on the Illinois River, the winter of 2000 was the fourth mildest since 1959 and very little ice formed. Accumulated freezing degree days (AFDD's), the cumulative sum of the degrees below the freezing mark, based on daily average air temperature, are a good indicator of the relative coldness of a winter and the potential for ice growth. Figure 6 shows the AFDD curve for the winter of 2000, which peaked at 307, less than half the long-term average of 742 (Figure 7). Figure 8 plots daily average air temperature for Chicago, showing two subfreezing periods, the first from late December to early January and the second from the last week of January to mid-February.

Ice thickness on a lake or river can be estimated from the equation:

$$ti = C(AFDD)^{0.5} \quad (1)$$

where *ti* is ice thickness in inches, AFDD is accumulated freezing degree (F) days and C is a coefficient that usually ranges from 0.3 to 0.6. Using 0.3 as a coefficient, theoretical ice thickness (Figure 6) reaches a maximum of only 12.7 cm (5 in). Observed ice thickness turned out to be significantly less than this, however, due possibly to upstream thermal inputs from industry.

The prevailing winter winds at Chicago are from the west and average 17.7 kmph (11 mph). Average discharge on the Illinois River at Marseilles during January of 2000 was about 85 m3/s (3,000 cfs), roughly one-third the

[1] Personal Communication, J. W. Hart, op cit.

long-term average of 283.7 m3/s (10,019 cfs). Pool stage was fairly constant at el 484.2,[1] seldom varying more than several tenths of a foot (Figure 9).

Scope

Evaluation of the Operations and Maintenance Navigation Information (OMNI) data, operations and maintenance schedules and costs, hydrodynamic conditions, and validation of the model as a design tool were performed. Ice passage conditions were recorded by the Rock Island District and ERDC using time-lapse photography to document the effectiveness of the submersible tainter gates in passing ice. The video footage was obtained under the direction of ERDC and Rock Island District personnel. The Cold Regions Research and Engineering Laboratory (CRREL) provided consultation and analysis. Data recorded in the OMNI system was evaluated to determine any operational limitations of the remote operating system as well as the submersible tainter gates. Field-testing was conducted to obtain vibration data of the submersible tainter gates for various operations and flow conditions that occurred during a 12-month period. The data acquired during this period were analyzed to determine the gate vibration response to flows over or under the instrumented gates. The analysis included the determination of acceleration amplitudes and maximum displacements in the vertical, longitudinal, and transverse directions. The submersible tainter gates at Marseilles Dam do not significantly vibrate under normal operation for flows under and over the gate, or with passing ice.

To evaluate the cost savings realized by installing the remote operating system a Life Cycle Cost (LCC) analysis investigated the sum of construction, repair and labor costs of the remote system vs. the costs of the four full-time dam employees that it replaced. A qualitative analysis of ice passage was done by CRREL using February 1989 time-lapse video footage from a CRREL video camera mounted during the winter of 1988 and an ITL video camera mounted during the fall of 1999 on a pole on the north shore, upstream of the headrace gates. OMNI data and hydrodynamic conditions were used to correlate field conditions with data collection. To validate the model as a design tool, results from the physical model study conducted in 1985 were compared with field data. To perform the required data collection, four of the eight flow control gates were instrumented with accelerometers to monitor vibration and inclinometers to monitor gate motion. The lock and dam operation personnel recorded the date, time, and gate opening for each instrumented gate used in the flow release operation. An onsite data acquisition system recorded the accelerometer and inclinometer sensor outputs for flow releases that used the instrumented gates. The conditions evaluated included gates in the raised positions, gates in the submerged positions, and all combinations of single or multiple gate operations. The existing data in the OMNI system were used to examine variation in pool levels and the response time involved in changing the gate settings and the effectiveness in maintaining the pool within the tight tolerances that were established by the Rock Island District.

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[1] All contours and elevations cited herein are in feet referred to mean sea level (msl) unless otherwise noted. (To convert feet to meters, multiply by 0.3048)

Hydraulic Model Study of the Gates[1]

During 1985, a 2-D physical model study of the Marseilles Dam submersible gate was conducted at ERDC to:

a. Determine the magnitude and frequency of the hydraulic forces acting on the lifting cables while the gate was submerged.

b. Verify anticipated stilling basin performance for all probable operating conditions.

c. Determine discharge characteristics and coefficients with various operating scenarios.

The Marseilles model (Figure 13) was constructed to a linear scale of 1:20, model to prototype. It reproduced a 36.6-m-(120-ft-)wide section of the spillway and stilling basin including one freely suspended 18.3-m-(60-ft-)wide by 4.9-m-(16-ft-)high submersible tainter gate, two 2.5-m-(8-ft-)wide piers, and two 6.7-m-(22-ft-)wide by 1.8-m-(6-ft-)high portions of the tainter gate on either side of the piers. The model tainter gate (Figure 14) was constructed of brass and simulated a prototype weighing 72,574.4 kg (160,000 lb) (dry weight). The upstream and downstream skin plates and trunnion arms were reproduced to scale. Originally the rubber side seals were omitted, simulating a 10.2-cm (4-in.) gap between the gate and the piers. This provision was made to avoid friction between the gate and piers and was part of the type 1 and 2 designs. However, this provision proved to be too significant a deviation from the prototype and was responsible for most of the vibration initially recorded. To reduce friction forces to a minimum, the gate trunnions were mounted in roller bearings in the adjacent piers. The gate-to-sill clearance simulated was 2.5 cm (1 in). The piers and ice deflectors shields (Figure 4) were constructed of transparent plastic; the portion of the model representing the spillway sill and apron was fabricated of sheet metal. The two adjacent gates were simulated schematically and reproduced only the shape and size of a nonsubmersible-type tainter gate. The gate lifting mechanism consisted of a cable at each end of the gate attached to load cells suspended by a pulley system (Figure 13). Each model cable was sized to reproduce the elastic properties of four prototype cables proposed for each end of the gate.

Water used in the operation of the model was supplied by pumps, and discharges were measured with venturi meters. The tailwater in the downstream end of the model was controlled by an adjustable tailgate. Steel rails set to grade provided reference planes. Water-surface elevations were obtained with point gages. Velocities were measured with a pitot tube. Load cells and an oscillograph recorder were used to measure and record the magnitude and frequency of the total forces acting on each end of the gate. Chart speed used during testing was 2.5 cm/s (1 in/s).

[1] U.S. Army Engineer Waterways Experiment Station. (1989). "Submersible-type tainter gate for spillway, Marseilles Lock and Dam," Vicksburg, MS.

Model tests were conducted to observe the conditions with flow over and under the gate and to determine the magnitude and frequency of the hydraulic forces acting on the lifting cables with various gate openings and submergences of the gate. To measure the forces on the gate, the pool elevation was held constant while the position of the gate and the tailwater were varied.

All tests were conducted with the upper pool level maintained at a constant elevation of 483.17. Prior to the start of a test, the force-measuring equipment was checked to ensure that it was working properly, the moving parts of the test gate were examined, and the water levels of the upper pool and the lower pool below the gate were properly adjusted. After the force-measuring device was zeroed, the device was then placed in operation (raising or lowering the test gate). The force on the hoisting cables was measured by raising the crest of the gate in 0.3-m (1-ft) increments to a desired elevation and holding it there for a measurement. All model force data presented in the tables in this report were measured in this manner.

Tests were conducted with two different spillway crest designs for the submersible-gated spillway. These designs, furnished by the Rock Island District, differed only in the shape of the spillway crest upstream from the gate. The type 1 (original) design (Figure 15) had a curved shape with an 27.1-m (89-ft) radius, and the type 2 design had a 0.8-m-(2.5-ft-)broad horizontal sill preceded by a 1V on 1.2H sloping face (Figure 15). Tests were conducted to determine discharge characteristics, stilling basin performance, loads on the gate lifting cables, and vibration tendencies of decreasing the clearance between the gate and pier and increasing the gate-to-sill clearance.

Initially, tests were conducted to assure that the natural frequency of the model cables were not in the range of the natural frequency of the exciting forces measured in the model. The prototype cable natural frequency was estimated by the Rock Island District to 4.5 Hz.

Forces induced in the gate lifting cables by flow under and over the subject gate were measured with a normal upper pool (el 483.17) in combination with various tailwater elevations. A profile sketch and definitions of terms are presented in Figure 16. A sample oscillograph record and sample calculation are presented in Figure 17. Test results are tabulated in Tables 1 through 6.

During tests an undular jump or "rooster tail" developed immediately downstream of the gate with several combinations of gate opening and tailwater elevations with a normal upper pool (el 483.17). Vibrations of the gate with flow under the gate were recorded with these conditions. The model test results indicated the original (type 1) would likely permit the gate cables to be subjected to loads occurring at a random frequency during normal operations with flow under small gate openings due to the contact of the gate with flow. The magnitude of these vibrations, however, was very small (less than 3 percent) compared to the gate's weight. With flow over the type 1 design structure, the likelihood of forces acting on the cables at a periodic frequency was indicated for essentially all submergences and expected headwaters and tailwaters. The frequency of the induced forces (1.6-3.4 Hz) was considered unacceptably close to the natural frequency of the prototype lifting cables (4.5 Hz). Because of the proximity of the frequency of the flow-induced loads on the cables to the natural frequency of the prototype values, the type 1 design structure was considered unstable.

The model test results indicated the type 2 design would likely permit the gate cables to be subjected to loads occurring at a random frequency during normal operations with flow under small gate openings due to the contact of the gate with flow. The magnitude of these vibrations, however, was very small (less than 2 percent) compared to the gate's weight. With flow over the type 2 design structure, the likelihood of forces acting on the cables at a periodic frequency was indicated for gate submergences of up to and including 1.8 m (6 ft). There was some reduction in the frequency and magnitude of the periodic vibrations with the type 2-design structure. Loads began to occur at a random frequency for gate submergences of 2.1 and 2.4 m (7 and 8 ft) (fully submerged).

The type 3-design structure incorporated the type 2-design spillway crest and the extension of the gate end shields to decrease the gate-to-pier clearance from 10.2 to 1.3 cm (4 in. to 0.5 in). Forces induced in the gate lifting cables by flow under and over the subject gate were measured with a normal upper pool (el 483.17) in combination with various tailwater elevations.

The model test results indicated the type 3 design would likely permit the gate cables to be subjected to loads occurring at a random frequency during normal operations with flow under small gate openings due to the contact of the gate with flow. The magnitude of these vibrations, however, was very small (about 1 percent) compared to the gate's weight. With flow over the type 3-design structure, the forces acting on the cables occurred at a random frequency for submergences of 0.6, 1.5, 1.8, and 2.1 m (2, 5, 6, and 7 ft). The gate cables were not subjected to any vibrations for most gate submergences.

Because of the likelihood of the occurrence of random vibrations during normal operation of the gate with flow under or over the gate, ERDC suggested a brace to physically hold or lock the gate into position. A friction shoe (Figure 18) that could be installed on each side of the gate between the gate and pier was designed by the Rock Island District and was tested in the model. Although tests with the friction shoe indicated essentially no occurrence of vibrations, there was some doubt that these results were anything but qualitative because the friction in the model supplied by the friction shoe cannot be directly scaled to simulate prototype friction. The value of the friction was that it provided a factor of safety in the event that vibration occurred. Therefore, the type 3 design structure with a friction shoe installed on each side of the gate was recommended for prototype construction. The Rock Island District, however, opted not to include the friction shoe in the construction contract for the submersible tainter gates with the following rationale. The total amplitude, Δ_p, of the highest load fluctuation measured in the model was 680.4 kg (1,500 lb). Only one-half of that load fluctuation would have to be overcome by friction to negate the exciting forces and prevent vibrations (Figure 17). One-half of that, or 170.1 kg (375 lb), would have to be overcome by friction on each side of the gate. A conservatively low estimate of the prototype trunnion friction on each side of the gate is 272.2 kg (600 lb). The side seal friction at each side of the prototype is estimated at 1,360.8 kg (3,000 lb), giving a significant factor of safety. In addition, the load fluctuations in the model acted at random frequencies rather than at periodic frequencies; thus, the deflection in the cables will not build resonantly. The first of the prototype gates was put into operation in January 1987, and the last (eighth) gate was put into operation in March 1988. All of the prototype submersible tainter gates have been operating practically vibration free.

2 Monitoring Program

Monitoring Plan

Advantages of submersible gates are the capability of skimming loose ice with a minimum amount of flow, and avoiding downstream scour often associated with large underflow gate openings at low tailwater. Also, submerged operation largely avoids the problem of freezing-in of side seals. Vibration of gates has been reported at some of the 110-ft-wide submergible gates on the Ohio River. On some of these projects, a retrofit to a sharp-crested bottom seal eliminated the problem[1] but at others, submerged mode of operation was discontinued. A monitoring plan was developed prior to monitoring the Marseilles Dam site. During the development of the monitoring plan specific hypotheses to be tested were laid out. The hypotheses to be tested include the following:

a. The remote operating system increased the capability of the dam to maintain operation during extreme weather or river conditions.

b. The remote operating system meets the operating constraints previously identified.

c. The remote operating system is a reliable system that provides considerable cost savings over the previous onsite manual operation.

d. Operational limitations of the remote operating system can be identified, with proposals to minimize these limitations.

e. The submersible tainter gates are more effective in passing ice than the conventional counter weighted tainter gates. An operation schedule can be developed to enhance gate operation during adverse weather conditions.

f. Adjustment of the submersible tainter gates in freezing conditions is less hazardous, less time consuming, and more effective and efficient than the old steam method that was used on the counter weighted tainter gates.

[1] U.S. Army Engineer District, Louisville. (1985). "Submergible gate use within the Corps, case histories," Louisville, KY.

g. The submersible tainter gates at Marseilles Dam do not significantly vibrate under normal operation for flows under and over the gate, or with passing ice.

h. The model investigation accurately quantified vibration conditions for flows over and under the gates.

Equipment and Data Collection

After a visit to the dam and discussions with photographer David Ray, Information Technology Laboratory (ITL), it was decided to locate a time-lapse video camera on a pole on the north shore, upstream of the headrace gates. Figure 19 shows the camera location and the fields of view of both the ITL and CRREL cameras. Marseilles Lock personnel agreed to periodically change, install, and store the videotapes for the data collection personnel to retrieve on their monthly visits to check equipment and collect gate vibration data. The lockmasters also agreed to save the time-lapse videos from their surveillance cameras during the 2000 ice season for our review, but unfortunately the resolution of these images was not good enough to be of much use. They also kept a log of their gate changes during the submerged operation period. CRREL reviewed and tabulated the time-lapse data from the winters of 2000 and 1988 and also analyzed the CHL accelerometer data surrounding the three ice passage events.

The monitoring plan was designed to instrument four of the eight gates (Gates 1, 3, 5, and 7) at the dam for assessing vibration levels during flow release operations. The location of the instrumented gates on the structure is shown in Figure 3. Each of the four gates was instrumented with a triaxial accelerometer, to measure three axes of gate vibrations, and an inclinometer, to measure the gate rotation. These data were recorded for all operations during a 12-month period of normal water discharge for pool regulation and ice passage with the instrumented gates in the raised and submerged position, respectively.

The accelerometers, shown in Figure 20, are PCB Model 356A08, each having a frequency response of 0.3 Hz - 7000 kHz. These devices were chosen in order to obtain the low-end frequencies that are anticipated to be present during winter ice passage. The submersible tainter gates operate as a tainter gate and pivot at a trunnion pin located on each downstream pier face. The pivoting of the gate during raising or lowering operations creates an opening between the spill-way crest and the gate to allow water to flow under or over the gate, respectively. The gate rotates through different gate angles required to obtain the desired flow releases. As a result of the angular displacement of the gate, a strain gage accelerometer was rejected because the DC response was too low and therefore would limit the accuracy of the analog to digital signal being recorded.

The accelerometers were mounted on the inside of the gates and located at the center of the gate as shown in Figures 21a and 21b. Access to the inside of the gates was made through a small, 61-cm-(24-in.-)dia, manhole door near the end of the upper trunnion arm. The triaxial accelerometers were enclosed in a waterproof canister, as shown in Figures 21a and 21b, and were attached to the middle strut inside of each instrumented gate. They were set in a level horizontal position with respect to the gates being set at zero gate opening positions. The signal cables from the instruments were routed through small holes located at the top of the structural support webbing of the gate to the air vent opening located at the trunnion arm side of the gates. Figures 22a – 22c illustrate the space limitations inside the gate structure and the instrument cable routing during the installation. The cables were then passed through the gate air vent and up to the machinery access bridge above the gates, as shown in Figures 23a and 23b. A protective PVC conduit for the instrument cables was installed along the machinery service bridge above the gates. Approximately, 164.6 m (540 ft) of 7.6-cm-(3- in.-)PVC pipe were installed and anchored to the service bridge walkway, as shown in Figures 24a and 24b. The signal cables from each set of instruments were installed in the PVC conduit as it was assembled. At the north end of the machinery service bridge the cable conduit was routed under the stairway as shown in Figure 24c. At the north end of the dam, the cables were routed underground through an existing 5.1-cm-(2-in.-) diam metal conduit that terminated at the outside wall of the old boiler room building. A hole bored in the wall of the building allowed access of the instrument cables to the inside of the building near the data acquisition equipment table.

All the cables were connected to the data acquisition system. The cables were then checked for proper conductance prior to connecting them to the data acquisition system as shown in Figures 25a and 25b. The data acquisition system was turned on to assess the system operation and the integrity of all the instruments. The data acquisition system was found to be operating properly. However, upon checking the integrity of the instruments several problems were encountered. Accelerometer A1 (located on Gate 1) had no signal on the y-axis. Accelerometers A3 and A7 (located on Gates 3 and 7, respectively) had no signal on the y-axis and z-axis. The cables were again inspected for proper signal conveyance and determined to be satisfactory. The problem was determined to be within the accelerometer gage itself. It was determined that the malfunctions of the accelerometers were the result of a static electricity charge created by pulling the signal wires through the PVC pipe. This electrical charge had entered the ends of the cables and overloaded the sensors. Only one spare triaxial accelerometer and mounting bracket were available to replace the damaged instruments. Accelerometer A7 was replaced with the spare. Two replacement accelerometers were ordered for sensors A1 and A3. The replacement gages were installed 1 month later during the first service trip to download the data from the data acquisition system. A tap test was performed on the operating accelerometers as a check on the instruments signal response. The tap test is performed by gently tapping on the outside of the accelerometer housing in various directions to produce excitation of the accelerometer. The axes of acceleration are identified as follows:

Vertical = x (vibration in the up and down direction; + = up, - = down)

Radial = y (vibration in the upstream and downstream direction; + = downstream, - = upstream)

Transverse = z (side-to-side direction (north-to-south); + = north, - = south)

To monitor movement of each instrumented gate, an inclinometer was installed near the accelerometers on the middle strut inside of each instrumented gate. These devices were also installed in a waterproof canister, shown in Figure 26. The inclinometer measured the angular rotation of the gate and served as a triggering device to activate the remote data acquisition system for recording the accelerometer data. Data recording did not begin immediately following any movement of the gates. A time delay of 15 min was programmed into the data acquisition system before the recording of the data would be initiated. This delay provided an ample time period for fine adjustment of the gate openings by the operator and also allowed sufficient time for the flow through the gates to stabilize. If no additional gate movements were detected by any of the inclinometers during this time delay period, the data recording was then initiated. The data were recorded for a 300-sec-period. After the completion of the data recording, the data acquisition system would remain in a standby mode until the next gate movement was detected by the inclinometers.

The signal conditioning system for the data acquisition system, Figure 27, contained the required amplifiers, filters, and analog-to-digital interfaces and received the data signals from the accelerometers and inclinometers. To provide for antialiasing of the accelerometer frequency response, each acceleration data channel was filtered with a 200 Hz eight pole low pass Bessel filter.

All the data signals were recorded remotely on a Gateway Pentium II Computer, Figure 28, that has a 350 MHz clock speed, 13GB hard drive, and 128 MB RAM. The analog data received from the signal condition system was converted to a digital signal by means of a National Instruments model MIO-16XE-10, 16-bit, analog-to-digital converter. The converter was capable of providing a sampling rate of 100,000 samples per sec. To insure data collection would not be interrupted during the event of a power loss at the recording area, an uninterrupted power supply (UPS) was installed.

Software was developed by ERDC for the Marseilles Dam monitoring program to enable the data acquisition system to record data remotely. The data acquisition software was developed as a Windows program and designed to detect the gate movements and record acceleration measurements when any gate movements occurred. The program operates in the following manner. As stated previously, the inclinometers on each of four instrumented gates were used to detect gate movement and record the angular position. When a gate movement of 2 deg was detected, a timer was started. The timer was set to run for a 15-min period. The timer would be reset each time a new gate movement of 0.03 rad (2 deg) was detected. If the timer reached the preset length of time (15 min) and had not been reset due to additional gate operations, sufficient time had passed for a steady state flow condition to be established, and the data recording was initiated. Triaxial acceleration measurements and gate tilt on each gate were recorded for a 300-sec period of time and at a sampling rate of 1,000 samples/sec. These recorded measurements were stored in a file that included the date and time of the data recording. The program was also designed to provide the user with the ability to scale, view, and print recorded data. Data can also be converted to other formats to enable analysis with other software products such as Matlab, Excel, DPlot, etc.

The recorded data were stored on the computer hard drive. At monthly intervals, ERDC personnel visited the project to perform routine checks of the sensors and the data acquisition system. During these visits, the data were downloaded from the hard drive on both 120 MB super disks and 100 MB Zip disks.

Data Results and Discussion

Elements of the monitoring plan included life-cycle cost of the remote operating system, collection of ice data, pool elevation variation, gate openings/submergences, and gate vibrations. More detailed information is provided in the following subparagraphs.

Life-Cycle Cost Analysis

A LCC analysis was performed to evaluate cost savings realized by installing the remote operating system (ROS). The LCC analysis investigated construction costs + repair costs + labor costs of the ROS vs. the costs of the four full-time dam employees that the ROS replaced. Advantages and disadvantages of the ROS were addressed. Recommendations were made for minimizing costs of replacement parts/down-time while maximizing operational efficiency. The benefit of ROS can be used at other dam sites to effectively reduce the labor force, especially in remote areas. A life cycle cost (LCC) analysis was conducted for three alternatives identified for operation of the Marseilles Dam: maintenance of the existing remote operation, manual operation, and replacement of the remote operating system. The design/evaluation period is indicated in Table 7, where costs associated with each alternative are listed and evaluated. Costs included in the analysis are initial capital costs (where appropriate), annual maintenance, and annual labor costs. Price levels are June 1999 and a discount rate of 6.875 percent has been used to annualize costs, where appropriate. This was a least cost analysis, rather than a benefit-to-cost analysis. Therefore, no assumptions concerning benefits or capital investment value were made. Table 7 summarizes the identified costs for the dam operational alternatives. Table 8 relates historical maintenance costs and labor requirements for operating alternatives.

a. *Alternative 1 – maintain existing remote operation.* The existing operating system is a computerized remote operation, with an original cost (1988) of $1,042,500. This is a sunk cost and was not considered in comparing alternative costs for a future operating period. Based on yearly cost records, the existing system has averaged $5,819 in annual maintenance costs. The existing system also requires $12,074 in annual labor costs for dam operation, which includes labor charges for operations during icing and nonicing periods.

b. *Alternative 2 - manual operation.* The dam was operated manually prior to 1988. This procedure required four full-time workers for a 24-hr/day operation. The costs associated with manual operations totaled $185,869 annually. These costs were stated at 1999 labor rates for the appropriate average wage-grade range.

c. *Alternative 3 – replace remote operating system.* For comparison purposes, the costs for a replacement of the existing remote operating system were briefly reviewed. It was assumed that a replacement system purchase cost would be similar to the cost of the original system. The new system would have a life-cycle period of 25 years and would require annual maintenance and labor costs similar to the existing system. Under these assumptions, a replacement system would accrue $109,386 in costs annually. Detailed specifications and costing of a replacement system were not pursued. However, the cost assumptions used provide a proper comparative perspective for reviewing dam operational alternatives.

Based on this analysis, the most cost efficient alternative for dam operations appears to be maintenance of the existing Remote Operation System (Alternative 1). This would be the least cost plan for the short term (5-year period of analysis) and for the longer term, under the assumption that annual maintenance costs would not increase dramatically.

Recorded Gate Operations and Inclinometer Readings

During the 12-month monitoring period, gate operations performed by the lock and dam operators were recorded on operation log sheets. The log of the recorded gate operations is listed in Table 9. The gate operation information recorded on these log sheets provided a means to correlate the displayed gate positions and times with the data recorded from the inclinometers of the instrumented gates. Figures 29 and 30 show the relationship of the raised and submerged gate openings obtained from the log sheets to the output of the inclinometers. Due to the design of the submersible tainter gates and the spillway sill, a transition zone exists for each gate between the raised position and submerged position at which no flow is initiated. This transition zone is the equivalent of 2 ft of gate opening, 0.3 m (1 ft) in the raised position and 0.3 m (1 ft) in the submerged position. As a result, a discontinuity in the linear relationship between the raised and submerged gate opening versus the angular position is evident in the plots shown in Figures 29 and 30. The transition between the raised and submerged "zero" flow position are incorporated into the digital displays of gate openings that are in the lock operation room.

Ice Passage Data

The winter months at Marseilles Dam, between 10/99 and 04/00, were characterized by little snowfall and above normal temperatures. Ice formation in the upper pool near the dam and the lock entrance canal was very light and ephemeral. During this period of the data recording, the lock operation logs show only one operation for flushing of the ice through the dam. According to the operation logs, the ice flushing occurred on 01/25/2000 and lasted for 10 min. The operations log entry (01/25/2000) show that Gate 7, an instrumented gate, was operated during the ice passage procedure and that it was lowered to a -1.5 m (-5.0 ft) position. At this position, the gate was held for only 10 min before being raised to the "zero" position. The preprogrammed time delay of the data acquisition system (15 min) was too long to obtain the vibration levels for this submerged gate position. By the time data recording was initiated, all the gates were in the "zero" position. The -1.5 m (–5.0 ft) gate position was the lowest submerged setting made during the winter months and no vibration data were obtained.

Winter of 2000 time-lapse video of ice passage

Table 10 summarizes the ice observations from the time-lapse videotapes. Before 21 January, the image area was ice-free. On that morning, a thin black sheet of ice covered the pool. All gates were submerged 0.2 m (0.5 ft) except for Gate 7, which was submerged 0.6 m (2 ft). The ice cover remained intact until 11:40 on 25 January when a towboat made several passes in front of the dam to fracture the ice. Gate 7, on the right hand side of the dam, was opened to 1.5 m (5 ft) for about 10 min to help clear out the ice and by 13:00, most of the ice had cleared the dam. Figure 31 shows vibration data surrounding the ice passage period. The greatest accelerations were in the 85 to 100 milli-g range occurring at Gates 3 and 1, which were submerged only 0.2 m (0.5 ft) and may have felt more impact from the passing floes than Gate 7, which was submerged 1.5 m (5 ft).

By the next morning, 26 January, thin black ice had reformed on the pool. This cover remained in place until about 13:00 on 28 January when strong easterly winds flooded the ice cover's upstream edge and moved the sheet towards the dam. Within half an hour, most of the ice on the pool had moved past the central gates on the dam, which were submerged 0.2 m (0.5 ft) at the time. The greatest accelerations, in the 95 to 145 milli-g range, occurred at centrally located Gates 5 and 3 (Figure 32).

During 29 and 30 January, the pool was open, with intermittent disperse floes passing. At dawn on the morning of 31 January, fractured floes filled the image area (Figure 33) At this time the gate openings were even at 0.4 m (1.5 ft). At 07:17, strong westerly winds caused the ice on the left side of the pool to shift upstream. At 07:27 the ice floes on the left side of the pool moved downstream and began to pass Gates 1 and 2. Between 07:30 and 07:50, the ice on the right hand side of the pool began moving, and at 07:50, the central ice moved. After 08:04, the pool was, for the most part, ice-free.

The 31 January ice passage resulted in greater accelerations than the previous two events as shown in Figure 34. It also appears from the acceleration data that a quantity of ice passed the dam in the darkness at around 04:00 a.m. Shortly after

08:00, the maximum acceleration for Gate 7 was 570 milli-g's. Because Gate 7 lies outside of the image area, it is unclear what caused this high value.

February 1988 video of ice passage at Gate 1

During the winter of 1988, CRREL installed a video camera on top of the south embankment on the downstream side of Gate 1. The winter of 1988 was average in terms of air temperature (Figure 7). Video footage shows much light to moderate ice passing the submerged gate between 4 and 11 February. On 8 February, a towboat broke up the ice cover in front of the dam and the video shows floes up to 6.1 m (20 ft) in width passing the gate easily. A large floe lodged itself on the right hand pier until the tow backed in and washed it past the gate (Figure 35)

Upper Pool and Tailwater Elevation Variation

The Marseilles Lock and Dam upper pool and tailwater elevations are recorded and maintained by the Rock Island District. Figures 36-39 are the tabular water level records for the 12-month study period that were posted on the Rock Island District Web site. Figure 40 is the time-history of the Illinois River stages at Marseilles, IL, for the calendar year 2000. The upper pool level elevations listed indicated a variation between 483.2 and 483.65 during the 12-month data collection period. The slight variation in the pool level is the result of the strict "flat pool" elevation requirements to meet the required navigation depth for commercial navigation. During the data collection period, no significant rises in river stage occurred until the spring of 2000 requiring gate openings as large as 2.1 m (7.0 ft) on one of the instrumented gates to pass the high river flows.

Gate Vibration Level Recordings

During the data collection period, the project operations personnel, to regulate the upper pool elevations, used various gate openings and combinations of gates. In general, the strict tolerances for maintaining the level of the upper pool resulted in the majority of the gate openings (raised or submerged) to be less than ±0.6 m (2.0 ft).

Due to the voluminous amount of data recorded during the 12-month study period, it would be impractical to reproduce multiple redundant listings and plots of vibration levels recorded for the same gate openings. Therefore, only representative data are provided in this report to illustrate the vibration effects of the more typical gate operations as well as those of the maximum gate openings. Tables 11 - 23 list the vibration levels for a representative selection of the gate operations. Figures 41 – 82 are graphical representations of the vibration magnitudes and resulting displacements.

Raised Gate Vibration Levels

Flow releases from Marseilles Dam, during the spring, summer and fall of the year, are generally performed with the gates operated in the raised position. The gate operations during these seasonal periods can be characterized as typically small gate openings for short durations (hours) to maintain the upper pool water levels. The majority of the raised position gate openings for discharge of normal river inflows were recorded to be no greater than 0.9 m (3.0 ft). The vibration levels recorded at these small openings indicated no significant increase from background noise levels recorded when the gates were in the closed position. This is illustrated through a comparison of the vibration levels shown in Table 11 (no instrumented gates open) with those vibration levels presented in Tables 12-14 for various single gate openings.

In general the vibration levels and displacements were extremely small (less than 0.3 g's and less than 0.002 cm (0.001 in.), respectively). These values represent the predominant vibration levels and displacements to which the gates are subjected for the particular gate openings during a particular segment of time.

For periods when a significant rise in river stage occurs, as indicated in Figure 40 between the periods April – July 2000, multiple gate operations are required to pass the inflows. These gate operations are characterized by larger raised gate openings 1.5 - 2.1 m (5.0 – 7.0 ft) for longer periods of time (days) to maintain the upper pool water levels.

The summaries of vibration levels recorded for the various instrumented gates operated at the larger openings during this period are presented in Tables 15 –19. Tables 15-16 and Figures 41 - 52 are representative sampling of vibration levels occurring with two-gate operation for gate openings ranging from 0.6 - 1.5 m (2.0 – 5.0 ft). Tables 17- 19 and Figures 53 - 79 are a representative sampling of the vibration levels occurring with a three-gate operation and gate openings ranging from 0.3 - 2.1 m (1.0 – 7.0 ft). The maximum values of vibration level and displacement observed during these operations were 0.20 g's and 0.005 cm (0.002 in.), respectively. These values represent the predominant vibration levels and displacements to which the gates are subjected for the particular gate openings during a particular segment of time and indicate that very insignificant movement is occurring for these raised gate operation conditions.

Submerged Gate Position Vibration Levels

Flow releases from Marseilles Dam, during the winter months of the year, are generally performed with the gates operated in the submerged position. The gate operations during these seasonal periods can be characterized as typically small gate openings for short durations (hours) to maintain the upper pool water levels. The majority of the submerged position gate openings for discharge of normal river inflows were recorded to be no greater than -0.6 m (-2.0 ft).

The vibration levels recorded at these small openings indicated a relative increase above those observed from background noise levels recorded when the gates were in the closed position. This is illustrated through a comparison of the vibration levels shown in Table 20 (no instrumented gates open) with those vibration levels presented in Tables 21-23 for various single and multiple gate openings.

In general the vibration levels and displacements were extremely small (less than 0.3 g's and less than 0.002 cm (0.001 in.), respectively). Tables 21-23 and Figures 80 - 82 are a representative sampling of the vibration levels occurring with a four-gate submerged operation and gate openings ranging from 0.4 - 0.6 m (1.5 – 2.0 ft). The maximum values of vibration level and displacement observed during these operations were 0.06 g's and 0.005 cm (0.002 in.), respectively. These values represent the predominant vibration levels and displacements to which the gates are subjected for the particular gate openings during a particular segment of time and indicate that very insignificant movement is present for these submerged gate operation conditions.

3 Conclusions and Recommendations

Conclusions

The monitoring program for Marseilles Dam on the Illinois River was very successful. The following is a summary of the observations made from the data collected over the 2-year duration of the program.

A Life Cycle Cost (LCC) analysis was conducted for three alternatives identified for operation of the Marseilles Dam: maintenance of the existing remote operation, manual operation, and replacement of the remote operating system. The LCC analysis investigated construction costs + repair costs + labor costs of the Remote Operating System (ROS) vs. the costs of the four full-time dam employees that the ROS replaced.

a. *Alternative 1 – maintain existing remote operation.* The original cost of the ROS is a sunk cost and was not considered in comparing alternative costs for a future operating period. Based on yearly cost records, the existing system has averaged $5,819 in annual maintenance costs. The existing system also requires $12,074 in annual labor costs for dam operation, which includes labor charges for operations during icing and nonicing periods.

b. *Alternative 2 - manual operation.* The dam was operated manually prior to 1988. This procedure required four full-time workers for a 24-hr/day operation. The costs associated with manual operations totaled $185,869 annually. These costs were stated at 1999 labor rates for the appropriate average wage-grade range.

c. *Alternative 3 – replace remote operating system.* The costs for a replacement of the existing remote operating system were briefly reviewed. Assuming that a replacement system purchase cost would be similar to the cost of the original system, the new system would have a life-cycle period of 25 years and would require annual maintenance and labor costs similar to the existing system. Under these assumptions, a replacement system would accrue $109,386 in costs annually. However, the cost assumptions used provide a proper comparative perspective for reviewing dam operational alternatives.

Based on this analysis, the most cost-efficient alternative for dam operations appears to be maintenance of the existing Remote Operation System (Alternative 1). This would be the least cost plan for the short term (5-year period of analysis) and for the longer term, under the assumption that annual maintenance costs would not increase dramatically.

The submergible gates at Marseilles Dam have greatly improved winter operation of the project. Submerging the gates during cold, low flow periods, with periodic cycling, eliminates freezing in the gates and the need for personnel to be on site. The costs and hazards of chipping ice, or thawing the gates with steam, have been eliminated by the new gate design. The remote operation system allows operation of the Marseilles Dam from a control room at the Marseilles Lock, approximately 3.9 km (2.4 mi) away, eliminating the need for 24-hr shifts on the dam site and the costs associated with those shifts. The remote operating system was proven to be efficient and effective in maintaining the strict pool tolerance and improving winter operation of the dam. Trespassing at the dam site has increased, perhaps because of the lack of an official human presence at the dam, but the three surveillance cameras serve as a deterrent.

At typical winter discharges, the gates effectively pass fragmented floes and loose brash, in the submerged mode without loss of pool, or scour damage to the downstream channel. To pass heavy brash however, it is still necessary to concentrate the flow by opening one or two gates nearest the canal in the raised mode. To draw ice beneath requires an opening of at least 1.5 m (5 ft), and it may be necessary to pull the gate clear of the water, similar to the practice with the old tainter gates.

The videotape analysis used to analyze ice passage was successful. The technique is relatively low cost, logistically simple, and provided a valuable visual record for analysis of the efficiency of the gates to pass ice in the submerged mode.

When passing light ice, measurable vibration in the 0.1-to 0.3-g range occurred above a background range of 0.006 to 0.02 g's. Unfortunately, due to the mildness of the winter of 2000, no data were obtained while passing moderate or heavy ice.

Mild winter weather conditions resulted in very light ice formation in the upper pool near the dam and the lock. The project operations log for the instrumented gates indicated a very short duration of gate submergence (-1.5 m (-5.0 ft) for a 10-min period) was used to initiate ice passage. The 10-min period was less than the data acquisition time delay (15 min) for steady flow to establish and the recording to be initiated. No vibration data were obtained for this operation.

The upper pool level elevations listed indicated a variation between 483.2 and 483.65 during the 12-month data collection period. This indicates that the remote operation system meets the constraint of a tight pool tolerance.

A significant rise in river stage occurred, as indicated in Figure 40, between the periods April – July 2000, and required multiple gate operations to pass the inflows. These gate operations are characterized by larger raised gate openings 1.5 - 2.1 m (5.0 – 7.0 ft) for longer periods of time (days) to maintain the upper pool water levels.

The vibration levels indicated that for these raised gate operation conditions very insignificant gate movement is present. The maximum vibration level values and displacement observed during these operations were 0.20 g's and 0.005 cm (0.002 in.), respectively.

Flow releases from Marseilles Dam, during the winter months of the year, were generally performed with the gates operated in the submerged position. The gate operations during these seasonal periods are characterized as typically small gate openings for short durations (hours) to maintain the upper pool water levels. The majority of the submerged position gate openings for discharge of normal river inflows were recorded to be no greater than - 0.6 m (- 2.0 ft). In general the vibration levels and displacements were extremely small (less than 0.3 g's and less than 0.002 cm (0.001 in.), respectively).

Vibration levels were found to increase with four-gate submerged operation and gate openings ranging from 0.4 - 0.6 m (1.5 – 2.0 ft). The maximum values of vibration level and displacement observed during these operations were 0.06 g's and 0.005 cm (0.002 in.), respectively. The values represent very insignificant movement for these submerged gate operation conditions.

Failure to continuously operate the gates in the submerged mode for periods exceeding 15 min had a negative impact on the collection and analysis of data for submerged operation during ice passage. Extended operation exceeding 15 min was required to activate remote collection of data to validate model results.

The absence of significant movement obtained during normal operation of the gates in the raised position appeared to validate the two-dimensional model study, which indicated only random vibrations of less than 1 percent of the gate's weight.

Recommendations

The relatively warm winters during the period of this monitoring effort produced a significant reduction in ice, which limited the need for submergence of the gates. This reduced the value of the monitoring effort at Marseilles Dam. In the future, the duration of the monitoring effort should be flexible enough to allow extension to capture more incidents for ice passage. Additional time and costs associated with this extension should be considered. The monitoring effort should be conducted in areas where there are colder winters, higher volumes of ice, larger submersible gates, and known incidences of vibrations to increase the knowledge of operating constraints and better define the variables that induce vibrations at Corps projects.

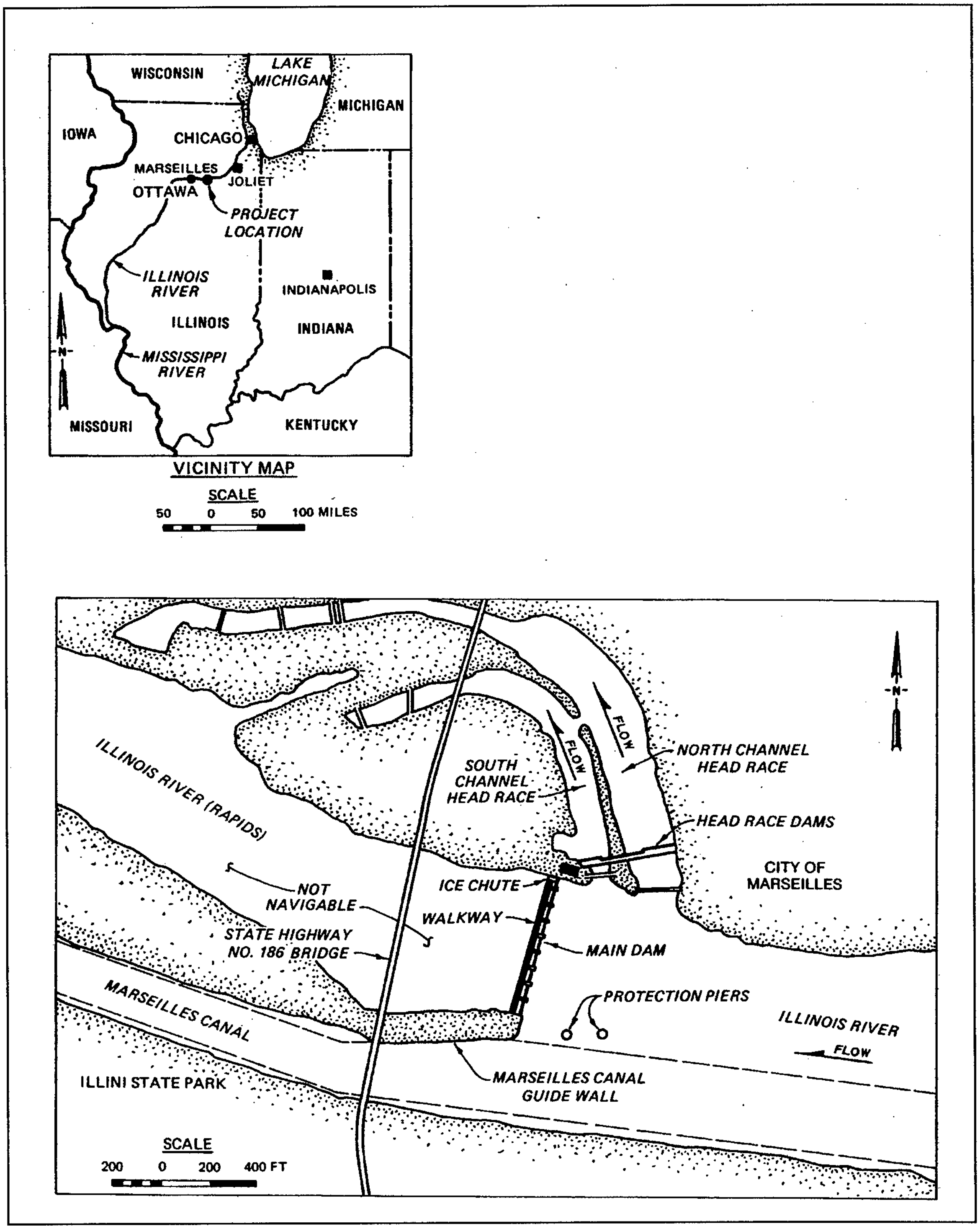


Figure 1. Project location

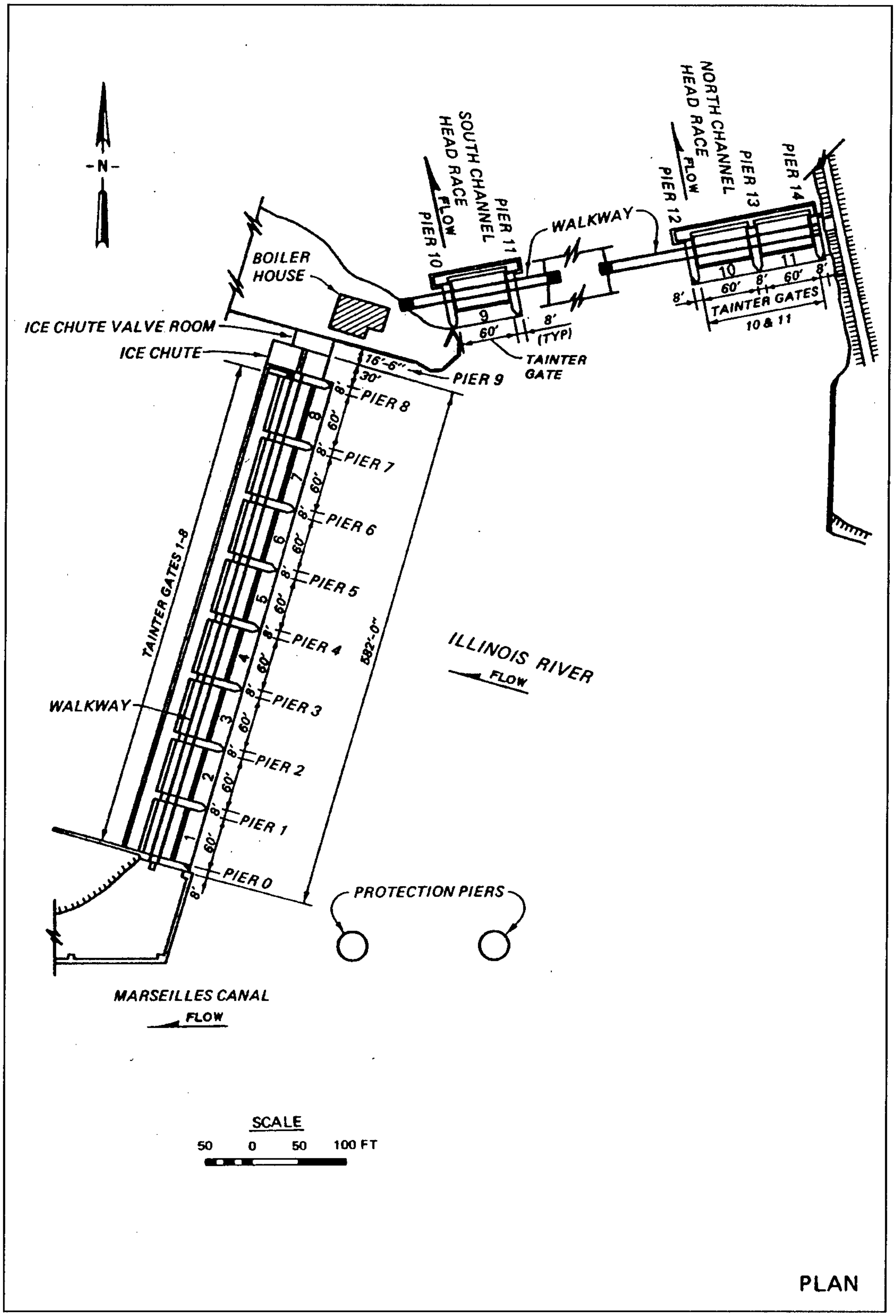


Figure 2. Plan view of Marseilles Dam

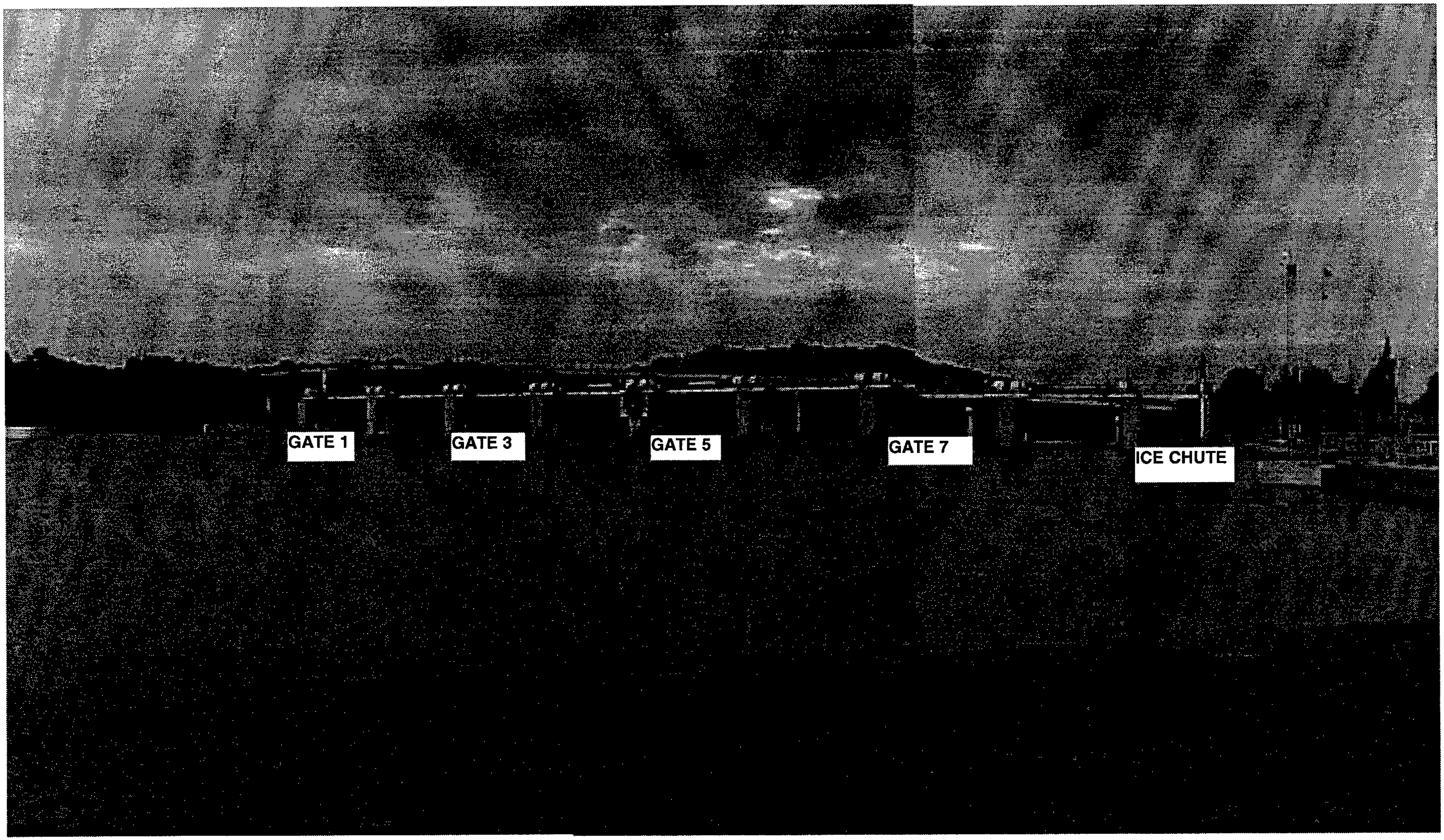


Figure 3. Upstream view of Marseilles Dam with instrumented gates identified

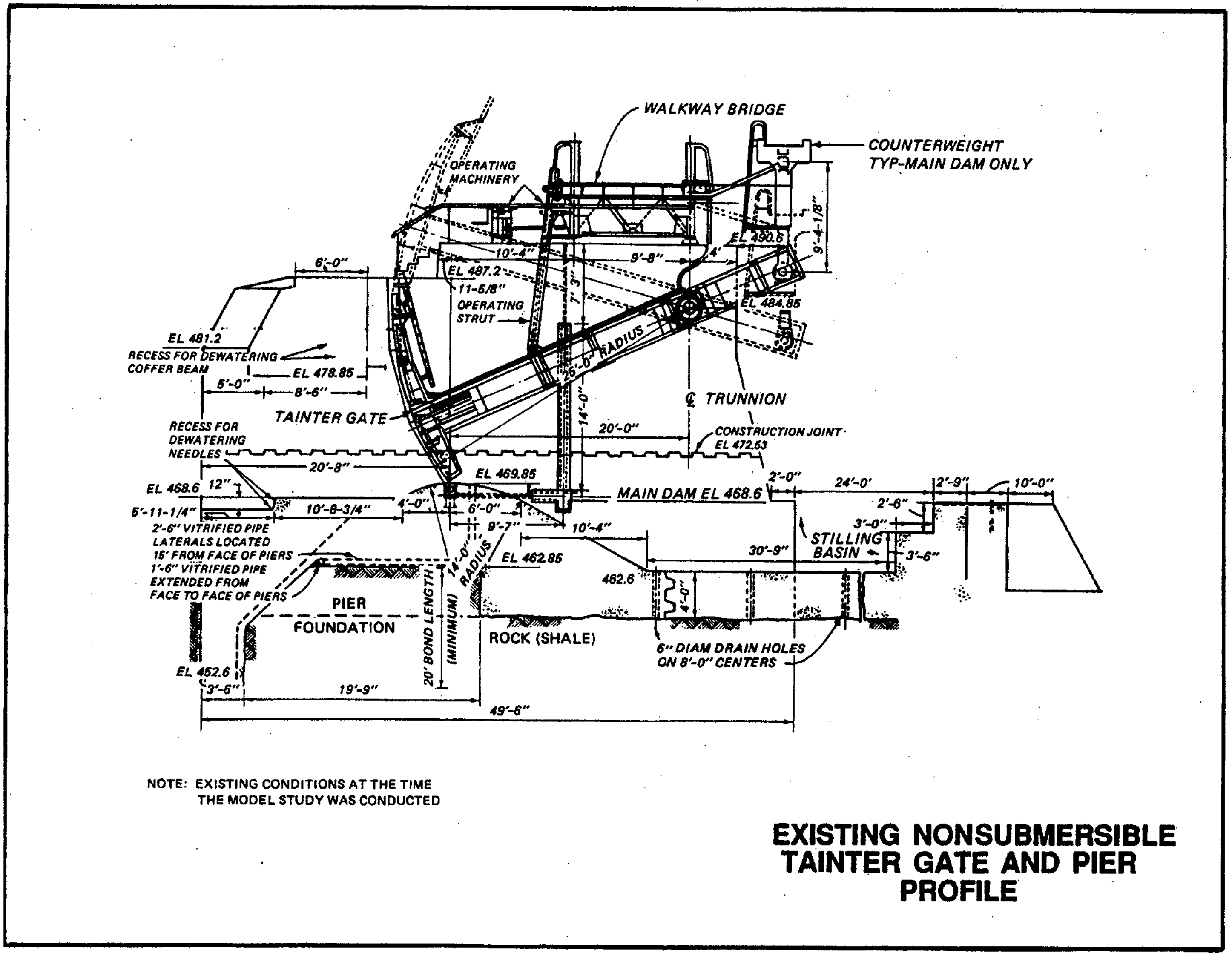


Figure 5. Nonsubmersible-type gate

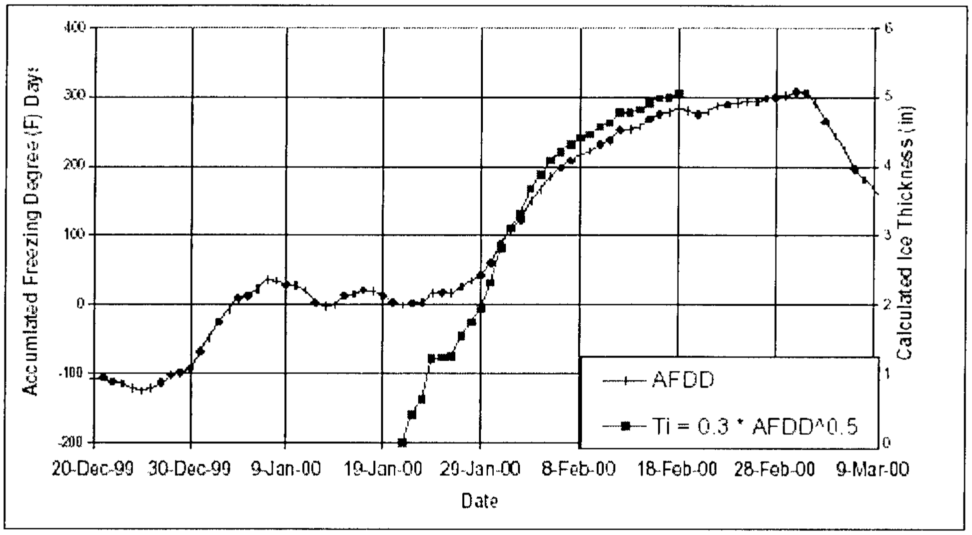


Figure 6. Accumulated freezing degree days at Chicago, IL, winter of 2000

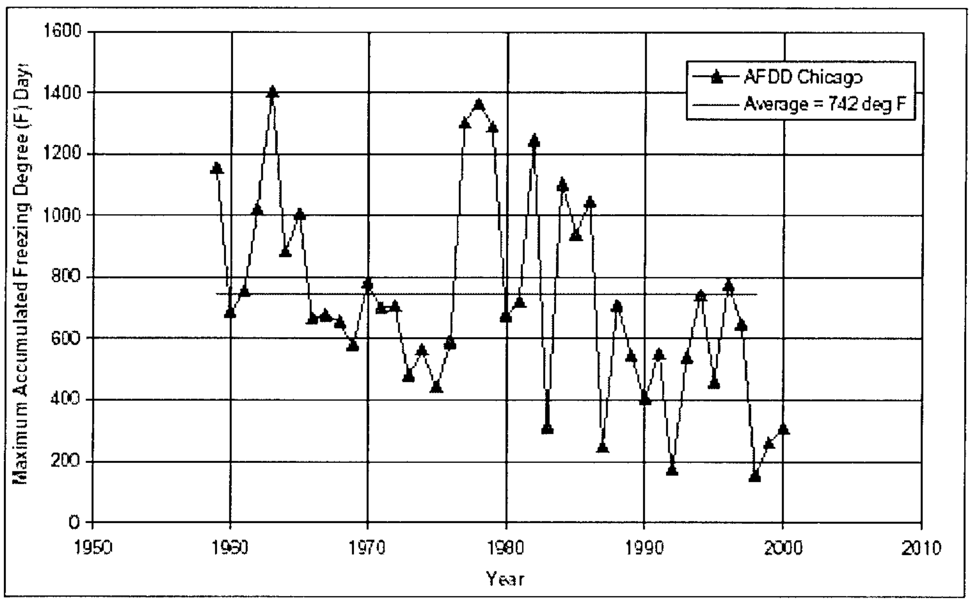


Figure 7. Maximum accumulated freezing degree days at Chicago, IL,1959-2000

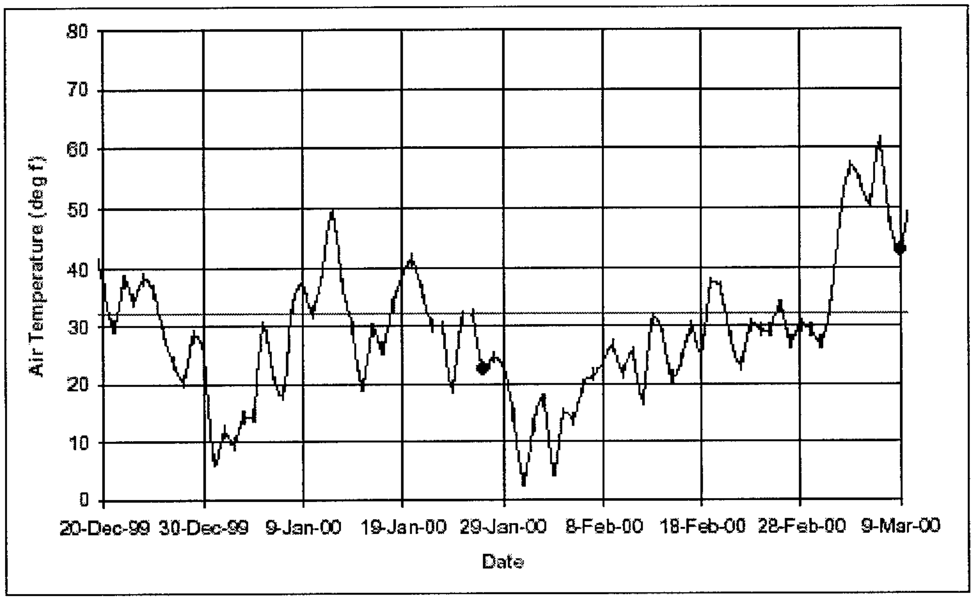


Figure 8. Daily average air temperatures at Chicago, IL, winter 2000

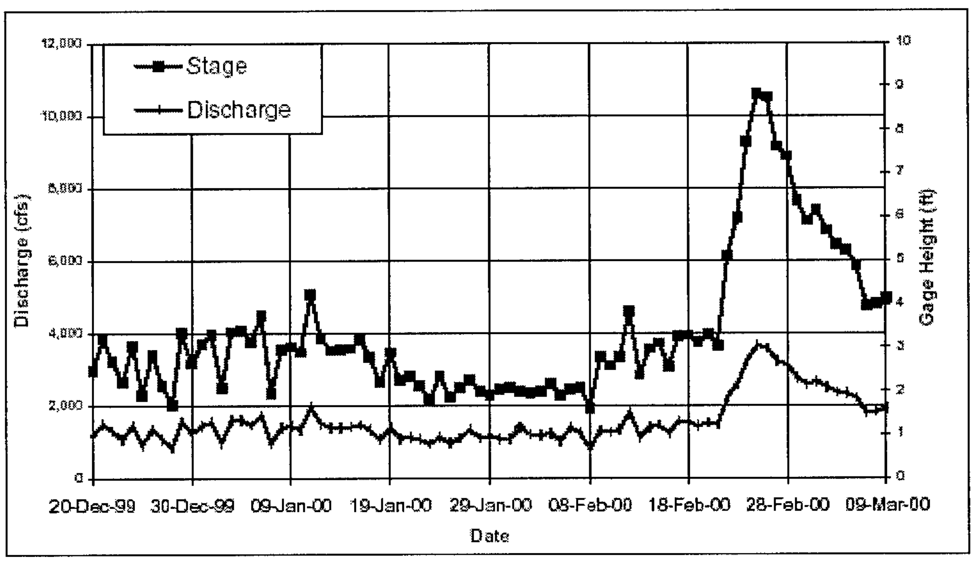


Figure 9. Daily average stage and discharge, Illinois River at Marseilles, IL, winter, 2000

Figure 10. Steaming tainter gates at Dresden Island Dam

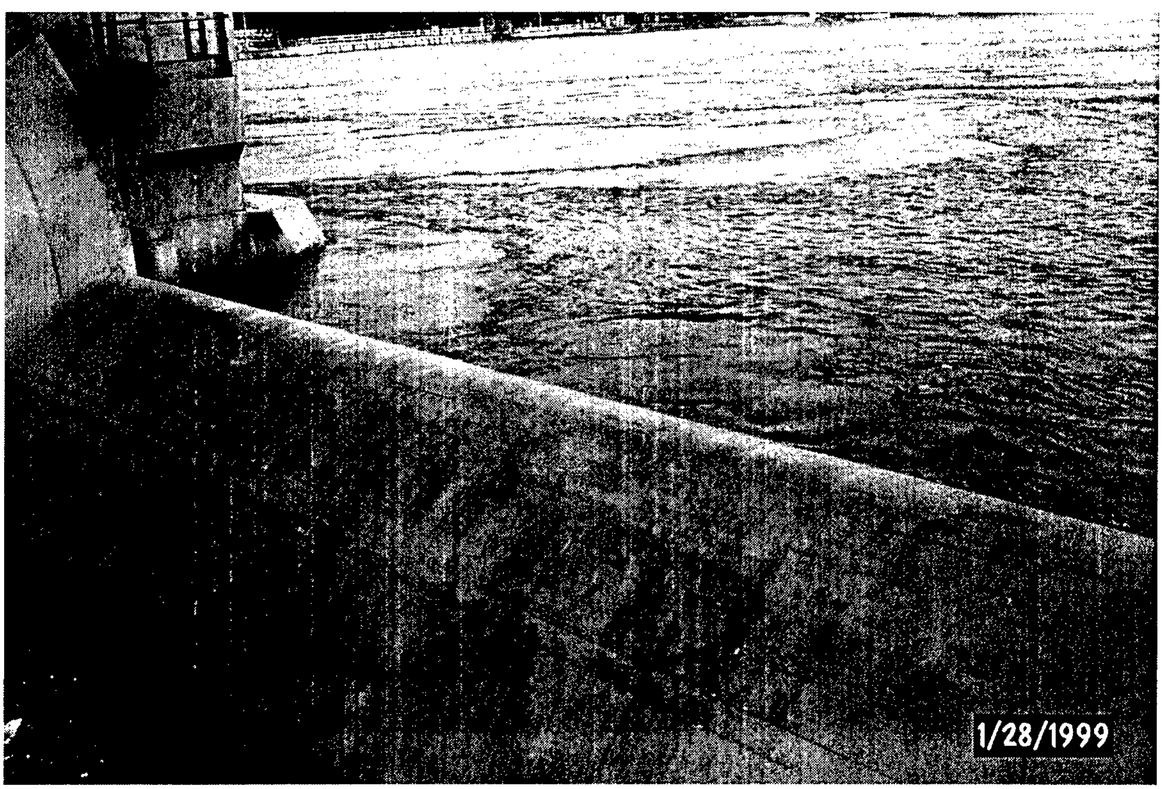


Figure 11. Submersible gate at Marseilles Dam in underflow mode

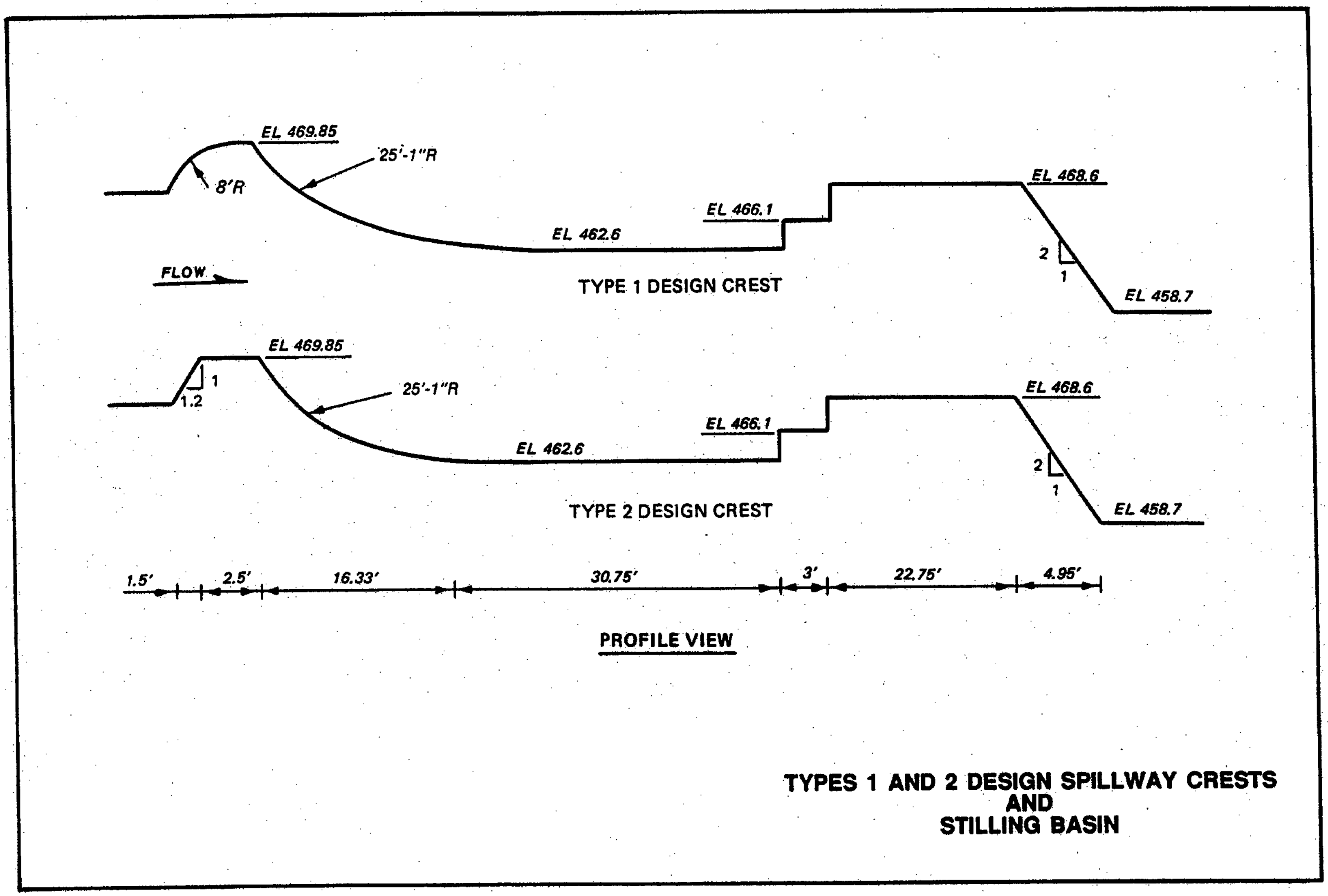
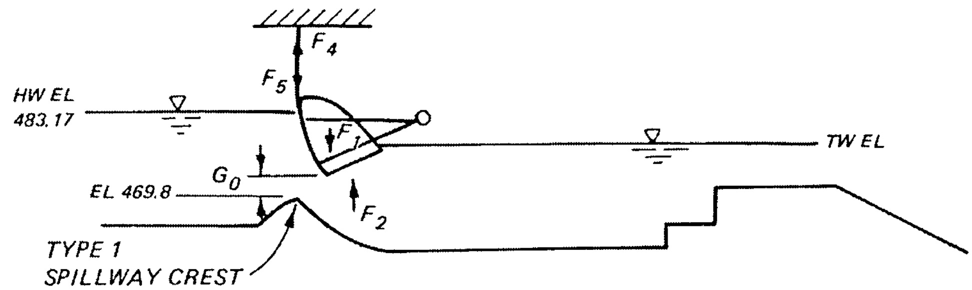
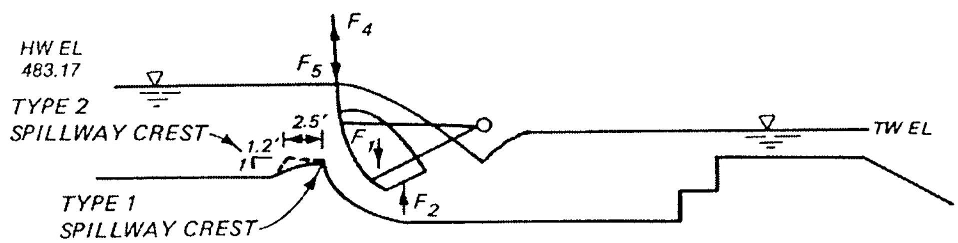


Figure 15. Types 1 and 2 design spillway crests and stilling basin



RAISED GATE DEFINITION SKETCH



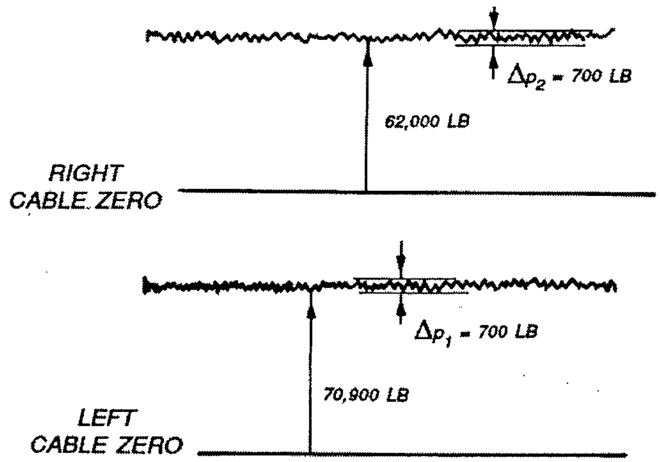
SUBMERGED GATE DEFINITION SKETCH

DEFINITION OF TERMS:

F_1 = DRY WEIGHT OF GATE SUPPORTED BY CABLES, LB
F_2 = TAILWATER DISPLACED BY GATE, LB
F_4 = MEASURED MAXIMUM LOADS DURING TESTS, LB
F_5 = FLOW-INDUCED LOAD ON CABLES, LB
HW EL = HEADWATER ELEVATION = 483.17 FT NGVD
TW EL = TAILWATER ELEVATION, FT NGVD (VARIES)

PROFILE SKETCH OF MODEL OPERATION

Figure 16. Profile sketch of model operation



SAMPLE OSCILLOGRAPH RECORD

SAMPLE CALCULATION

GIVEN: GATE SUBMERGENCE = 1 FT TW 470
TYPE 1 (ORIGINAL) APPROACH

F_1 = 115,300 LB

F_2 = 2,900 LB

$F_3 = F_1 - F_2$

F_3 = 115,300 - 2,900

F_3 = 112,400 LB

F_4 = 132,900 LB

$F_{5_{MAX}} = F_4 - F_3$

$F_{5_{MAX}}$ = 132,900-112,400

$F_{5_{MAX}}$ = 20,500 LB

$F_{5_{MIN}} = F_{5_{MAX}} - \Delta_p$

$F_{5_{MIN}}$ = 20,500 LB - 1,400 LB

$F_{5_{MIN}}$ = 19,100 LB

f = 3.4 HZ

$\Delta p = \Delta p_1 + \Delta p_2$

Δp = 700 + 700

Δp = 1,400 LB

DEFINITION OF TERMS:

F_3 = $(F_1 - F_2)$, SUBMERGED WEIGHT OF GATE SUPPORTED BY CABLES, LB

Δ_p = AMPLITUDE OF LOAD FLUCTUATIONS, LB

$F_{5_{MAX}}$ = MAXIMUM FLOW-INDUCED LOAD ON CABLES $(F_4 - F_3)$, LB

$F_{5_{MIN}}$ = MINIMUM FLOW-INDUCED LOAD ON CABLES $(F_{5_{MAX}} - \Delta_p)$, LB

f = frequency of vibration
HZ = Hertz, cyles/sec

SAMPLE FORCE CALCULATION AND OSCILLOGRAPH RECORD

Figure 17. Model sample force calculation and oscillograph record

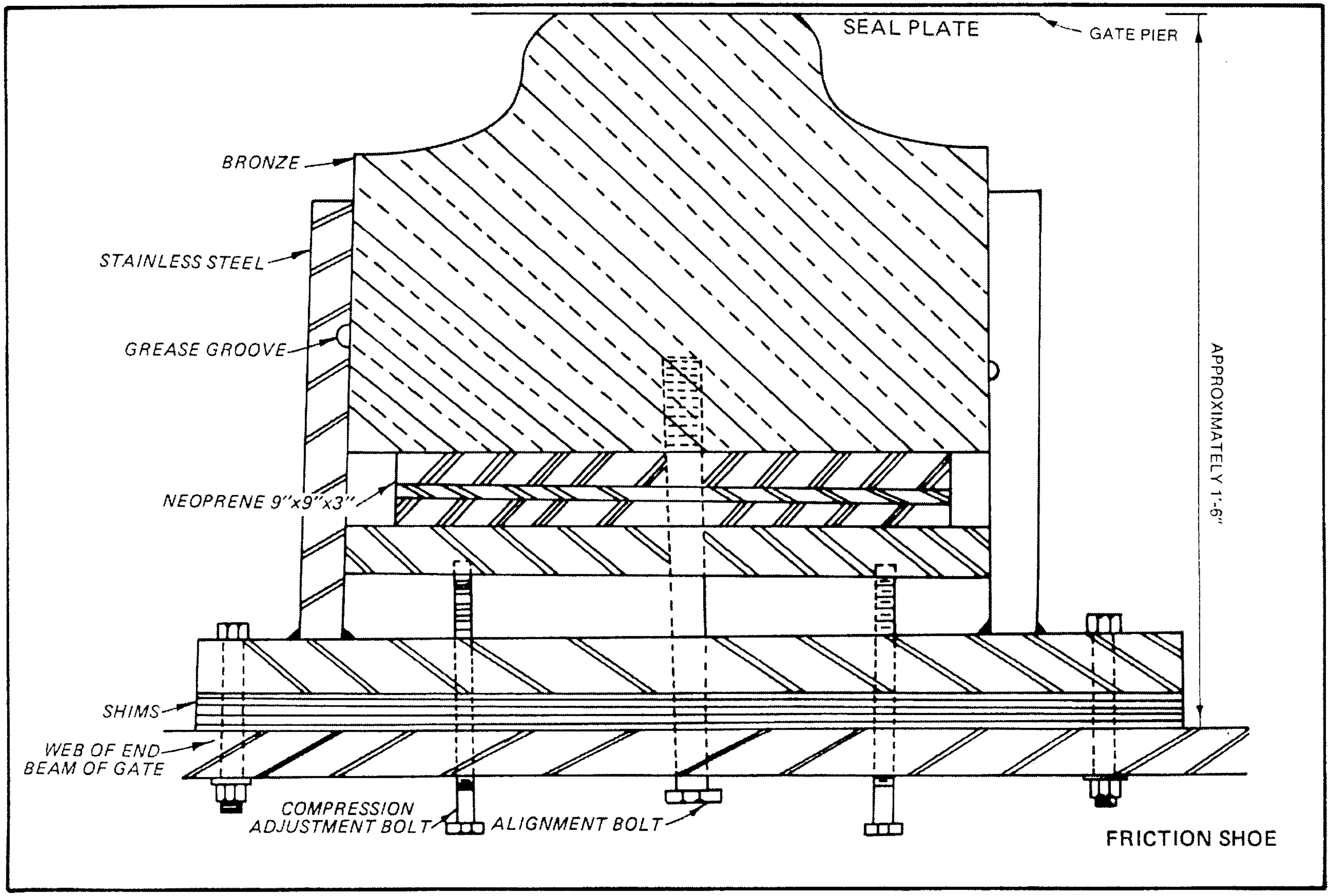


Figure 18. Friction shoe

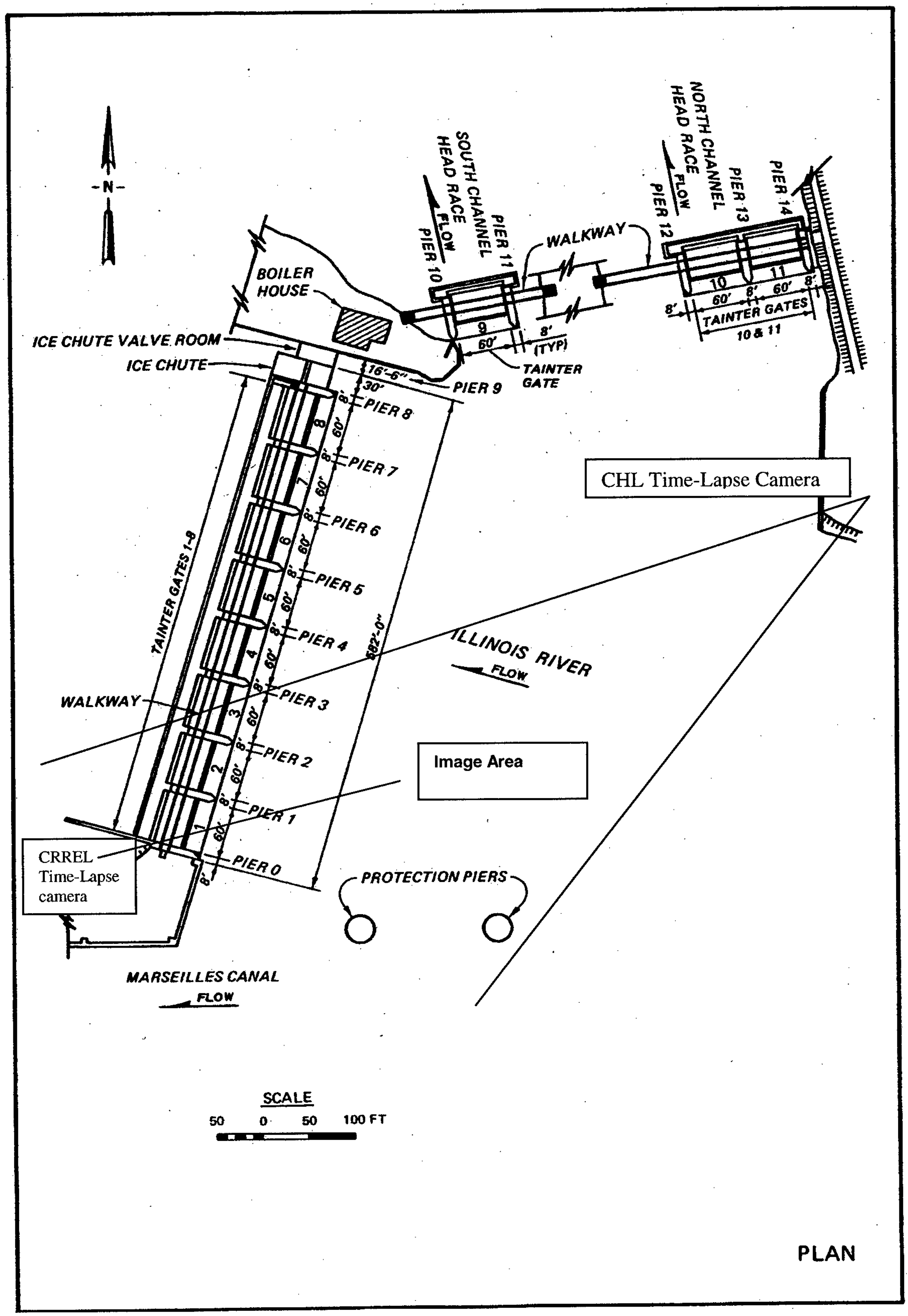


Figure 19. Site plan showing camera locations and fields of view

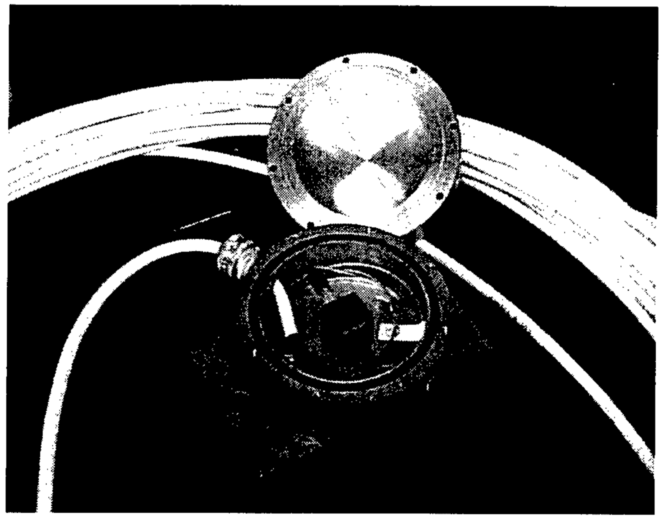
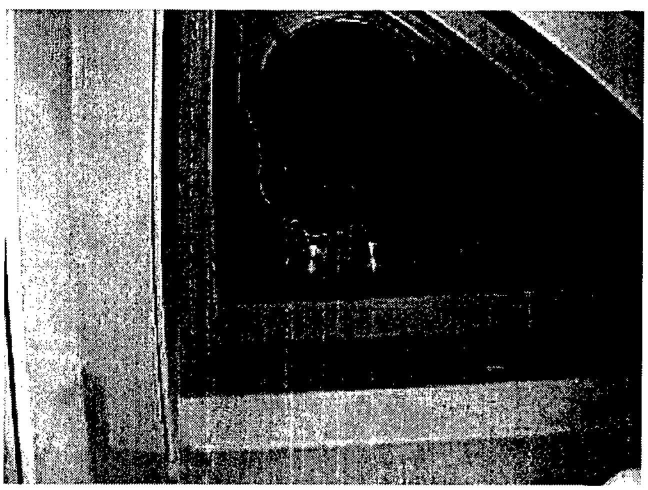
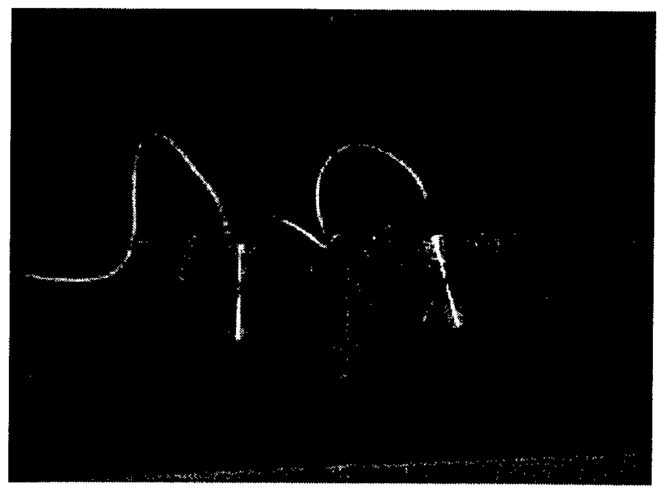


Figure 20. Triaxial accelerometer and protective housing



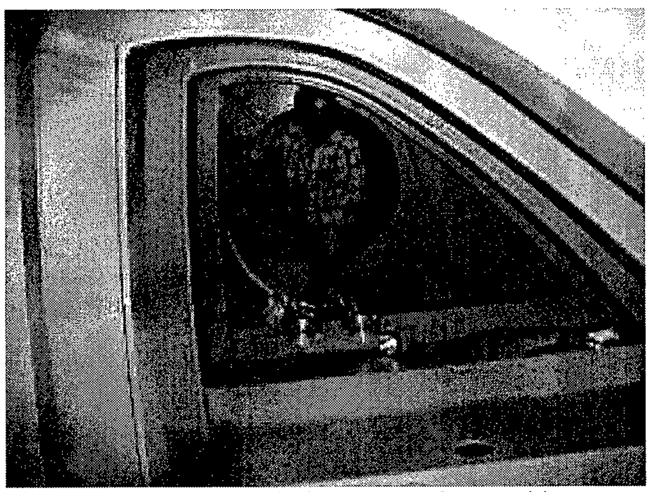
a. Sensors at the center of the gate



b. Accelerometer (left) and tilt meter (right) as installed inside the gate at Marseilles Dam

Figure 21. Accelerometer and tilt meter

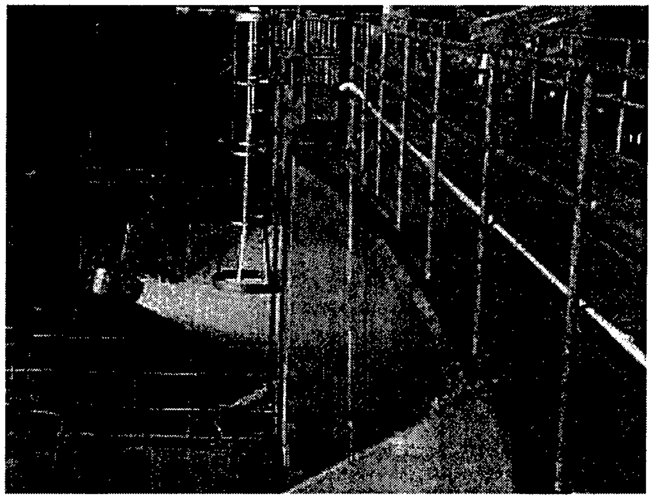
a. Getting instrument cable ready to pull to the top of the machinery access bridge



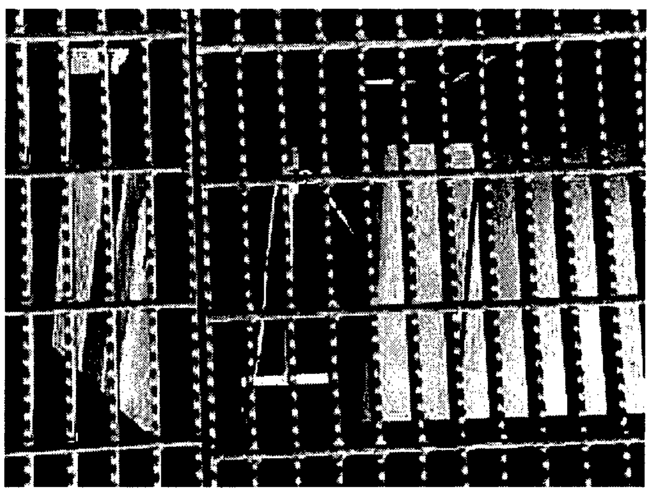
b. Pulling cable through the gate to the machinery access bridge

c. Exiting the gate after installing the instruments

Figure 22. Space limitations inside gate structure and instrument cable routing during installation

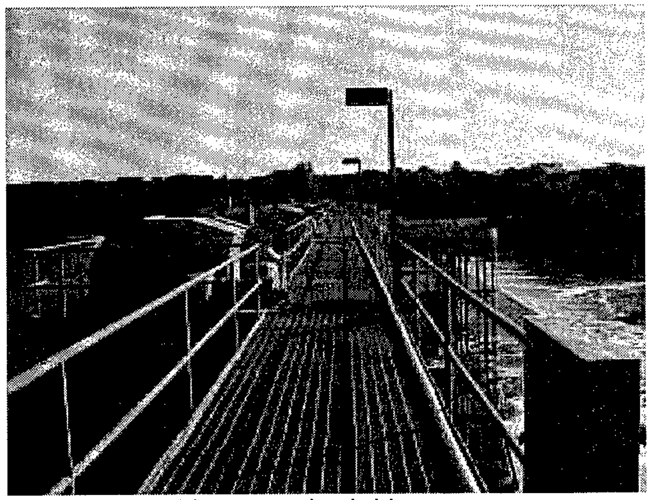


a. Instrument cables from gates to service bridge



b. Instrument cables exiting gate air vent (looking down through bridge grating)

Figure 23. Instrument cables


a. Along machinery service bridge


b. Access over the machinery access bridge

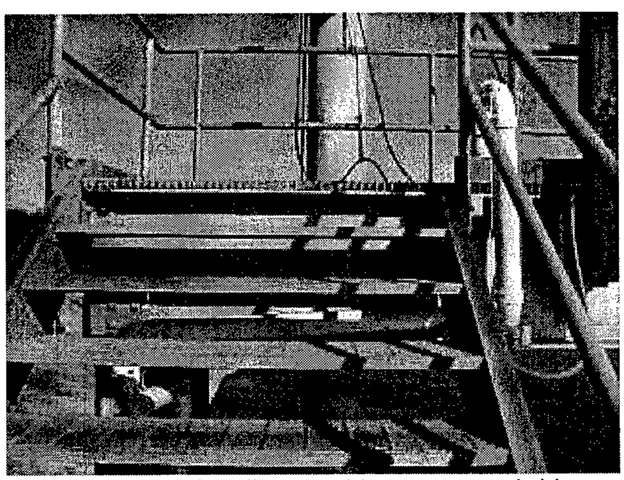
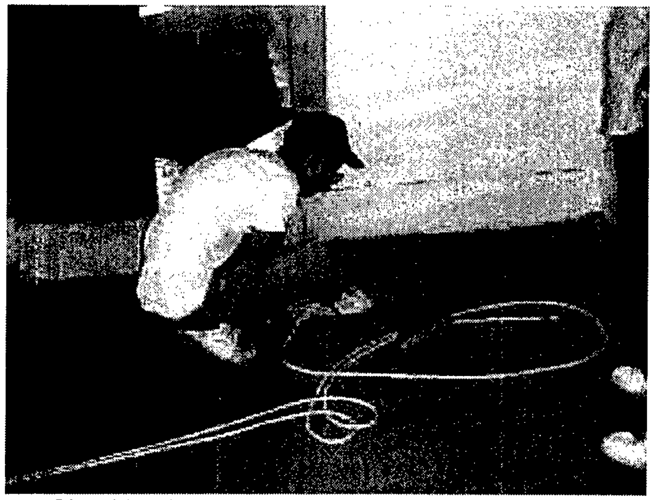

c. Under the stairwell to machinery access bridge

Figure 24. Instrument cable PVC conduit



a. Checking instrument cable integrity

b. Connecting instrument cables to the data acquisition system

Figure 25. Instrument cable connection

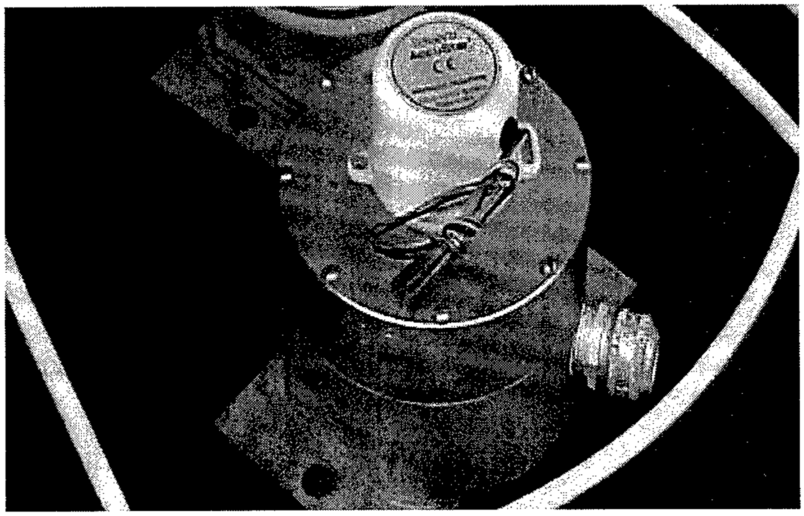


Figure 26. Inclinometer and protective housing

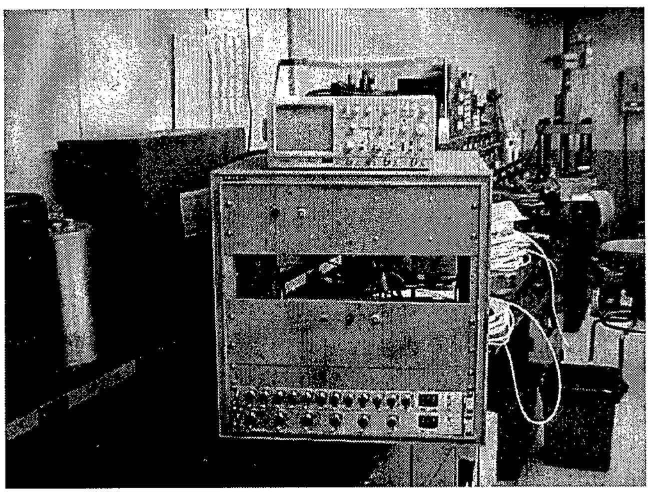


Figure 27. Data acquisition signal conditioning interface system

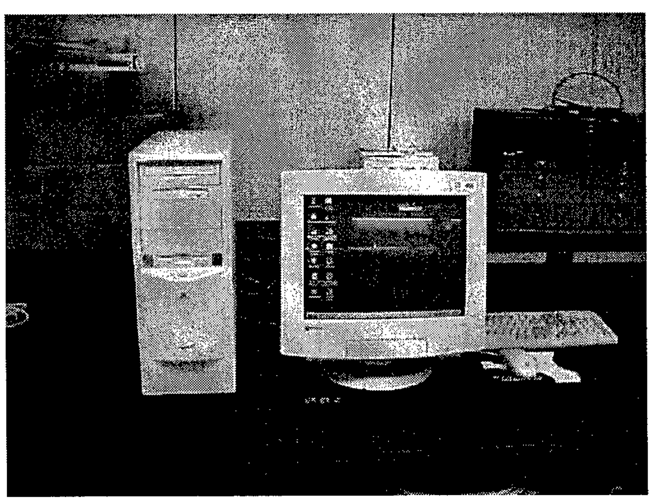


Figure 28. Data recording and storage central processing unit

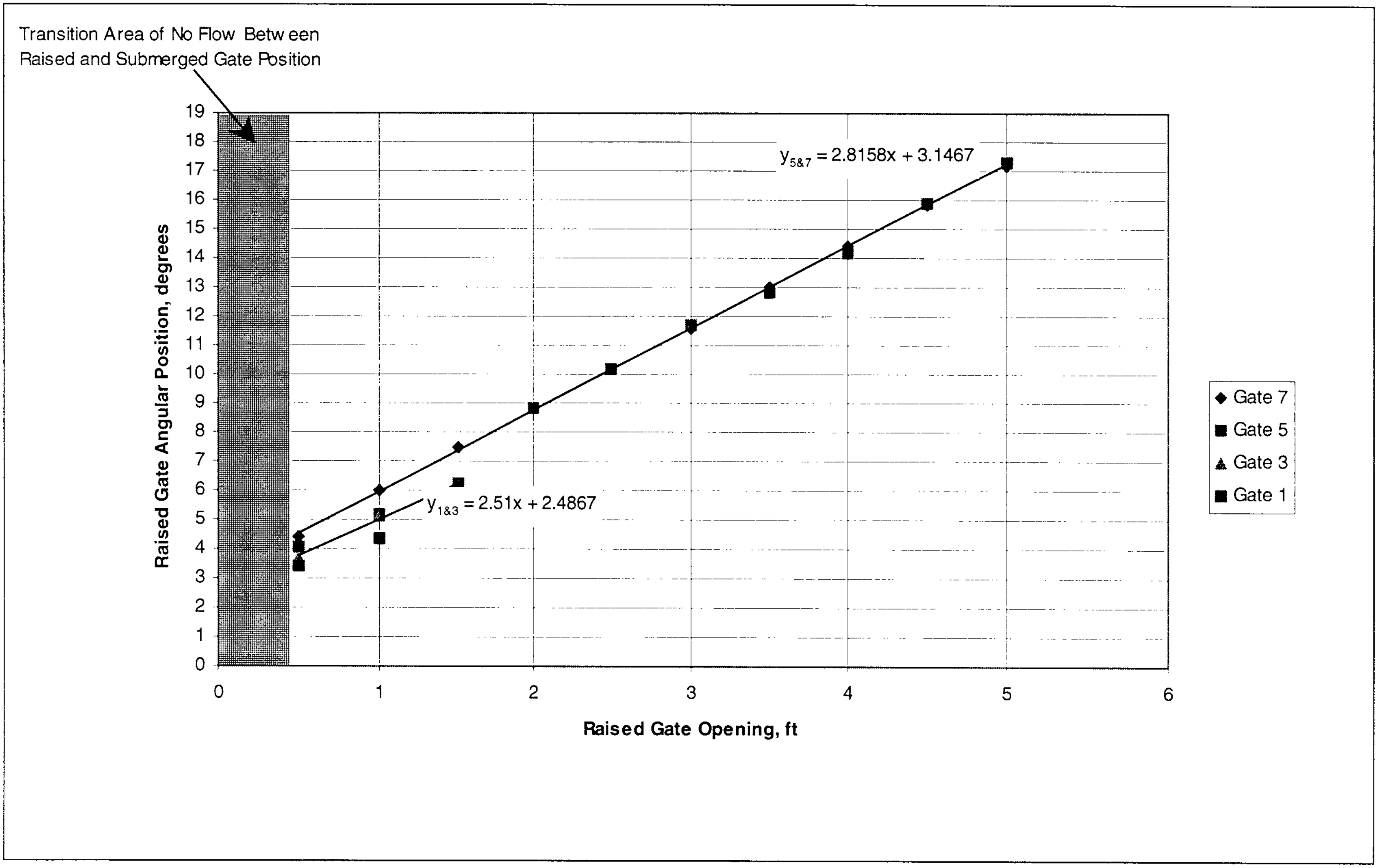


Figure 29. Marseilles Dam raised gate operation, gate opening vs. angular position

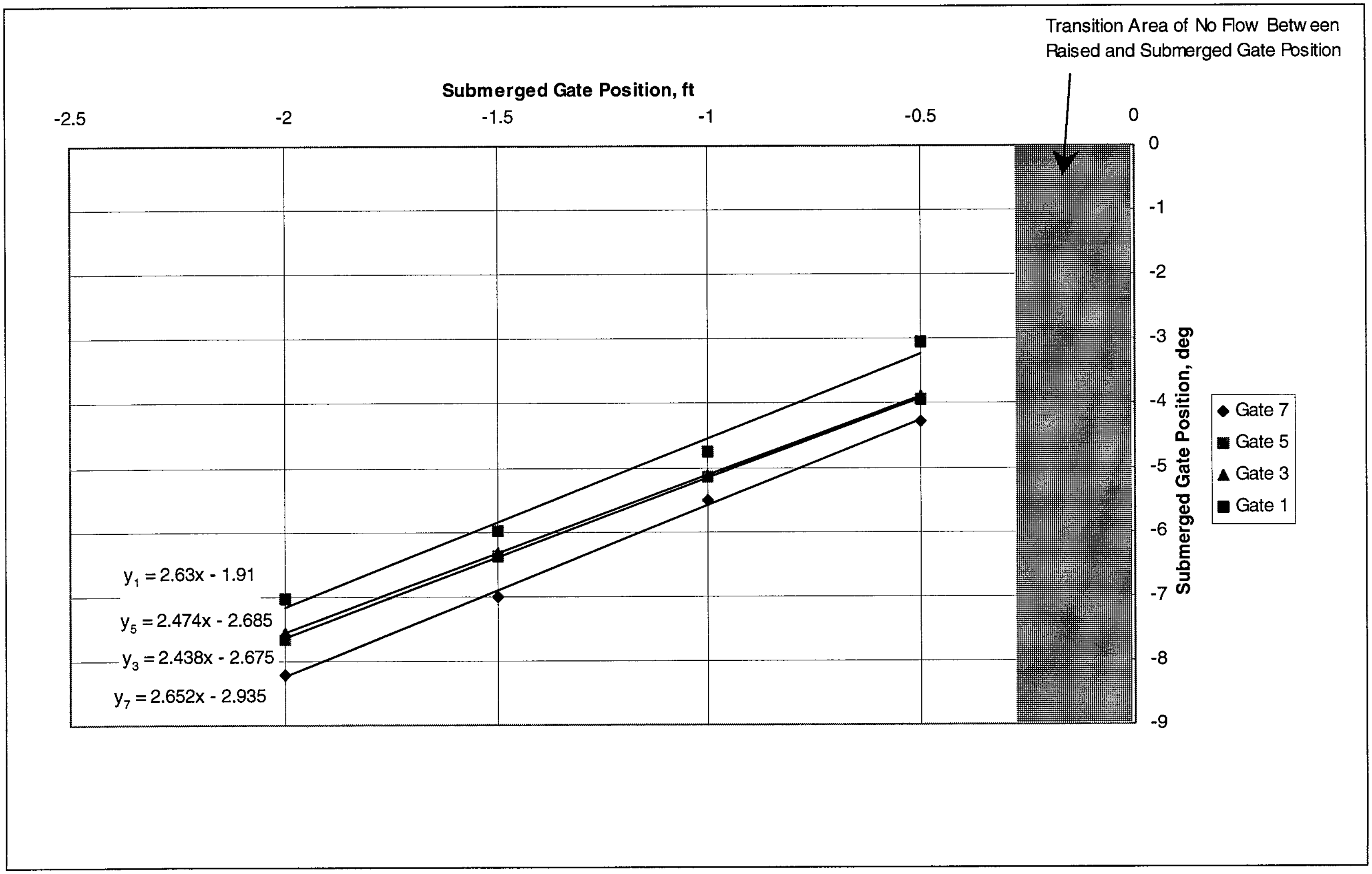


Figure 30. Marseilles Dam submerged gate operation, gate opening versus angular position

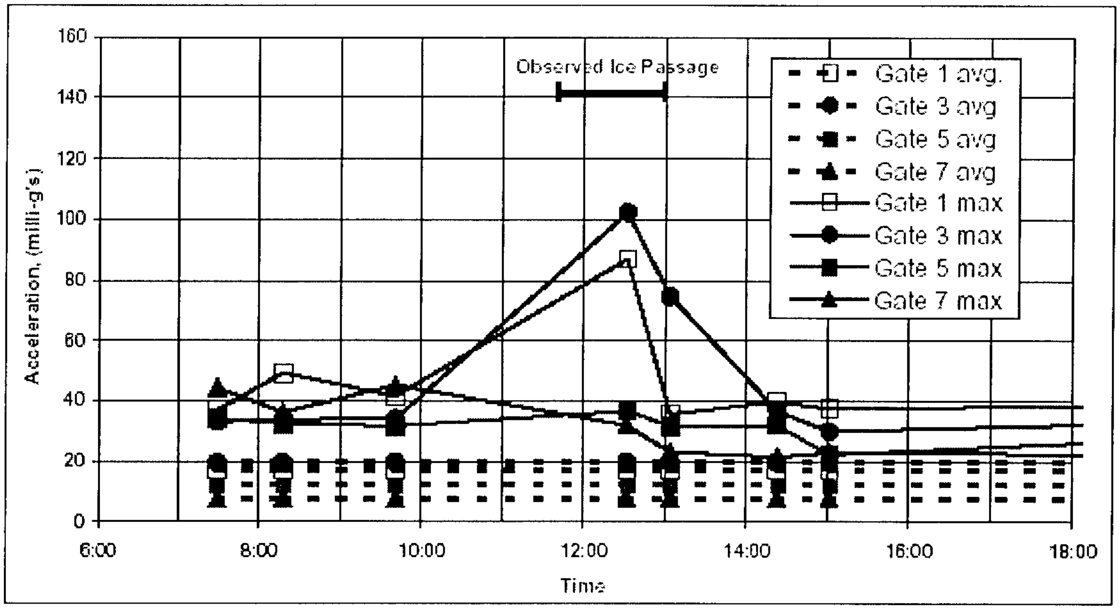


Figure 31. Maximum gate accelerations, 25 January 2000

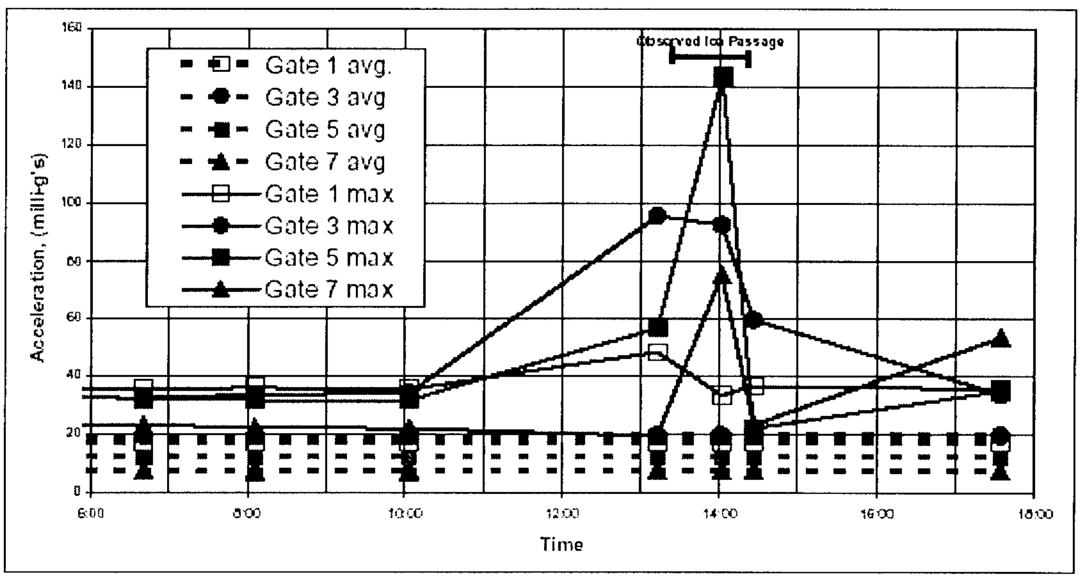


Figure 32. Maximum gate accelerations, 28 January 2000

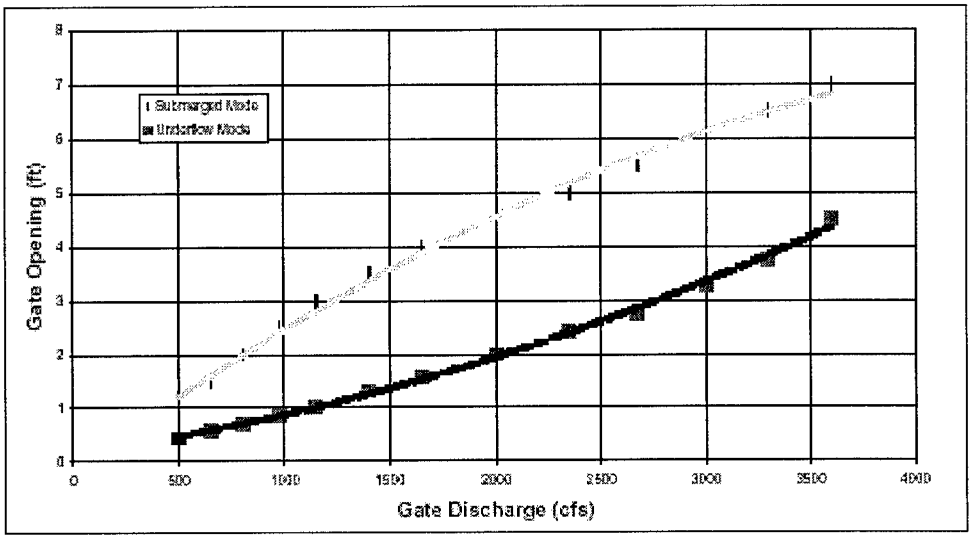


Figure 12. Approximate gate discharge vs. opening height at Marseilles

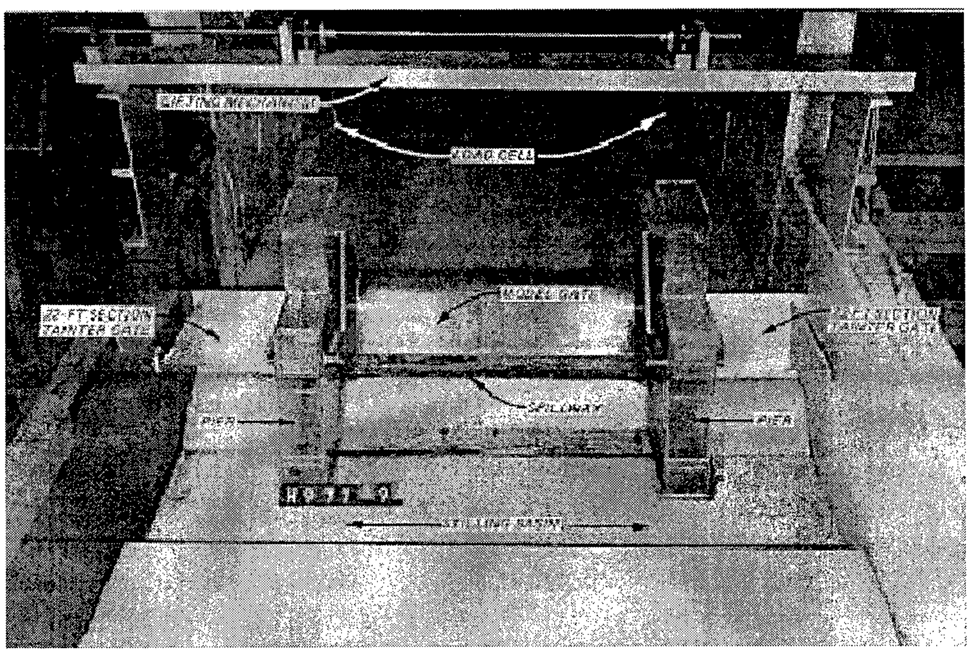


Figure 13. 1:20-scale 3-D physical model

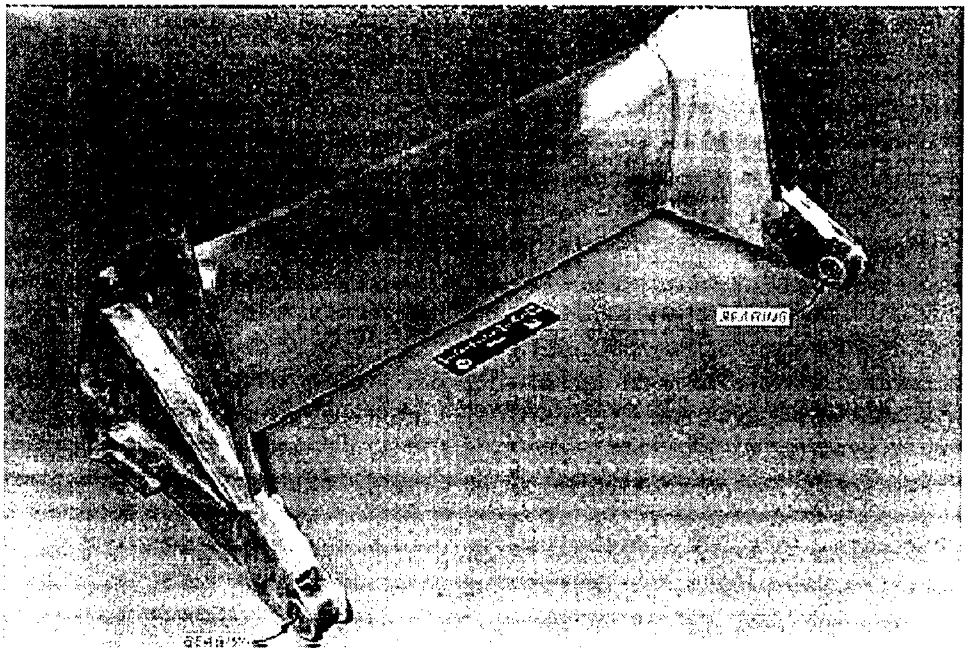


Figure 14. 1:20-scale model submersible tainter gate

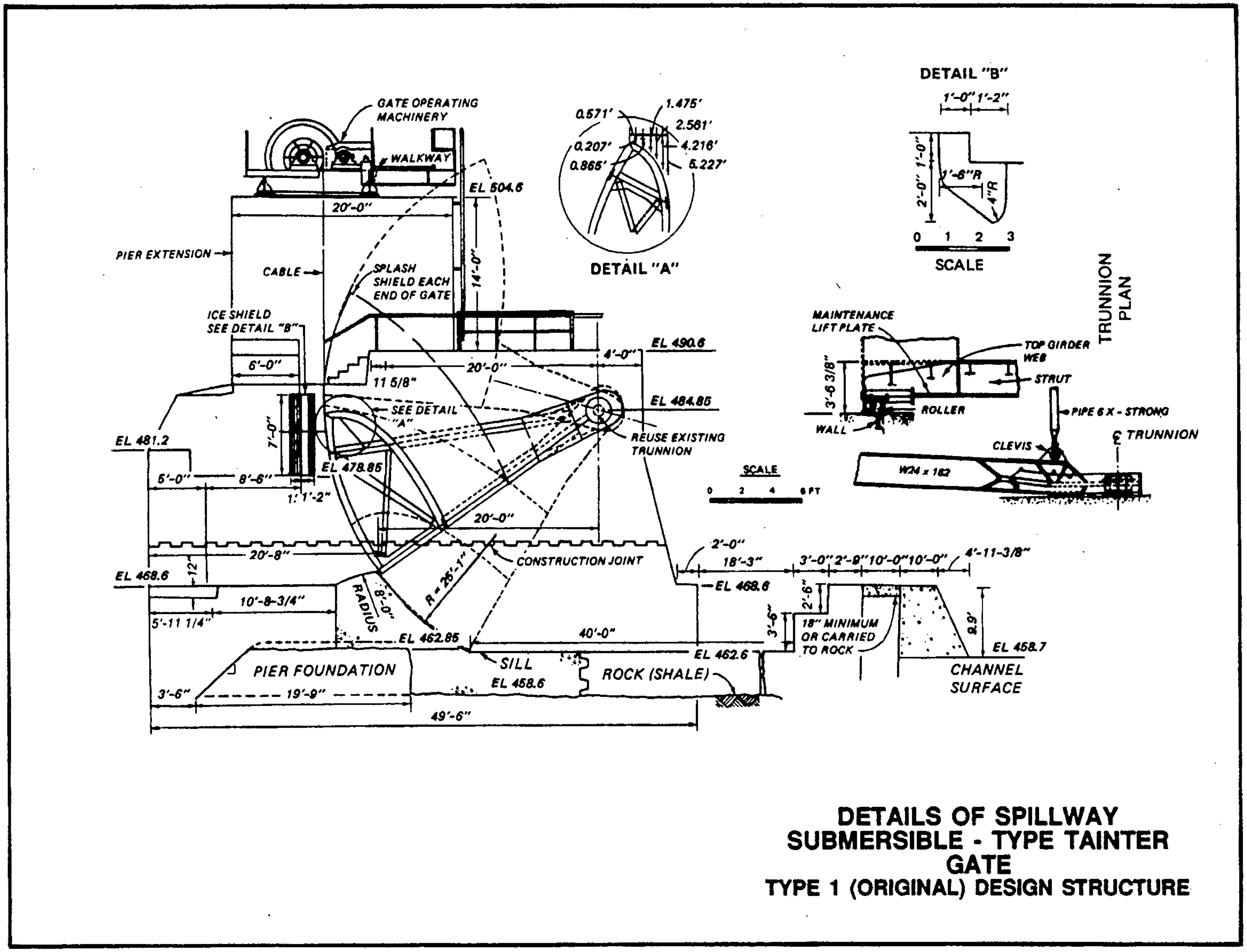


Figure 4. Submersible-type gate

Figure 33. Fragmented ice in pool, morning of 31 January 2001

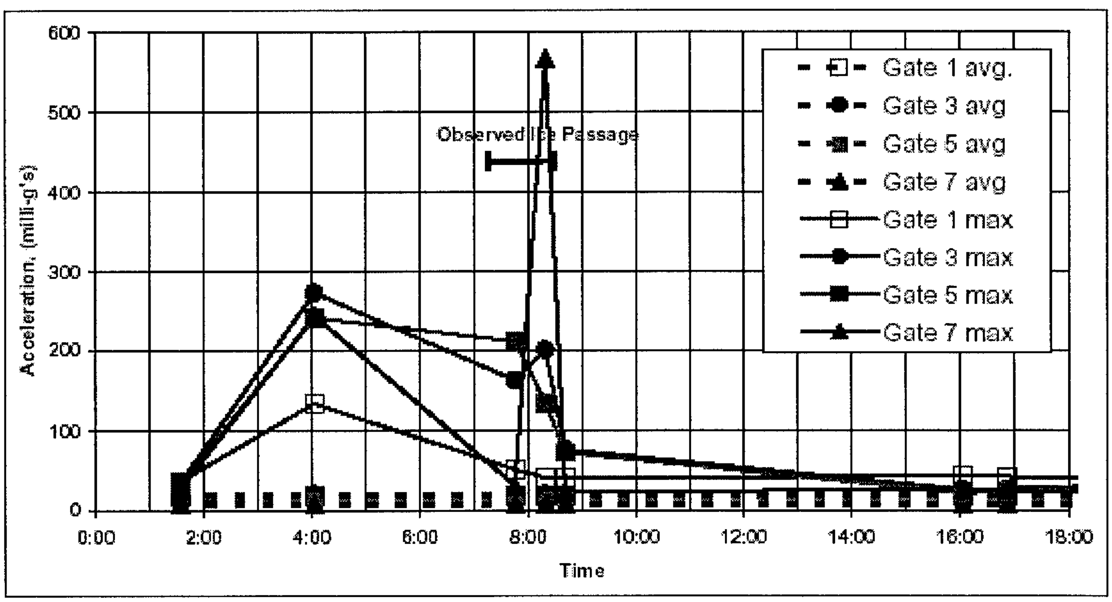


Figure 34. Maximum gate accelerations, 31 January 2000

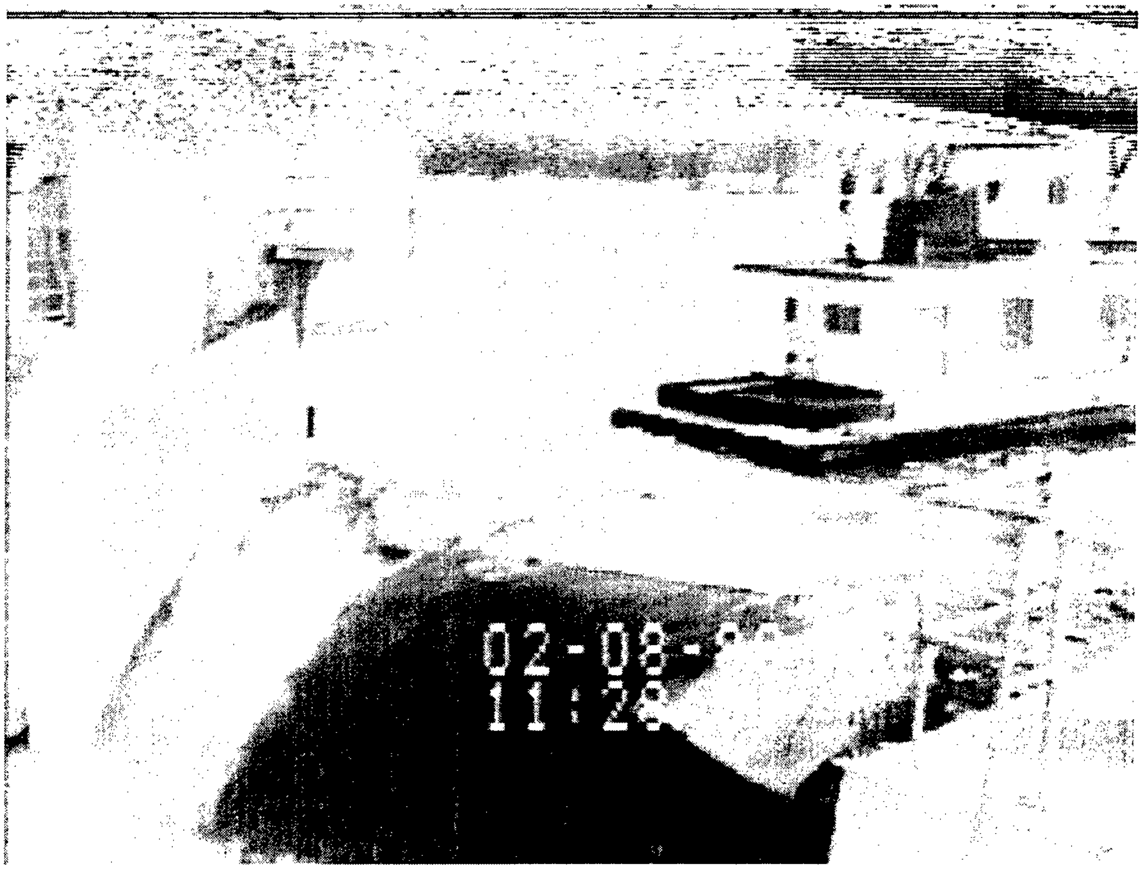


Figure 35. Tow washing ice floe off pier nose on 8 Feb 1988

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	483.41	483.36	483.42	483.52	483.31	483.43	483.40	483.50	483.53	483.30	483.50	483.35
2	483.35	483.27	483.32	483.50	483.27	483.51	483.43	483.40	483.54	483.50	483.50	483.51
3	483.33	483.36	483.47	483.48	483.50	483.34	483.42	483.43	483.40	483.52	483.50	483.55
4	483.40	483.45	483.47	483.41	483.27	483.36	483.40	483.53	483.52	483.50	483.37	483.53
5	483.40	483.32	483.46	483.40	483.39	483.40	483.41	483.60	483.46	483.30	483.51	483.58
6	483.35	483.41	483.45	483.35	483.42	483.45	483.47	483.42	483.54	483.34	483.37	483.37
7	483.54	483.42	483.41	483.52	483.40	483.40	483.45	483.38	483.55	483.50	483.60	483.32
8	483.40	483.28	483.43	483.34	483.47	483.49	483.52	483.40	483.49	483.50	483.48	483.52
9	483.41	483.47	483.30	483.41	483.30	483.29	483.55	483.38	483.49	483.59	483.50	483.58
10	483.48	483.47	483.52	483.43	483.49	483.46	483.29	483.36	483.42	483.59	483.52	483.47
11	483.41	483.49	483.50	483.46	483.40	483.50	483.52	483.42	483.30	483.59	483.59	483.42
12	483.42	483.35	483.42	483.30	483.40	483.30	483.60	483.40	483.51	483.48	483.32	483.52
13	483.43	483.47	483.48	483.39	483.43	483.52	483.34	483.26	483.50	483.58	483.53	483.43
14	483.55	483.39	483.44	483.48	483.42	483.46	483.40	483.35	483.55	483.43	483.59	483.52
15	483.28	483.32	483.33	483.50	483.29	483.10	483.57	483.44	483.49	483.46	483.60	483.60
16	483.47	483.39	483.34	483.38	483.36	483.39	483.42	483.49	483.53	483.55	483.57	483.56
17	483.31	483.50	483.46	483.24	483.32	483.32	483.45	483.39	483.49	483.55	483.52	483.68
18	483.33	483.35	483.39	483.37	483.32	483.25	483.30	483.46	483.52	483.43	483.58	483.50
19	483.32	483.23	483.36	483.14	483.35	483.47	483.27	483.37	483.53	483.54	483.59	483.47
20	483.35	483.57	483.42	483.30	483.20	483.33	483.54	483.50	483.51	483.41	483.64	483.42
21	483.51	483.36	483.47	483.14	483.08	483.48	483.34	483.44	483.58	483.55	483.68	483.45
22	483.47	483.31	483.13	483.32	483.42	483.41	483.27	483.43	483.57	483.22	483.58	483.40
23	483.16	483.37	483.25	483.44	483.28	483.36	483.59	483.48	483.50	483.52	483.43	483.53
24	483.41	483.52	483.26	483.10	483.30	483.32	483.50	483.49	483.68	483.37	483.61	483.48
25	483.29	483.28	483.35	483.16	483.20	483.48	483.50	483.46	483.53	483.46	483.65	483.53
26	483.25	483.15	483.27	483.28	483.40	483.51	483.41	483.52	483.50	483.42	483.66	483.42
27	483.33	483.52	483.46	483.06	483.25	483.46	483.46	483.42	483.40	483.54	483.48	483.53
28	483.35	483.45	483.51	483.22	483.47	483.51	483.50	483.46	483.43	483.59	483.60	483.48
29	483.20	---	483.30	483.25	483.34	483.49	483.10	483.51	483.44	483.52	483.64	483.47
30	483.55	---	483.55	483.28	483.38	483.41	483.39	483.54	483.50	483.40	483.34	483.45
31	483.53	---	483.33	---	483.43	---	483.42	483.50	---	483.40	---	483.39
MIN	483.16	483.15	483.13	483.06	483.08	483.10	483.10	483.26	483.30	483.22	483.32	483.32
MAX	483.55	483.57	483.55	483.52	483.50	483.52	483.60	483.60	483.68	483.59	483.68	483.68
MEAN	483.39	483.39	483.40	483.34	483.35	483.41	483.43	483.44	483.50	483.47	483.53	483.48

Figure 36. Marseilles Lock and Dam 1999 Pool Elevations

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	458.79	462.03	459.98	459.27	462.56	459.66	459.39	458.79	458.93	459.39	458.93	459.05
2	459.00	461.84	459.72	459.26	462.33	460.54	459.61	459.23	458.78	459.20	458.90	458.78
3	458.90	462.21	459.80	459.31	461.51	461.94	459.73	459.03	458.98	458.90	458.92	458.84
4	459.01	461.76	459.89	459.31	461.31	460.96	459.36	458.83	458.82	459.55	459.02	459.01
5	459.08	461.28	459.74	459.37	460.81	460.56	459.28	458.85	458.88	459.25	458.82	459.45
6	459.13	460.87	460.06	459.32	460.40	460.06	459.36	459.12	458.88	459.10	458.90	459.40
7	459.20	460.62	460.03	459.11	460.75	459.66	459.32	458.93	459.00	459.30	458.86	459.45
8	459.06	460.54	460.12	459.40	460.53	459.26	459.22	459.00	459.00	459.16	458.80	459.10
9	459.08	460.46	460.25	459.75	460.07	459.61	459.10	459.02	458.85	459.08	458.93	459.20
10	459.15	460.78	460.10	460.29	460.00	459.12	459.24	458.91	458.83	458.72	458.79	458.90
11	459.26	460.66	459.90	460.32	459.79	459.70	459.40	458.96	459.16	458.77	459.03	459.04
12	459.42	461.09	459.69	460.13	460.29	461.21	459.11	459.15	458.94	458.85	458.77	459.11
13	459.06	461.06	459.69	459.79	461.83	461.40	459.00	459.17	458.96	458.91	458.76	458.91
14	458.91	460.33	460.04	459.73	462.08	465.05	459.12	459.16	458.89	458.81	458.84	459.03
15	459.51	460.33	459.73	459.77	461.29	465.03	459.08	459.37	458.96	458.82	458.89	459.11
16	459.01	460.14	459.79	460.94	461.01	462.90	459.11	459.07	458.86	458.81	458.96	459.12
17	459.51	460.26	460.29	464.39	460.74	461.62	459.12	459.08	458.88	458.83	458.79	459.16
18	459.28	459.85	461.37	465.36	461.05	460.93	459.24	459.07	458.98	458.96	458.84	458.96
19	459.54	459.91	461.30	464.09	460.50	460.16	459.07	459.11	458.84	458.96	458.97	458.88
20	458.93	459.86	460.55	463.25	460.30	459.86	459.19	459.03	458.84	458.87	458.98	459.15
21	459.09	459.56	460.27	462.62	460.09	459.75	459.57	459.30	458.99	458.92	458.86	459.07
22	459.40	459.23	460.26	462.63	460.59	459.94	459.87	459.04	458.99	458.88	458.94	458.97
23	461.81	459.75	459.90	464.01	460.70	460.24	459.39	458.98	458.81	458.93	458.84	458.82
24	465.70	459.56	459.52	466.87	460.74	460.17	459.84	459.38	458.72	458.95	458.81	459.11
25	466.52	459.50	459.53	465.52	460.29	459.76	459.28	459.34	458.94	459.11	458.85	458.47
26	466.04	459.80	459.79	463.92	459.91	459.38	459.48	459.07	458.86	458.87	458.89	459.24
27	464.98	459.96	459.59	462.94	459.65	459.41	458.93	459.34	458.87	458.88	458.89	458.79
28	464.98	459.60	459.41	463.69	459.21	459.43	459.09	459.17	459.19	458.85	458.90	458.90
29	464.90	---	459.73	464.33	459.44	459.32	459.21	458.95	459.78	458.80	459.10	458.94
30	463.58	---	459.42	463.68	459.25	459.43	459.05	458.84	459.34	458.90	459.10	459.13
31	462.52	---	459.31	---	459.30	---	458.91	458.99	---	458.85	---	459.01
MIN	458.79	459.23	459.31	459.11	459.21	459.12	458.91	458.79	458.72	458.72	458.76	458.47
MAX	466.52	462.21	461.37	466.87	462.56	465.05	459.87	459.38	459.78	459.55	459.10	459.45
MEAN	460.72	460.46	459.96	461.75	460.59	460.54	459.28	459.07	458.96	458.97	458.90	459.04

Figure 37. Marseilles Lock and Dam 1999 tailwater elevations

	Jan	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	483.45	483.41	483.48	483.53	483.48	483.49	483.34	483.46	-M-	483.52	483.42	483.36
2	483.45	483.58	483.41	483.54	483.56	483.37	483.40	483.36	-M-	483.44	483.38	483.47
3	483.44	483.40	483.50	483.51	483.49	483.46	483.49	483.47	-M-	483.55	483.43	483.48
4	483.38	483.29	483.55	483.52	483.50	483.35	483.45	483.49	-M-	483.55	483.53	483.40
5	483.45	483.33	483.60	483.57	483.40	483.41	483.28	483.43	-M-	483.48	483.37	483.32
6	483.47	483.53	483.58	483.48	483.34	483.41	483.44	483.34	-M-	483.52	483.56	483.57
7	483.48	483.40	483.57	483.60	483.53	483.34	483.30	483.36	-M-	483.53	483.53	483.31
8	483.55	483.33	483.55	483.47	483.40	483.37	483.39	483.55	483.41	483.41	483.55	483.52
9	483.38	483.30	483.54	483.49	483.48	483.40	483.35	483.52	483.43	483.32	483.55	483.51
10	483.50	483.40	483.50	483.47	483.33	483.65	483.47	483.36	483.40	483.56	483.47	483.32
11	483.55	483.35	483.50	483.46	483.53	483.28	483.50	483.35	483.49	483.49	483.53	483.58
12	483.55	483.44	483.46	483.42	483.48	483.50	483.11	483.44	483.56	483.41	483.43	483.52
13	483.53	483.43	483.37	483.42	483.50	483.47	483.15	483.63	483.54	483.42	483.40	483.59
14	483.44	483.37	483.41	483.34	483.40	483.39	483.42	483.45	483.27	483.52	483.56	483.49
15	483.34	483.38	483.55	483.50	483.46	483.44	483.48	483.52	483.46	483.55	483.51	483.43
16	483.43	483.50	483.52	483.45	483.20	483.25	483.55	483.41	483.52	483.48	483.53	483.20
17	483.44	483.43	483.46	483.43	483.28	483.25	483.42	483.48	483.41	483.58	483.38	483.46
18	483.49	483.40	483.22	483.60	483.50	483.30	483.41	483.54	483.46	483.56	483.40	483.38
19	483.45	483.24	483.38	483.51	483.58	483.33	483.57	483.43	483.44	483.49	483.39	483.25
20	483.45	483.40	483.50	483.45	483.38	483.46	483.41	483.54	483.41	483.67	483.40	483.38
21	483.49	483.45	483.36	483.31	483.51	483.53	483.47	483.55	483.54	483.60	483.38	483.40
22	483.54	483.53	483.50	483.37	483.50	483.35	483.51	483.52	483.41	483.41	483.40	483.41
23	483.53	483.43	483.46	483.26	483.39	483.24	483.38	483.51	483.44	483.43	483.42	483.35
24	483.38	483.38	483.46	483.30	483.34	483.28	483.47	483.46	483.34	483.34	483.49	483.38
25	483.50	483.51	483.38	483.52	483.55	483.41	483.47	483.46	483.46	483.33	483.32	483.33
26	483.48	483.52	483.25	483.43	483.56	483.24	483.51	483.40	483.34	483.33	483.47	483.33
27	483.47	483.39	483.48	483.33	483.42	483.34	483.40	483.40	483.31	483.35	483.45	483.37
28	483.39	483.49	483.57	483.38	483.58	483.34	483.33	483.44	483.32	483.25	483.44	483.32
29	483.37	483.39	483.55	483.48	483.60	483.38	483.48	483.46	483.49	483.50	483.49	483.40
30	483.38	---	483.52	483.45	483.56	483.43	483.34	483.45	483.38	483.32	483.44	483.34
31	483.42	---	483.55	---	483.43	---	483.37	-M-	---	483.48	---	483.28
MIN	483.34	483.24	483.22	483.26	483.20	483.24	483.11	483.34	483.27	483.25	483.32	483.20
MAX	483.55	483.58	483.60	483.60	483.60	483.65	483.57	483.63	483.56	483.67	483.56	483.59
MEAN	483.46	483.41	483.48	483.45	483.46	483.38	483.41	483.46	483.43	483.46	483.45	483.40

Figure 38. Marseilles Lock and Dam 2000 Pool Elevations

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	458.97	459.06	459.64	459.24	459.55	461.89	459.79	459.21	-M-	459.53	459.30	459.36
2	458.98	458.95	459.36	458.87	459.66	462.13	459.63	459.37	-M-	459.43	459.59	459.23
3	458.95	458.76	459.00	459.07	459.48	460.99	460.28	459.54	-M-	459.48	459.46	459.37
4	459.14	458.89	459.20	459.15	459.52	460.50	460.47	459.41	-M-	459.89	459.44	459.52
5	459.10	458.98	459.25	459.07	459.23	460.14	461.26	459.05	-M-	459.85	459.34	459.49
6	459.02	458.89	459.20	459.02	459.39	460.35	461.11	459.30	-M-	460.03	459.30	459.14
7	458.94	458.91	459.00	459.00	459.30	460.34	460.90	459.88	-M-	459.73	459.90	459.60
8	458.93	458.78	459.12	459.32	459.40	459.83	460.67	459.76	459.45	459.85	459.84	459.21
9	458.91	458.90	459.27	459.04	459.58	459.80	460.40	459.48	459.39	459.60	459.62	459.27
10	459.04	458.80	459.08	459.13	460.03	459.72	460.91	459.20	459.46	459.34	460.10	459.26
11	459.34	458.89	459.00	459.07	459.65	459.64	466.12	459.30	459.42	459.40	460.75	459.17
12	458.94	459.06	459.06	459.19	460.00	459.81	464.87	459.36	460.70	459.51	459.91	459.33
13	459.04	458.79	458.96	459.00	460.27	460.33	462.57	459.09	460.29	459.24	459.67	459.07
14	458.97	459.07	459.07	459.12	460.18	461.38	461.43	459.02	460.36	459.67	459.73	459.02
15	459.02	458.96	459.12	459.12	460.06	461.91	460.58	459.04	460.20	459.33	459.55	459.47
16	458.99	458.94	459.13	459.01	459.80	461.70	460.06	458.96	459.56	459.48	459.38	459.03
17	458.86	458.92	458.98	459.25	459.80	460.93	459.51	458.97	459.66	459.31	459.79	459.62
18	458.76	458.96	458.91	459.39	459.20	460.69	459.40	459.31	459.52	459.35	459.46	459.33
19	459.07	458.85	459.07	459.00	459.54	460.16	459.44	459.16	459.55	459.38	459.29	459.23
20	459.04	459.15	459.18	459.86	459.87	459.87	459.41	459.25	459.67	459.25	459.46	459.48
21	458.91	459.10	459.15	462.92	459.67	460.85	459.35	459.09	459.82	459.25	459.42	459.72
22	459.01	459.10	459.23	463.79	460.10	462.96	459.28	459.00	459.65	459.42	459.52	459.45
23	458.94	459.01	459.20	462.67	459.70	462.06	459.30	458.96	460.36	459.34	459.34	459.59
24	458.99	459.40	459.03	462.10	459.61	460.97	459.07	459.62	460.09	459.65	459.30	459.98
25	459.01	459.86	459.14	461.11	459.70	463.21	459.23	459.35	459.91	459.60	459.25	460.00
26	459.01	460.15	459.26	460.64	459.35	463.89	459.19	459.42	459.87	459.51	459.40	459.76
27	459.00	459.86	459.35	460.15	459.40	462.38	459.08	459.47	459.83	459.43	459.17	459.95
28	458.97	459.73	459.27	459.96	459.81	461.14	459.14	459.33	459.80	459.40	459.44	460.01
29	458.85	459.44	458.87	459.85	459.97	460.64	459.12	459.43	459.90	459.42	459.48	459.12
30	458.99	---	459.01	459.74	460.05	460.12	459.32	459.44	459.59	459.30	459.52	459.56
31	459.10	---	458.93	---	459.84	---	459.44	-M-	---	459.55	---	459.24
MIN	458.76	458.76	458.87	458.87	459.20	459.64	459.07	458.96	459.39	459.24	459.17	459.02
MAX	459.34	460.15	459.64	463.79	460.27	463.89	466.12	459.88	460.70	460.03	460.75	460.01
MEAN	458.99	459.11	459.13	459.86	459.70	461.01	460.33	459.29	459.83	459.50	459.56	459.44

Figure 39. Marseilles Lock and Dam 2000 tailwater elevations

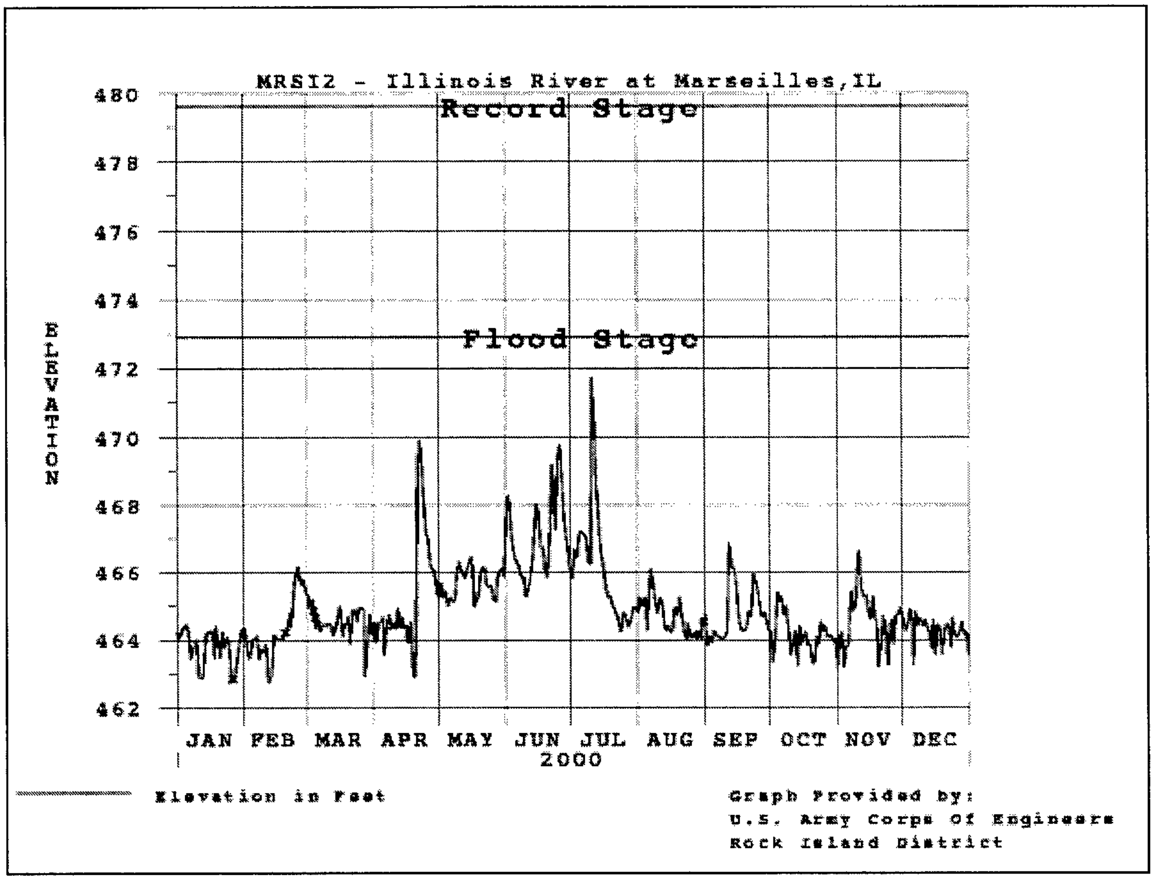


Figure 40. Time-history Illinois River stages at Marseilles

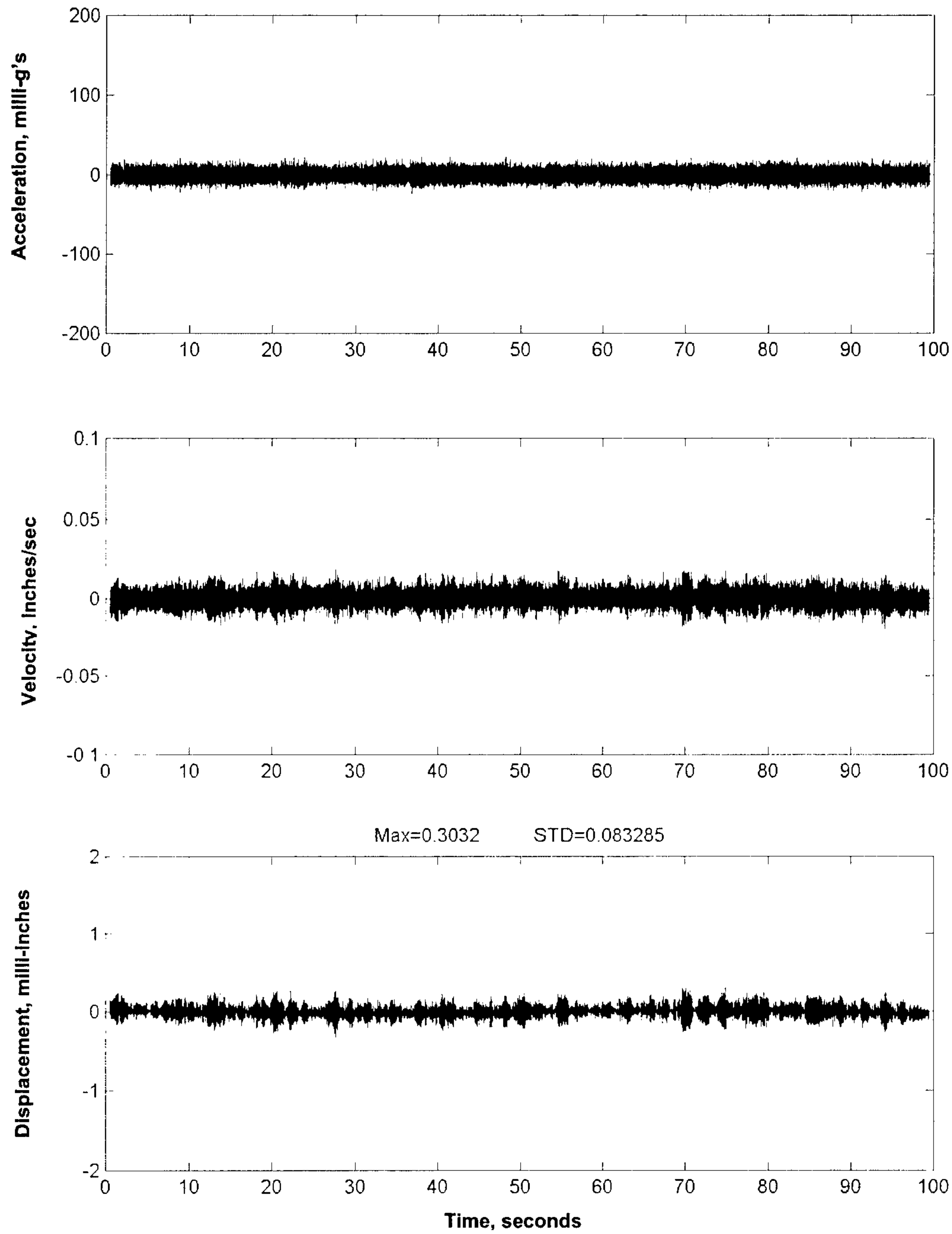


Figure 41. Vertical accelerations, Gate 5 raised position, 2.0-ft opening, 06/02/00

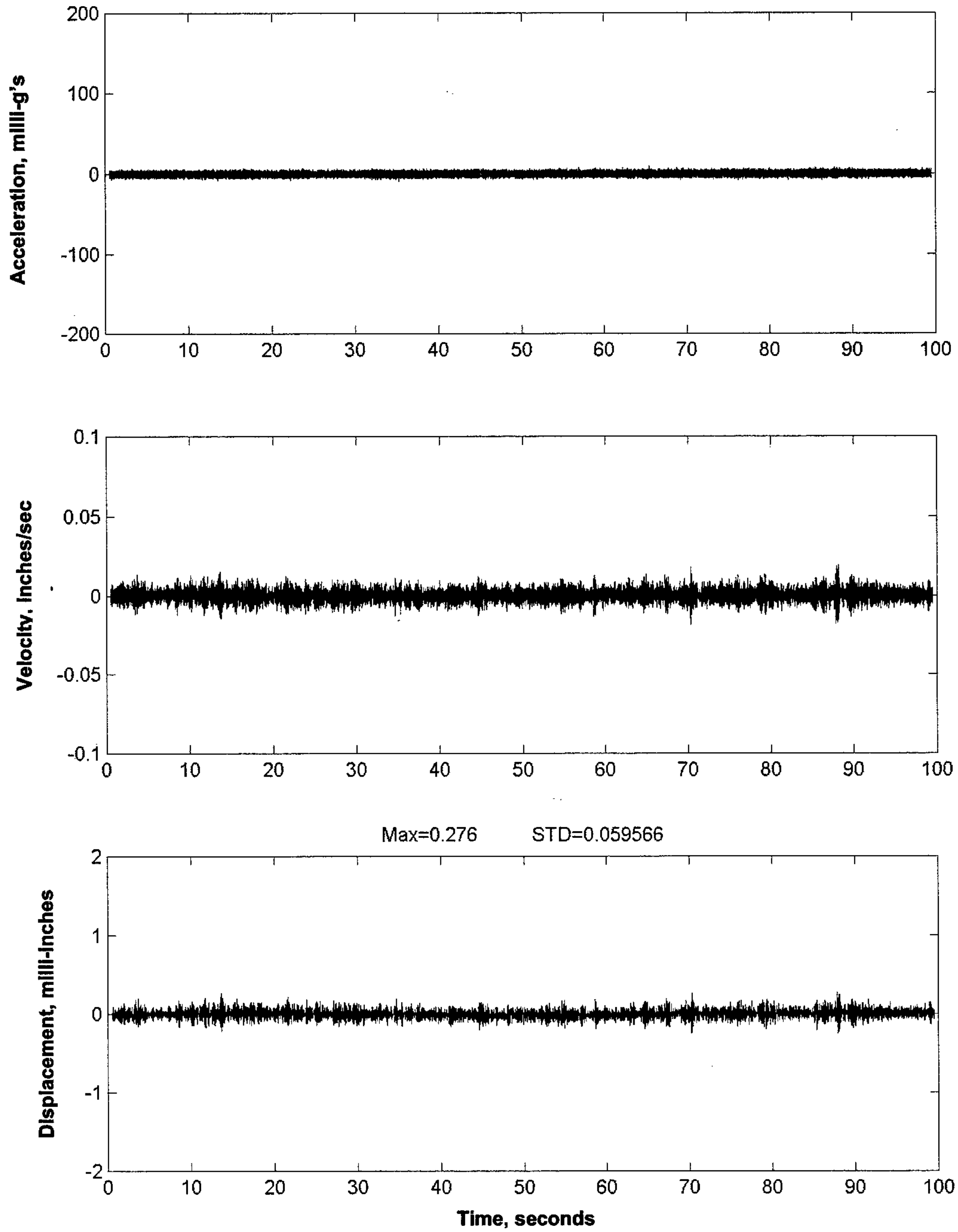


Figure 42. Radial accelerations, Gate 5, raised position, 2.0-ft opening, 06/02/00

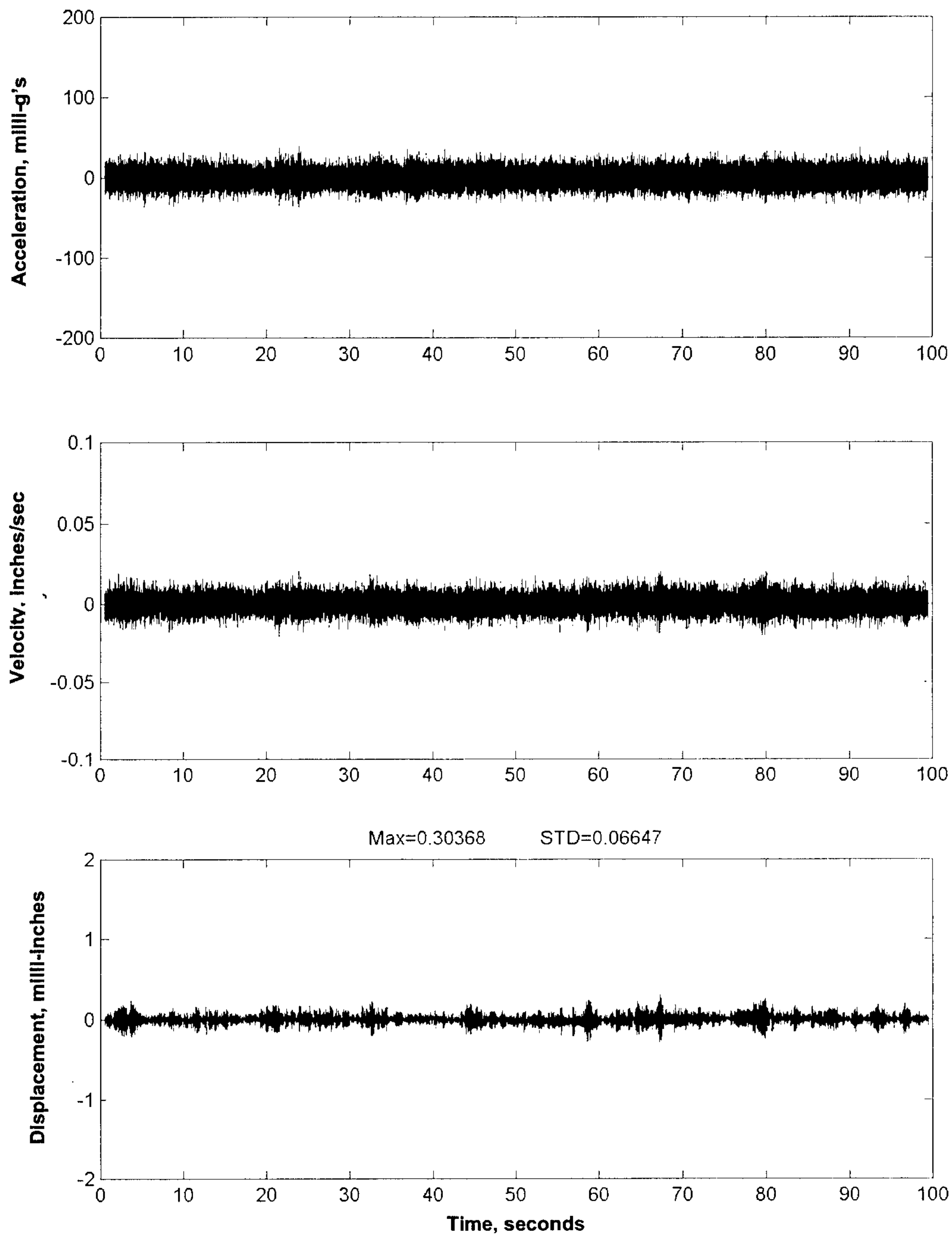


Figure 43. Transverse accelerations, Gate 5, raised position, 2.0-ft opening, 06/02/00

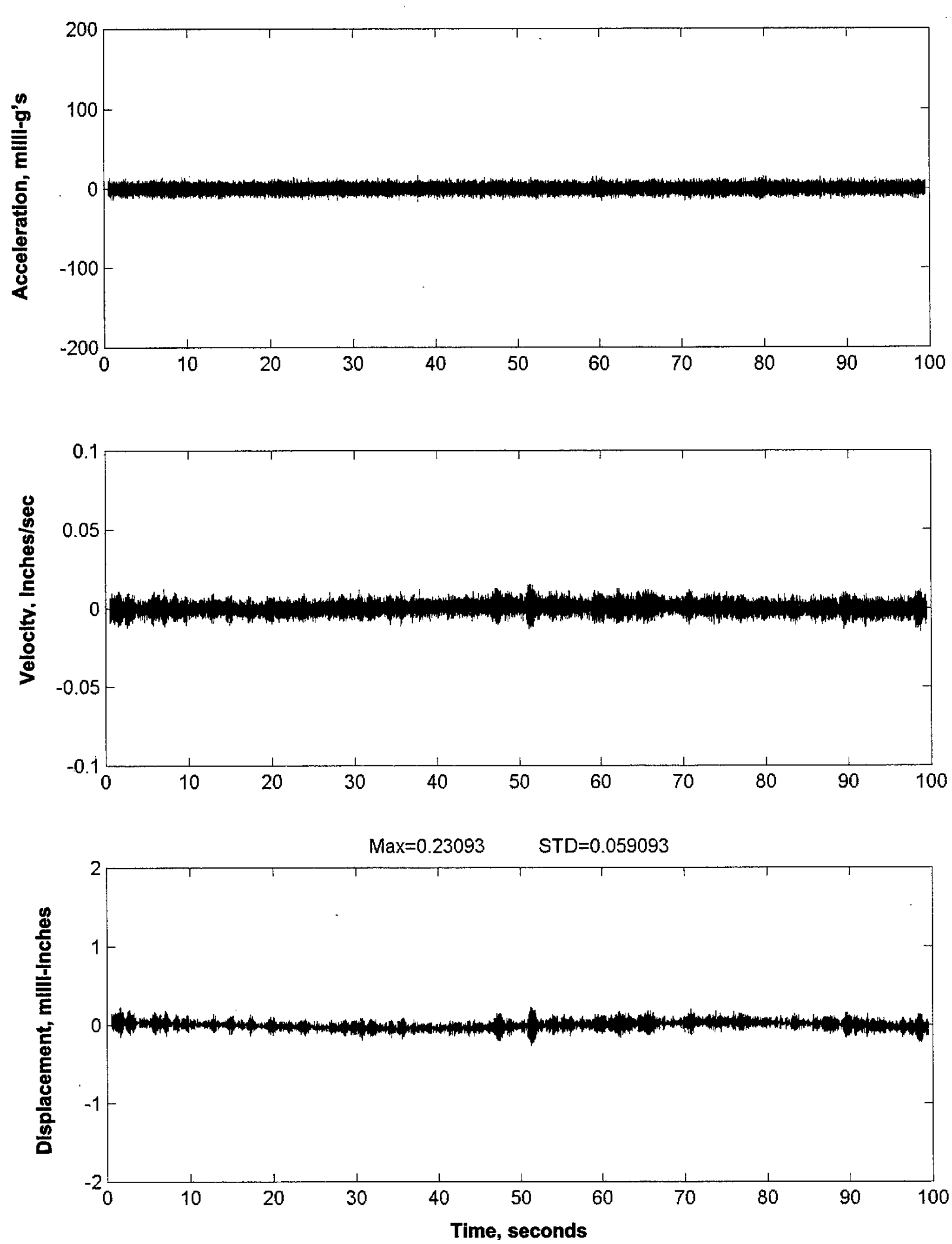


Figure 44. Vertical accelerations, Gate 7, raised position, 5.0-ft opening, 06/02/00

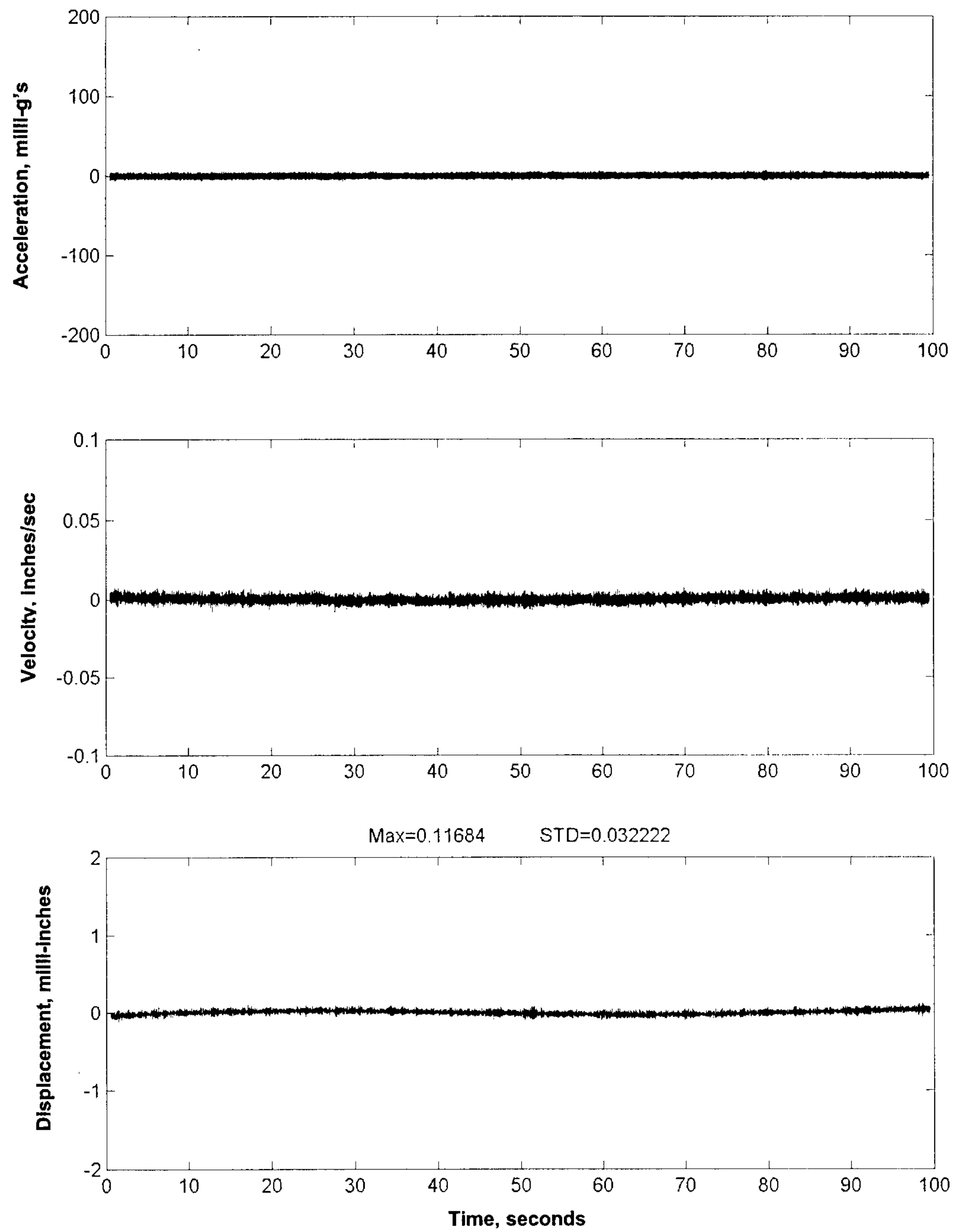


Figure 45. Radial accelerations, Gate 7, raised position, 5.0-ft opening, 06/02/00

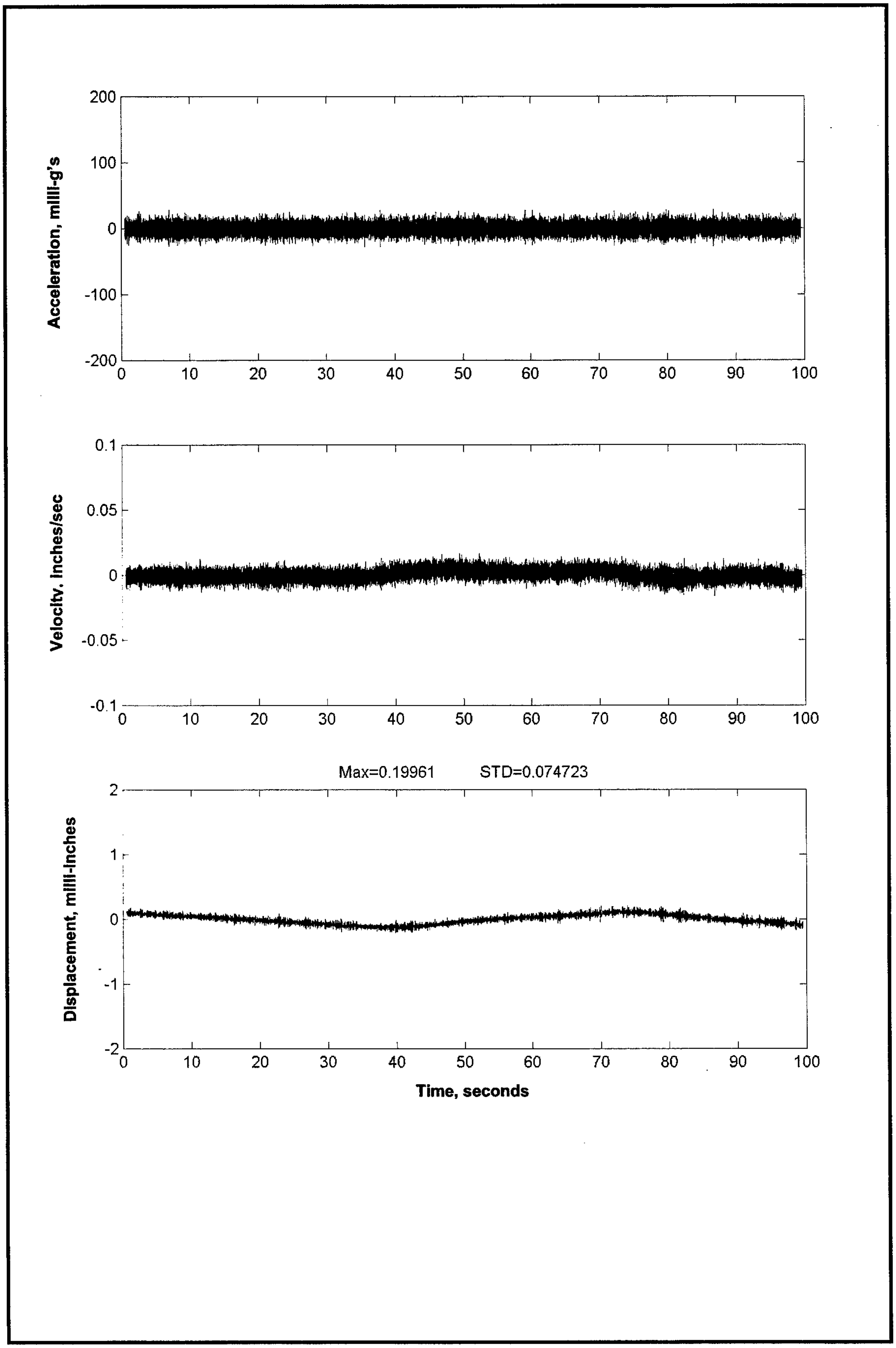


Figure 46. Transverse accelerations, Gate 7, raised position, 5.0-ft opening, 06/02/00

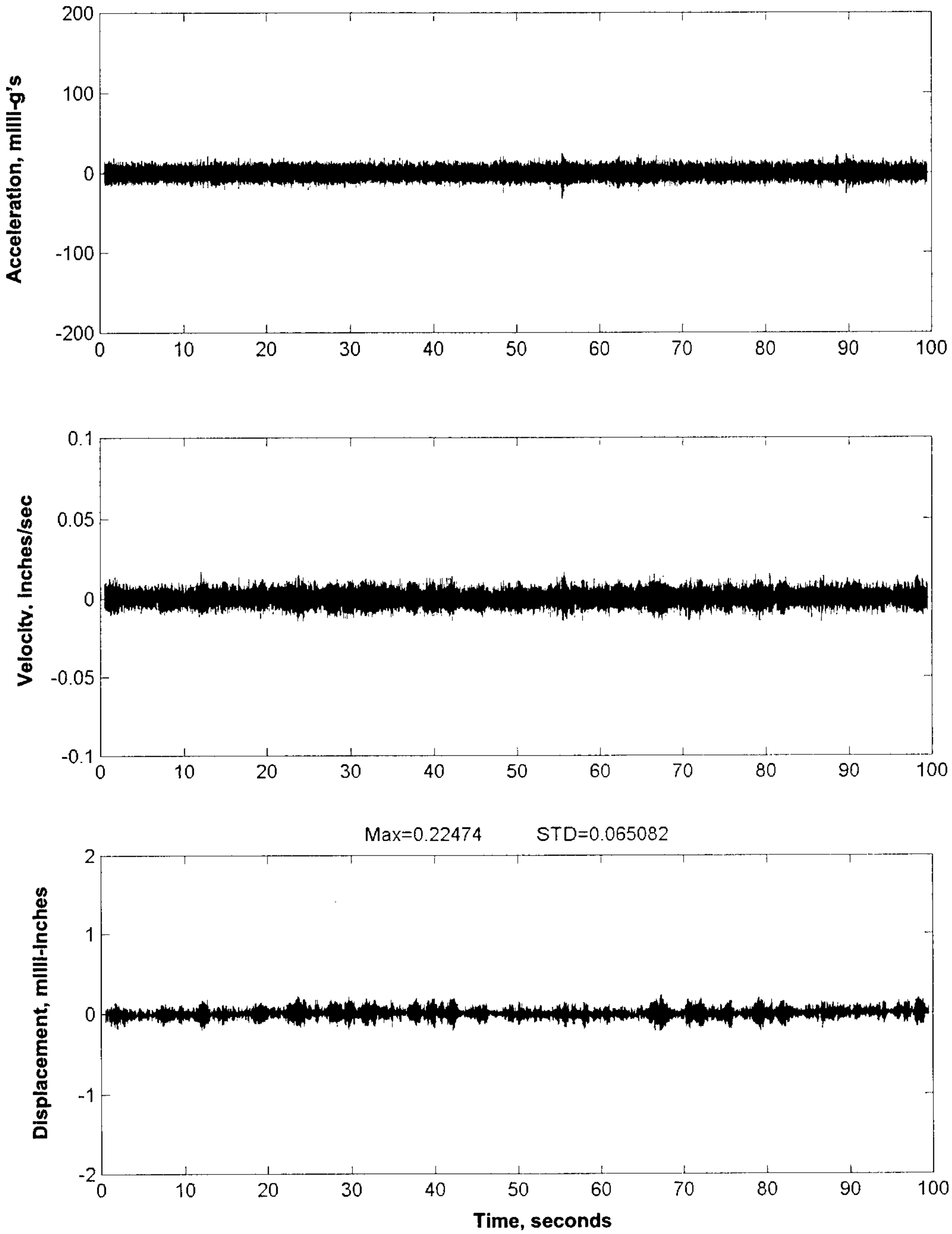


Figure 47. Vertical accelerations, Gate 5, raised position, 5.0-ft opening, 04/21/00

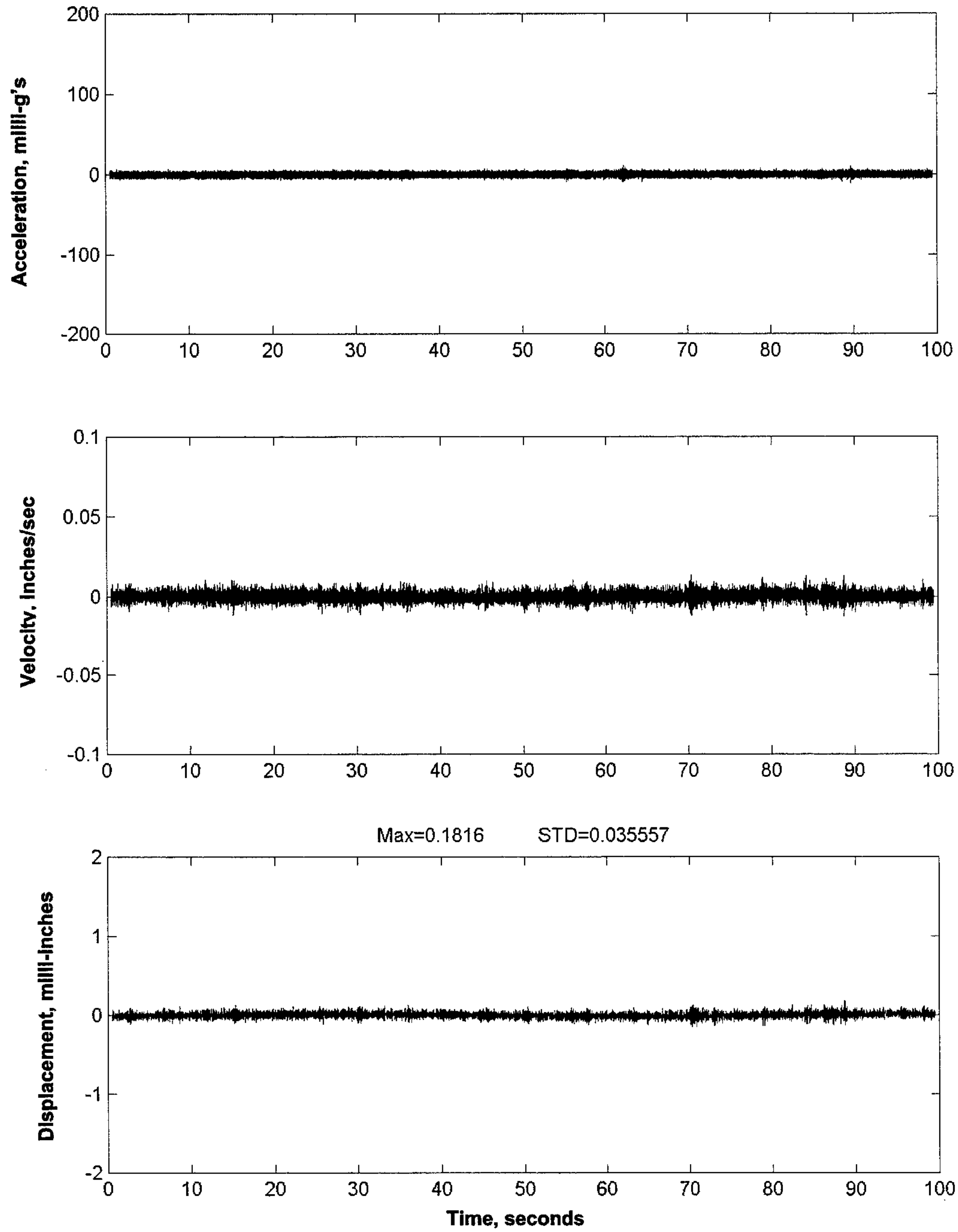


Figure 48. Radial accelerations, Gate 5, raised position, 5.0-ft opening, 04/21/00

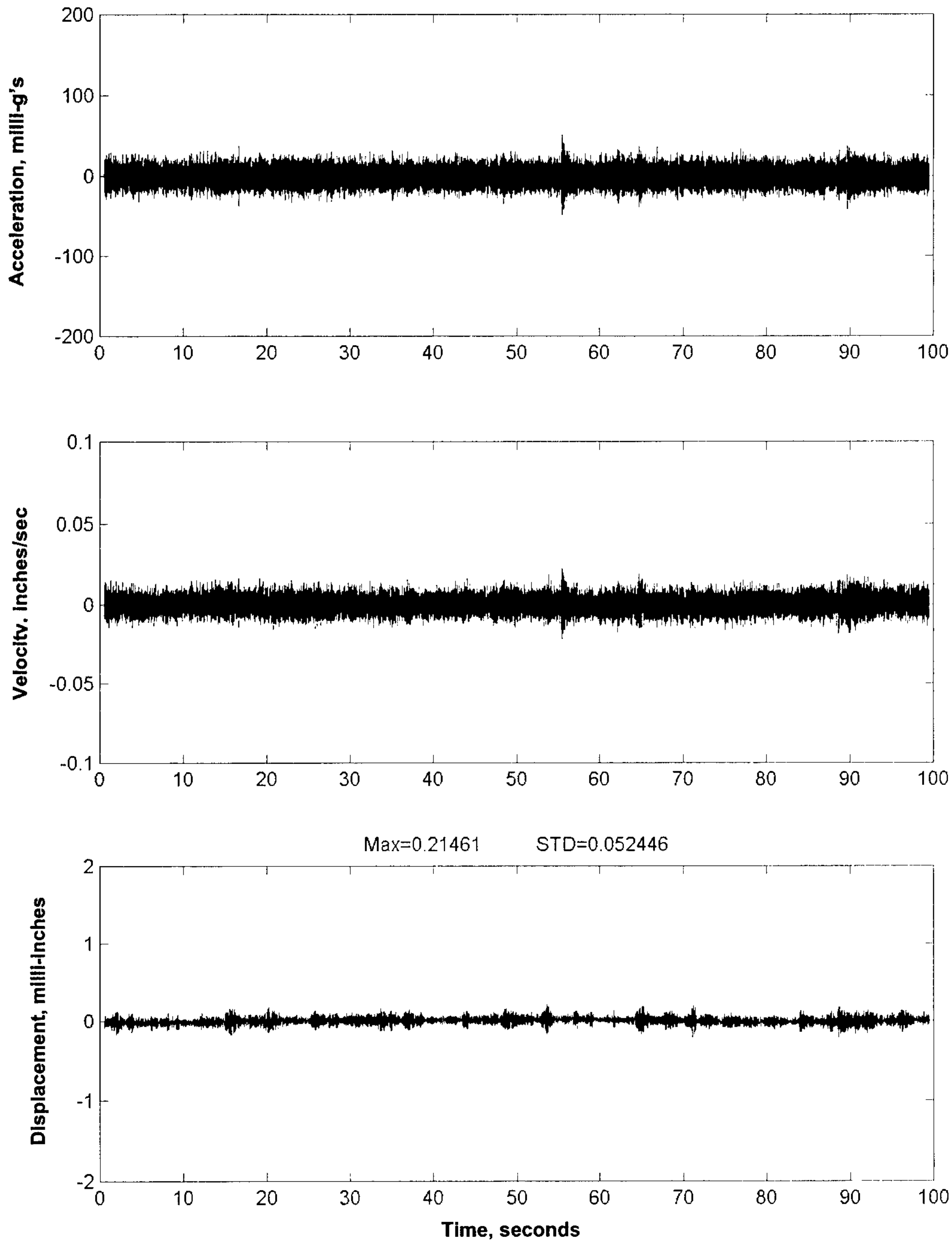


Figure 49. Transverse accelerations, Gate 5, raised position, 5.0-ft opening, 04/21/00

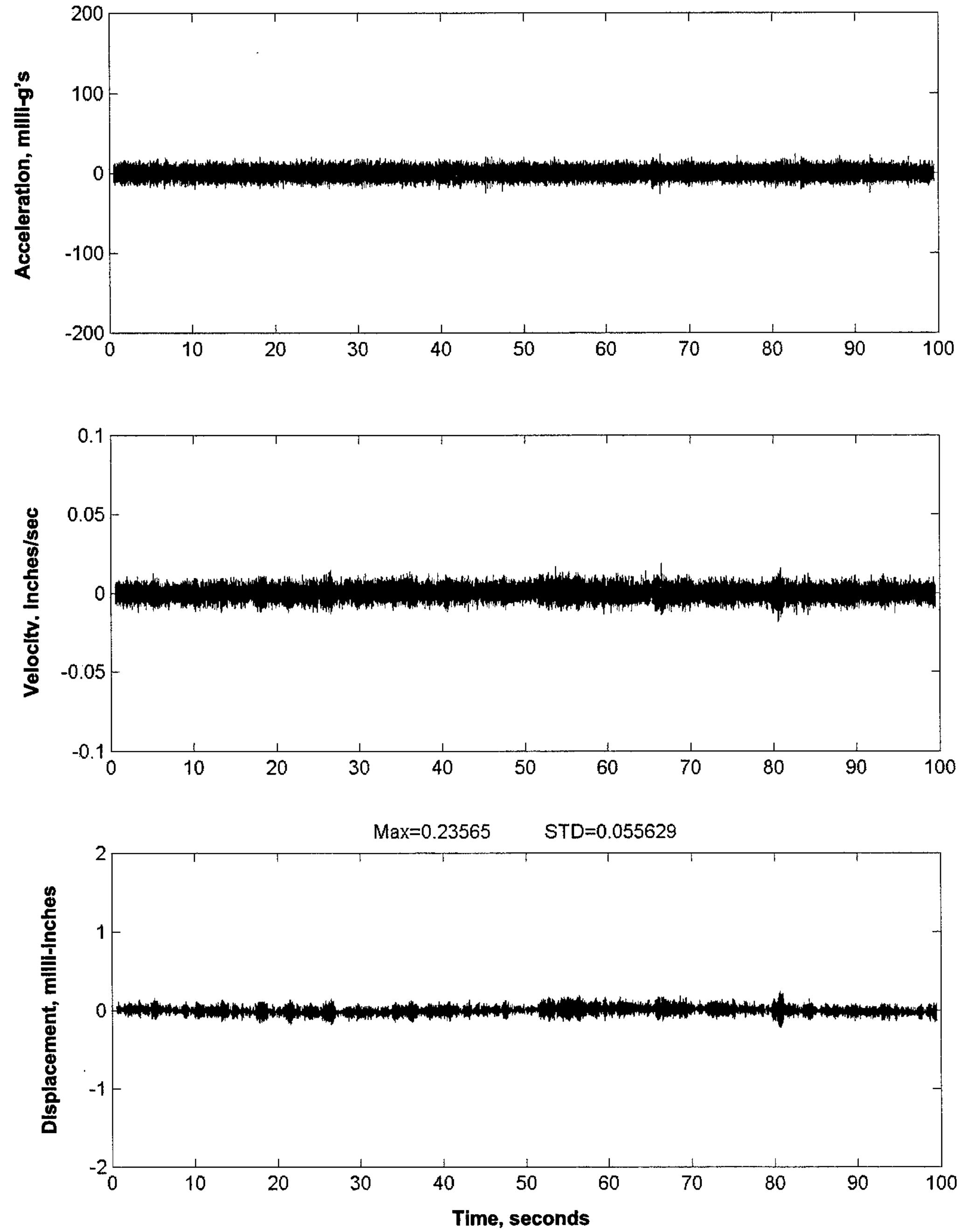


Figure 50. Vertical accelerations, Gate 7, raised position, 5.0-ft opening, 04/21/00

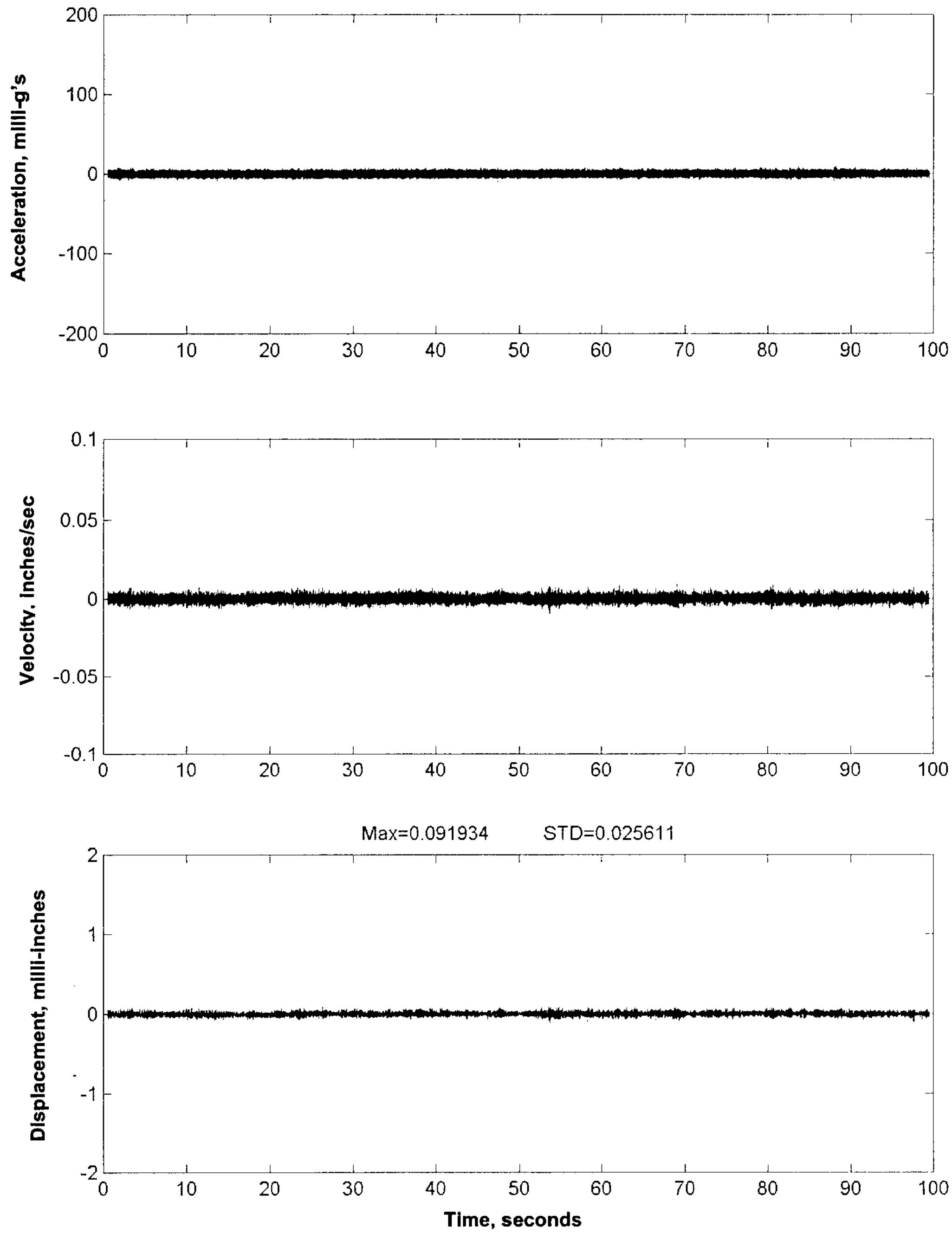


Figure 51. Radial accelerations, Gate 7, raised position, 5.0-ft opening, 04/21/00

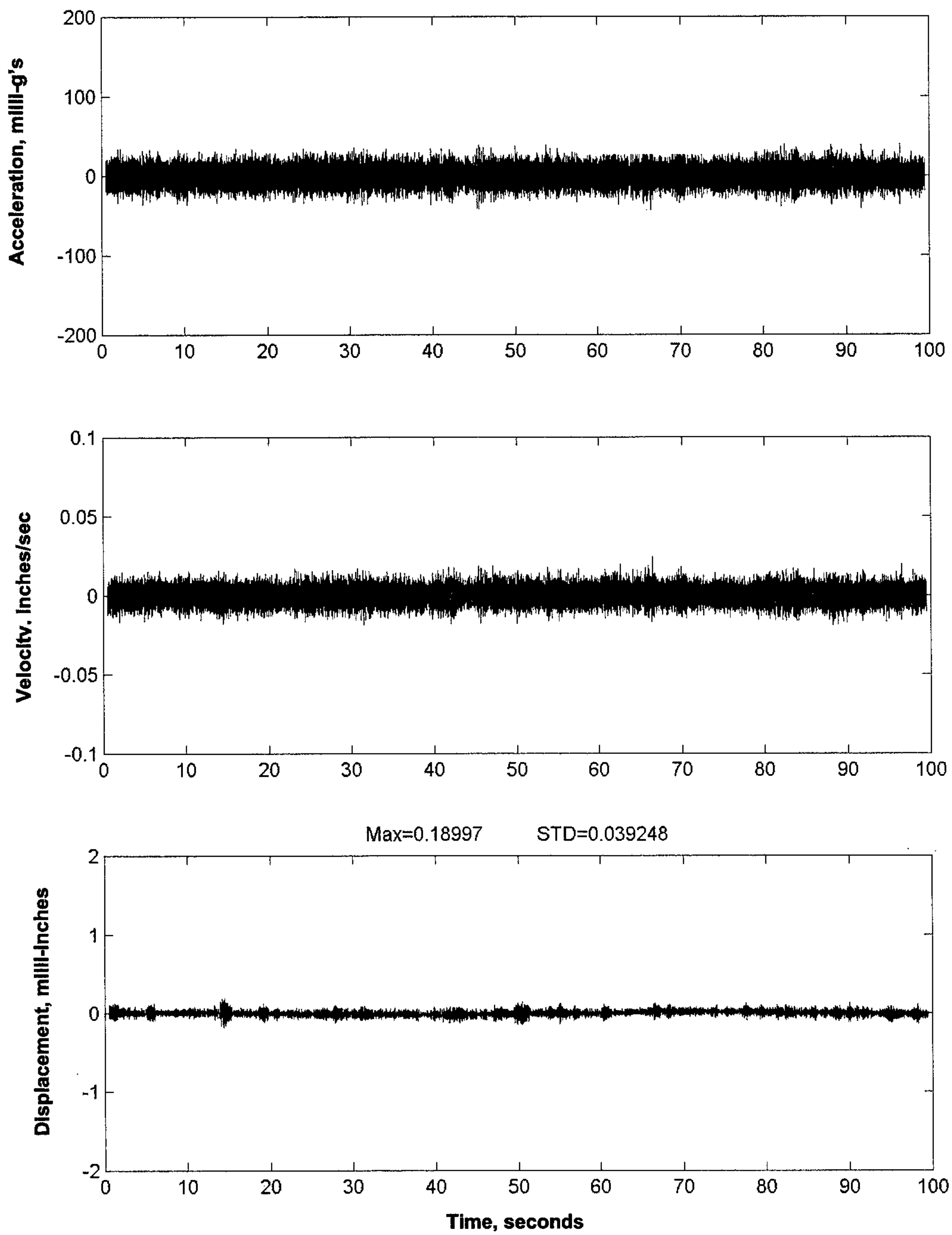


Figure 52. Transverse accelerations, Gate 7, raised position, 5.0-ft opening, 04/21/00

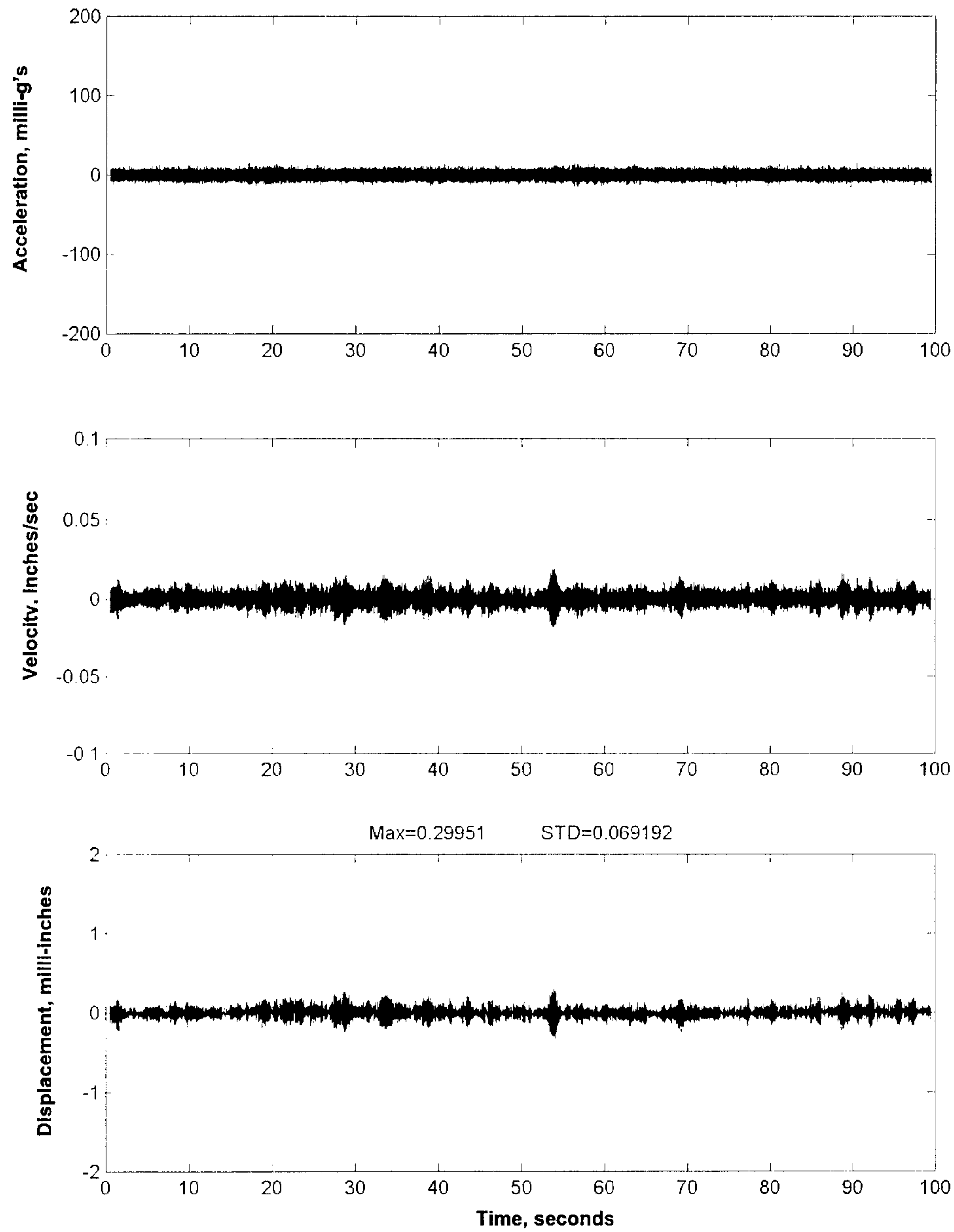


Figure 53. Vertical accelerations, Gate 3, raised position, 1.0-ft opening, 04/22/00

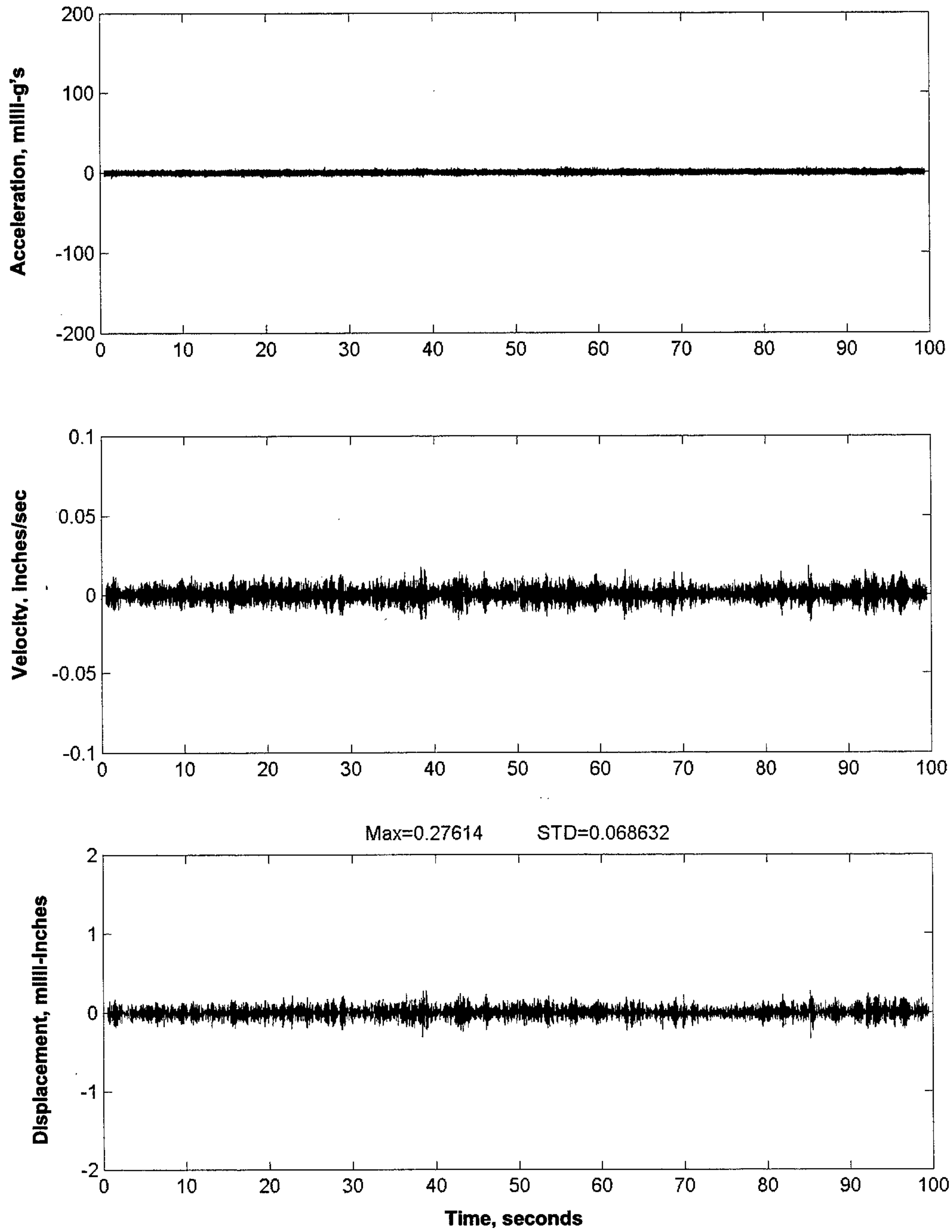


Figure 54. Radial accelerations, Gate 3, raised position, 1.0-ft opening, 04/22/00

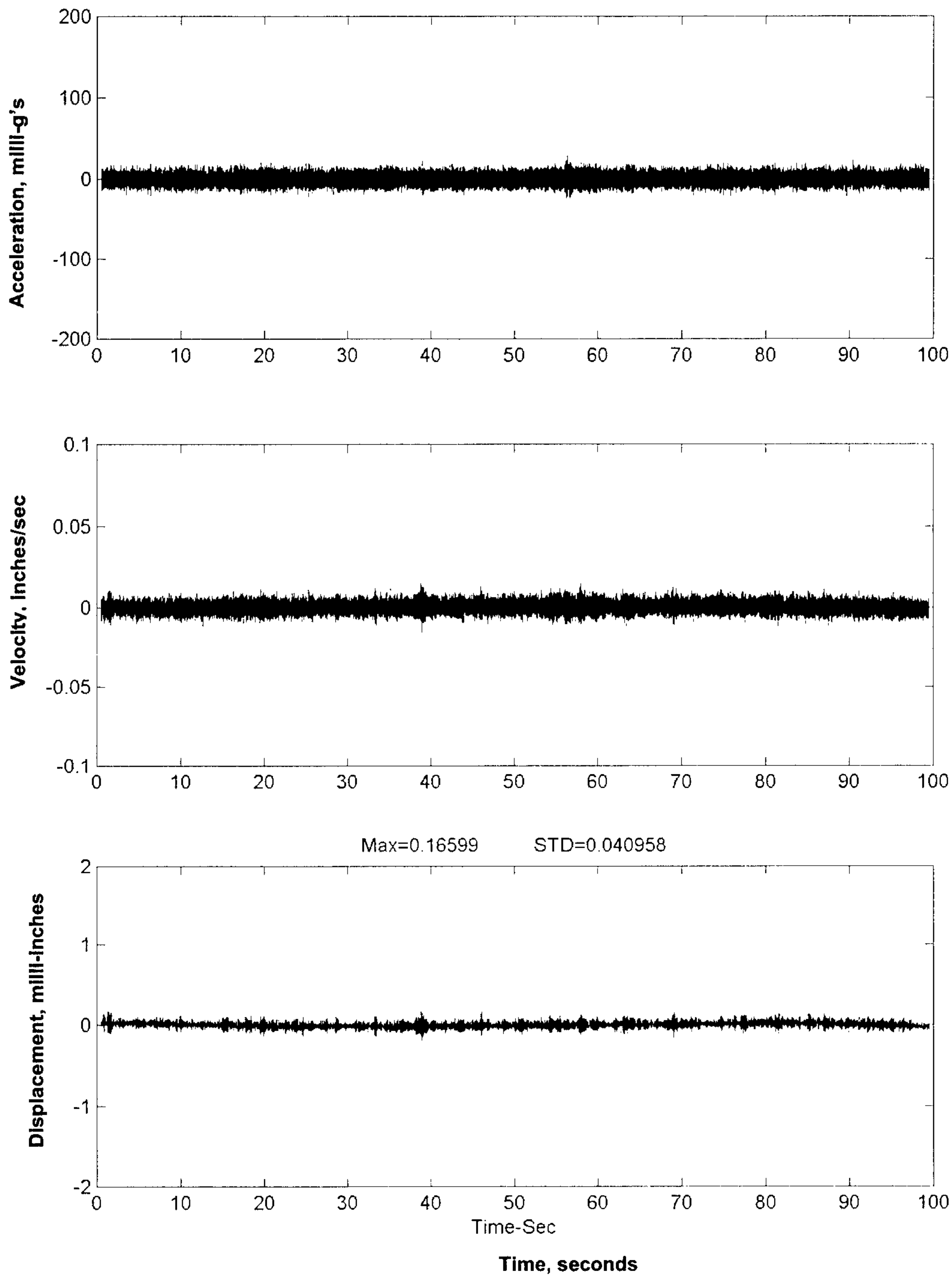


Figure 55. Tansverse accelerations, Gate 3, raised position, 1.0-ft opening, 04/22/00

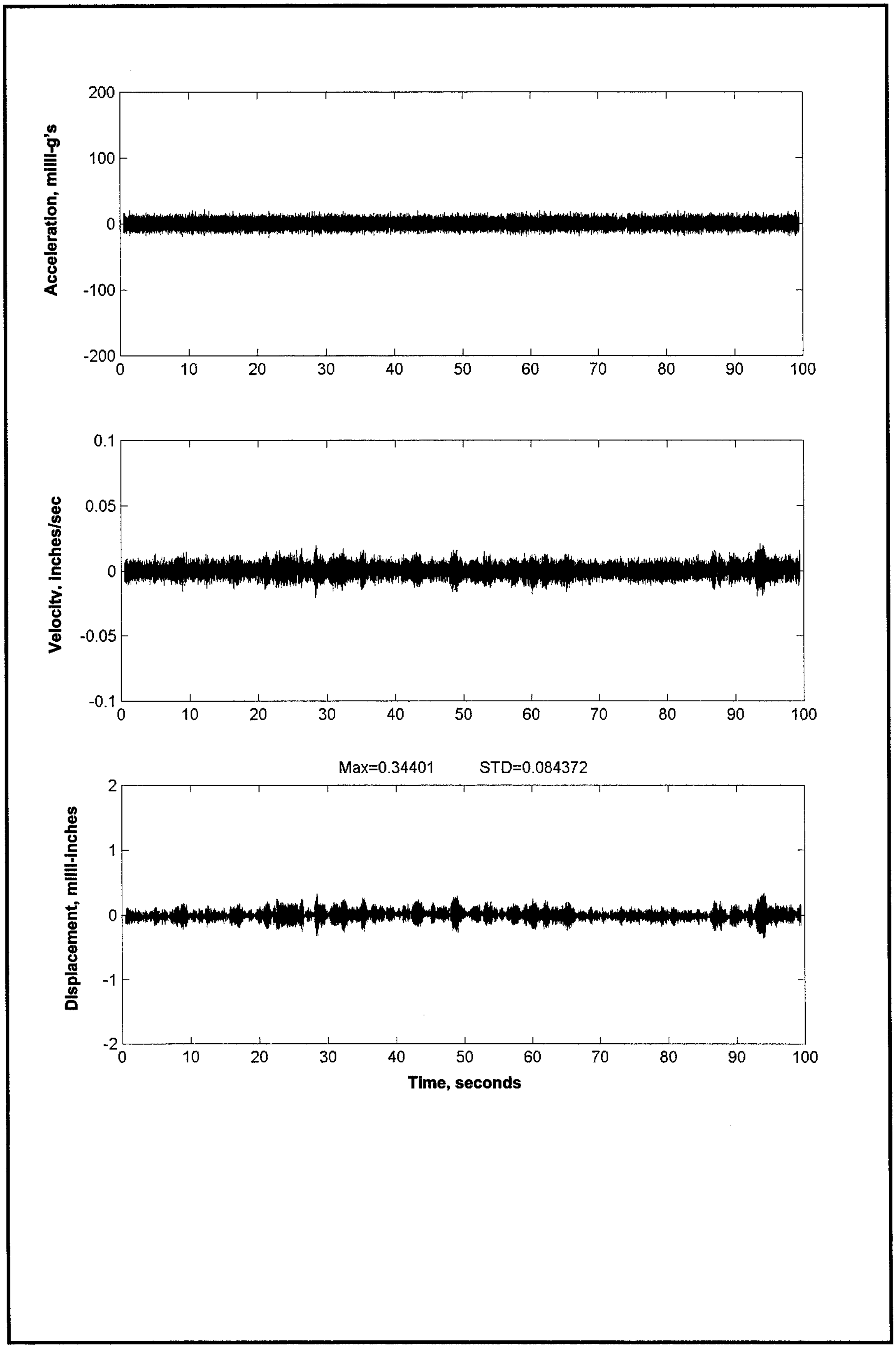


Figure 56. Vertical accelerations, Gate 5, raised position, 5.0-ft opening, 04/22/00

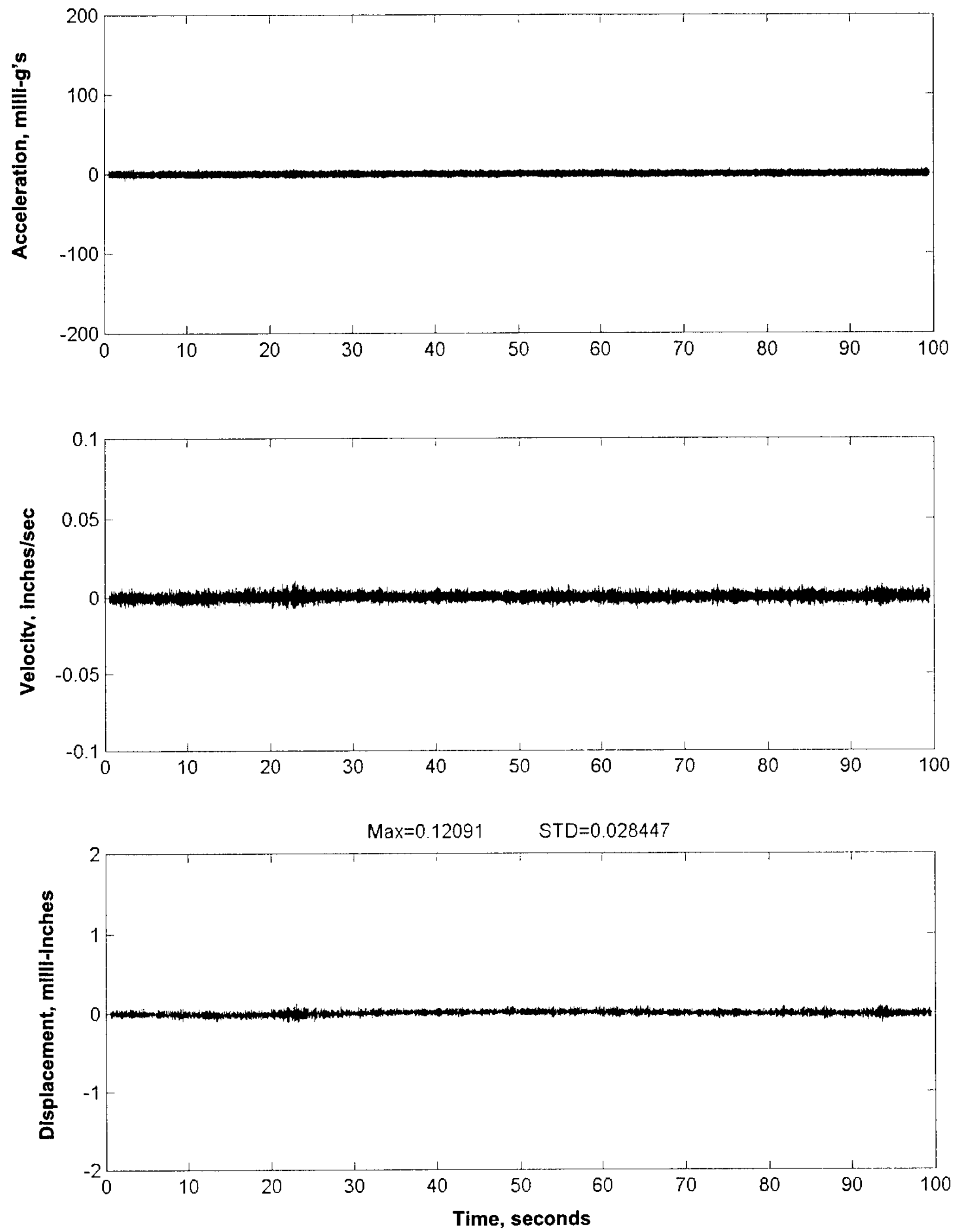


Figure 57. Radial accelerations, Gate 5, raised position, 5.0-ft opening, 04/22/00

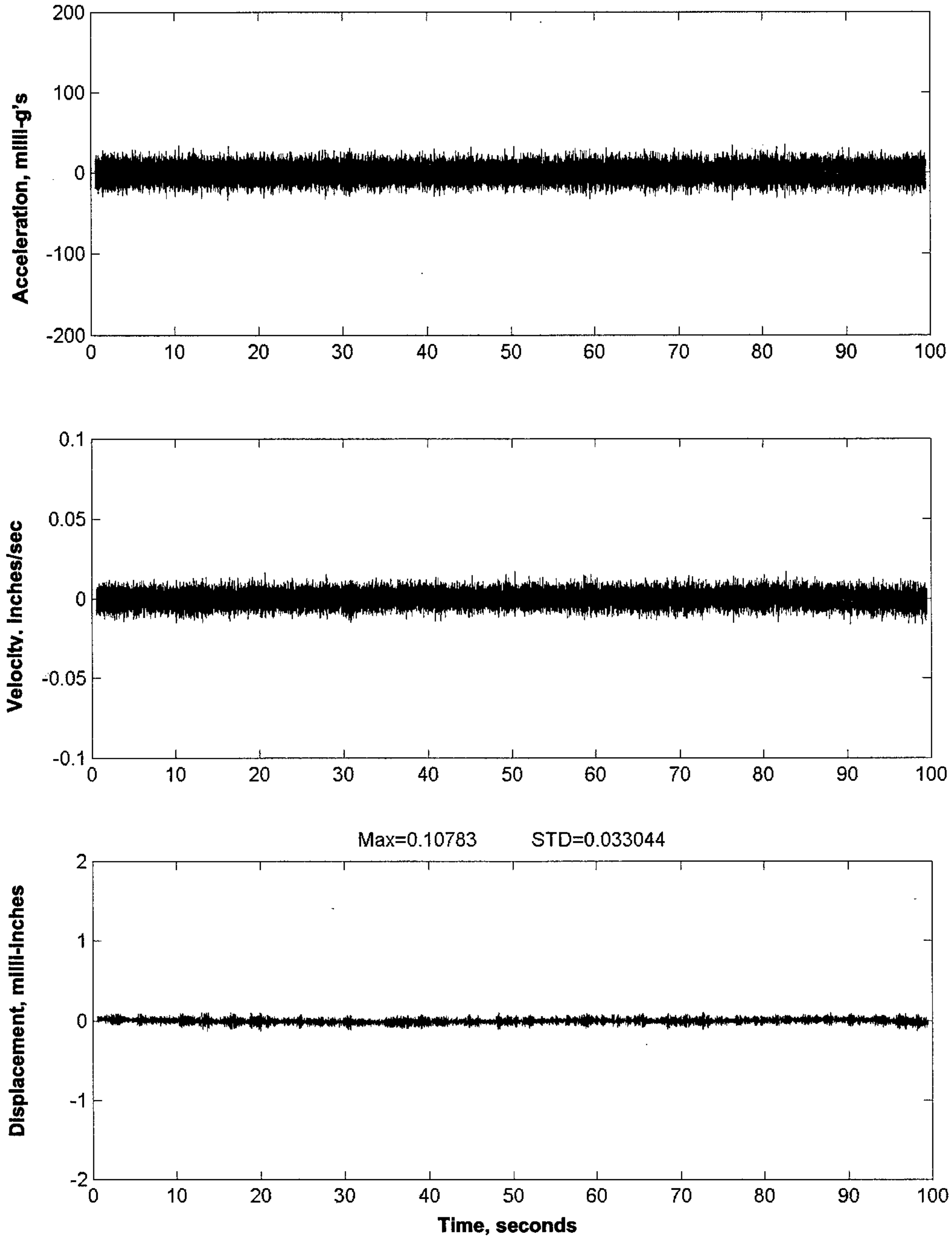


Figure 58. Transverse accelerations, Gate 5, raised position, 5.0-ft opening, 04/22/00

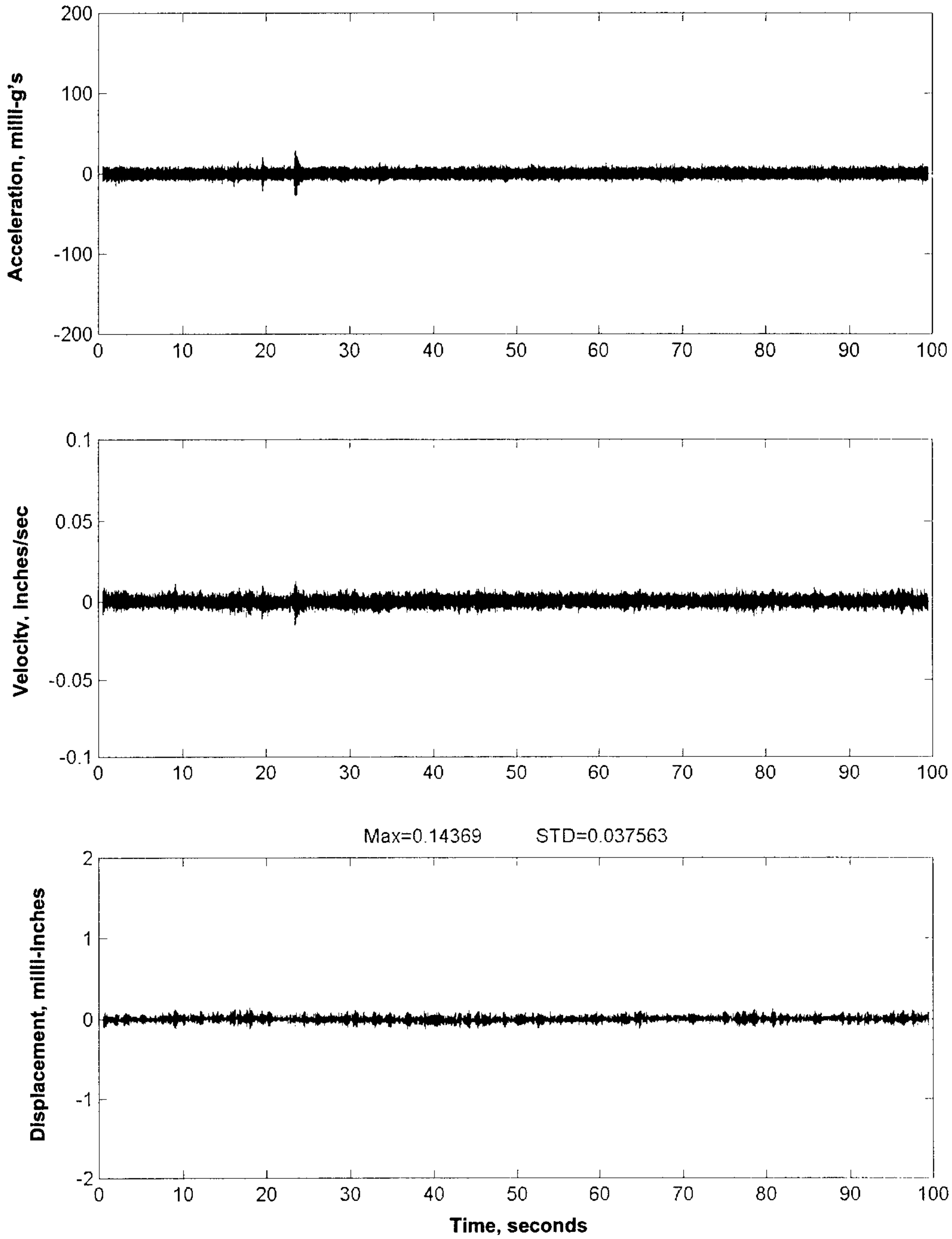


Figure 59. Vertical accelerations, Gate 7, raised position, 5.0-ft opening, 04/22/00

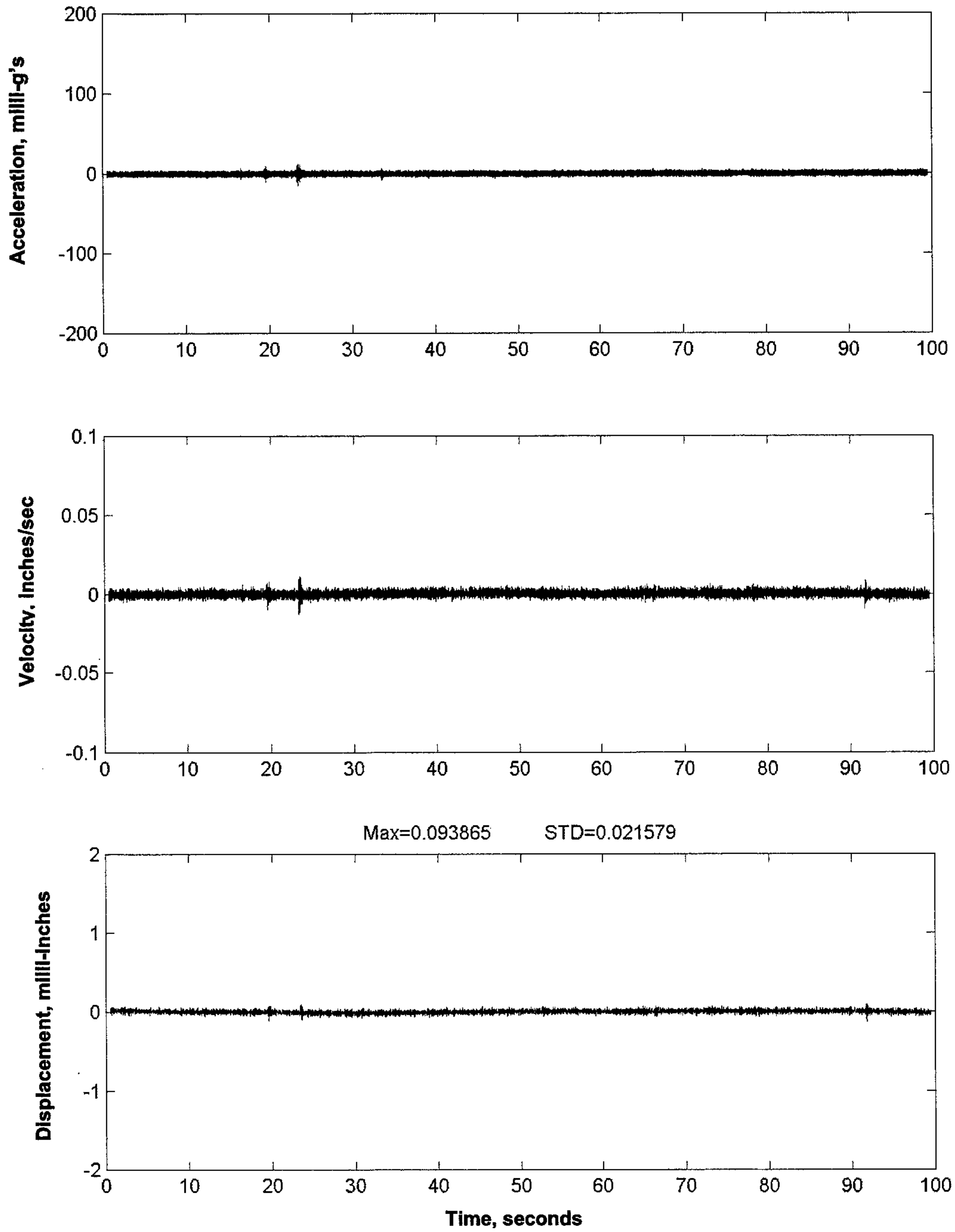


Figure 60. Radial accelerations, Gate 7, raised position, 5.0-ft opening, 04/22/00

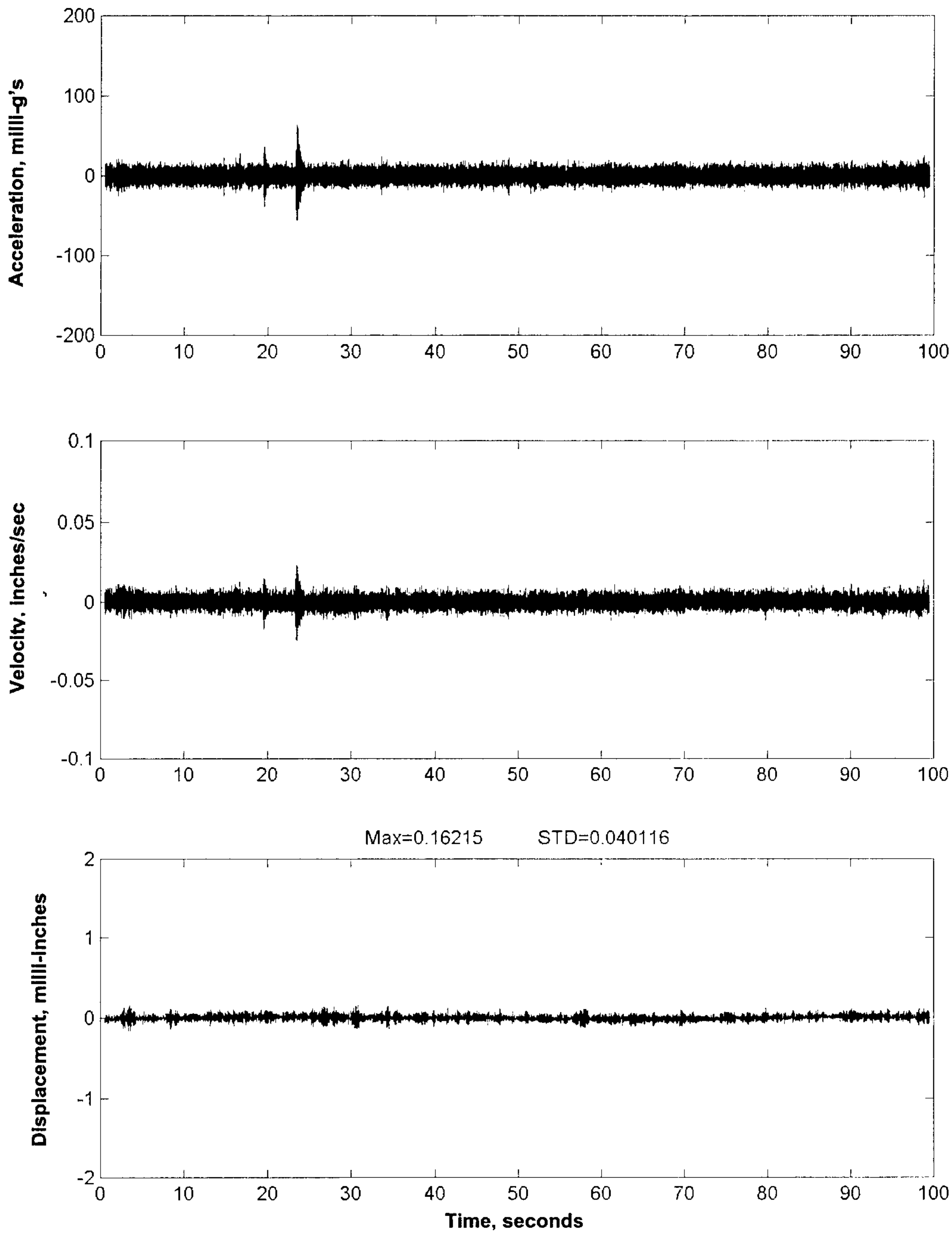


Figure 61. Transverse accelerations, Gate 7, raised position, 5.0-ft opening, 04/22/00

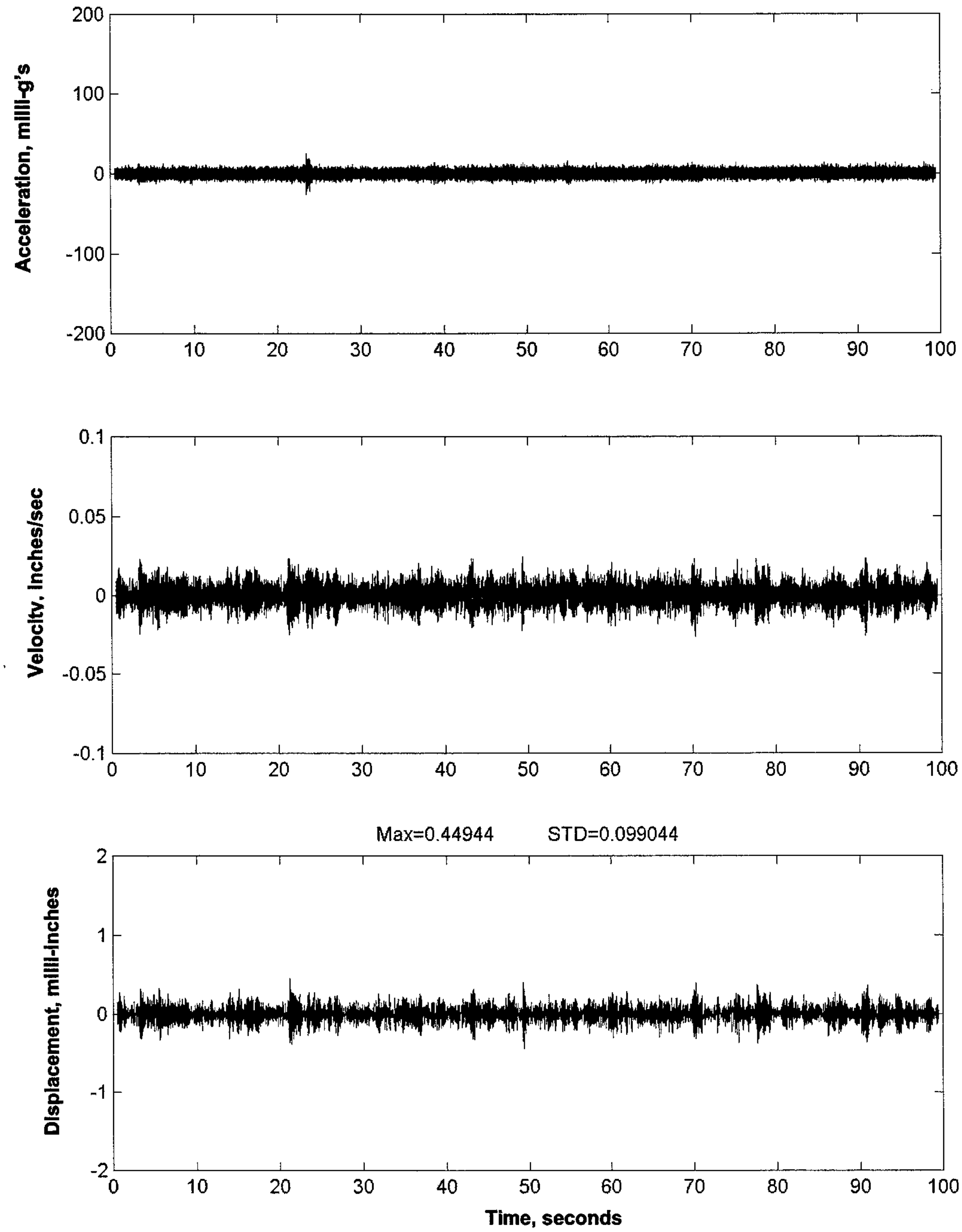


Figure 62. Vertical accelerations, Gate 3, raised position, 5.0-ft opening, 07/11/00

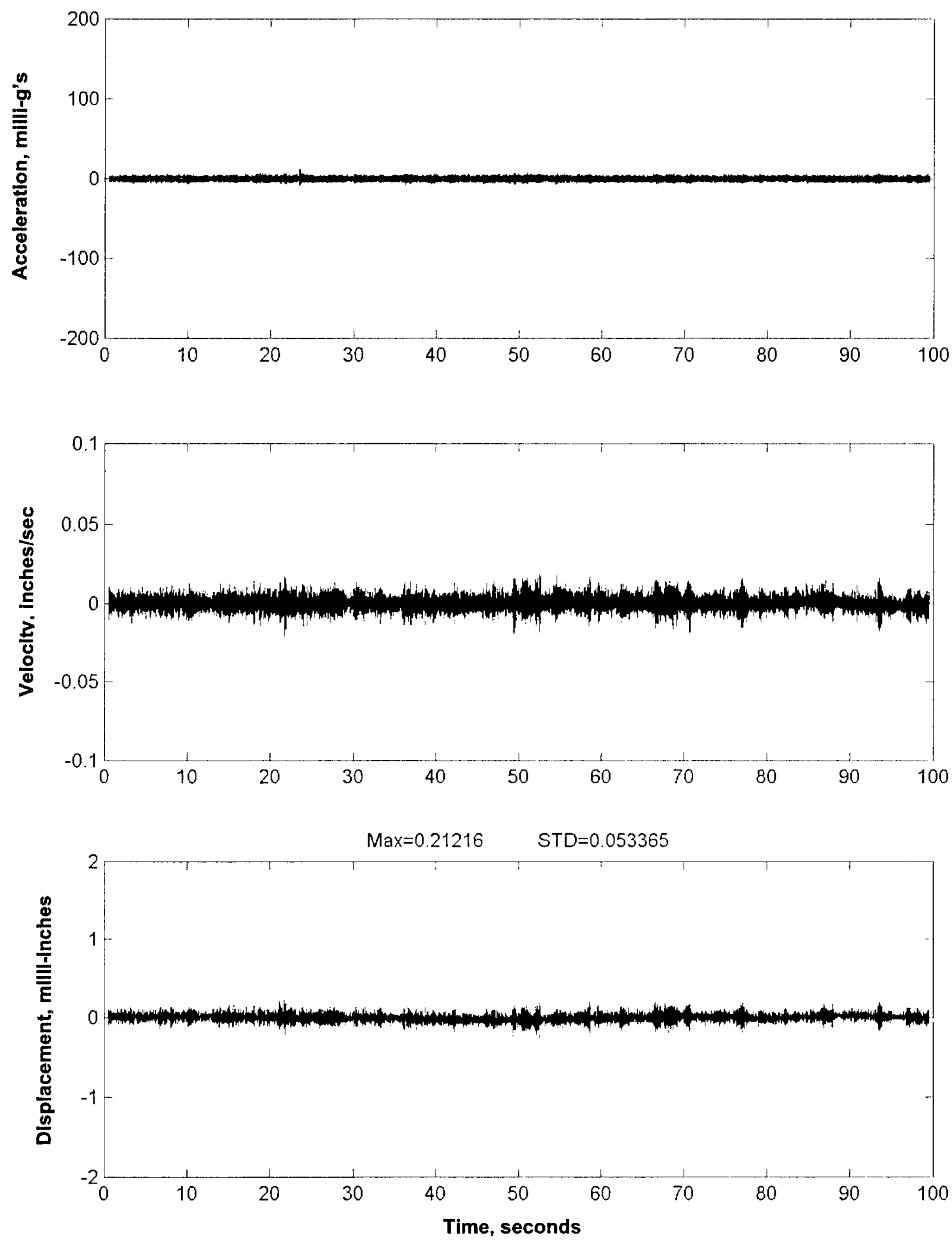


Figure 63. Radial accelerations, Gate 3, raised position, 5.0-ft opening, 07/11/00

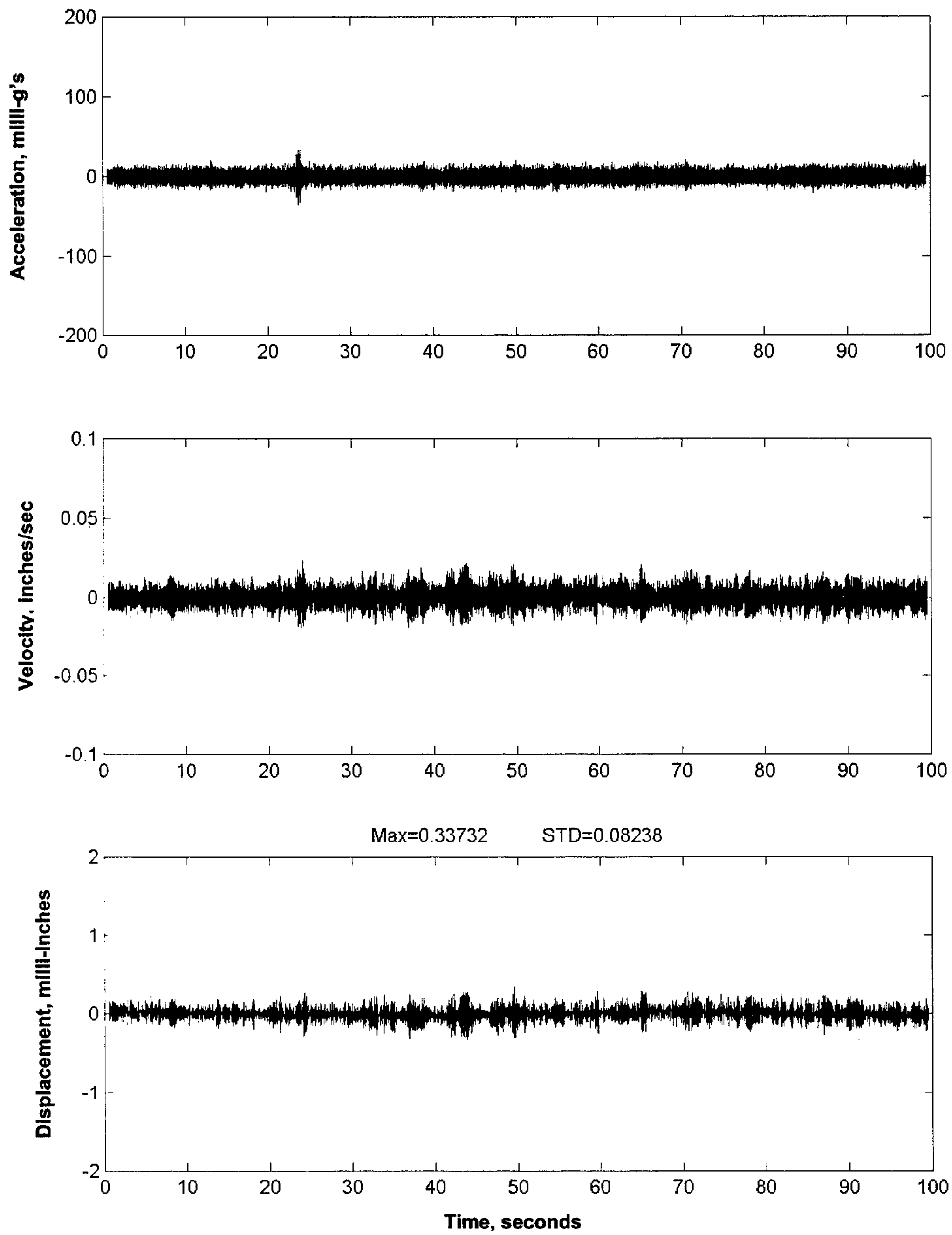


Figure 64. Transverse accelerations, Gate 7, raised position, 5.0-ft opening, 07/11/00

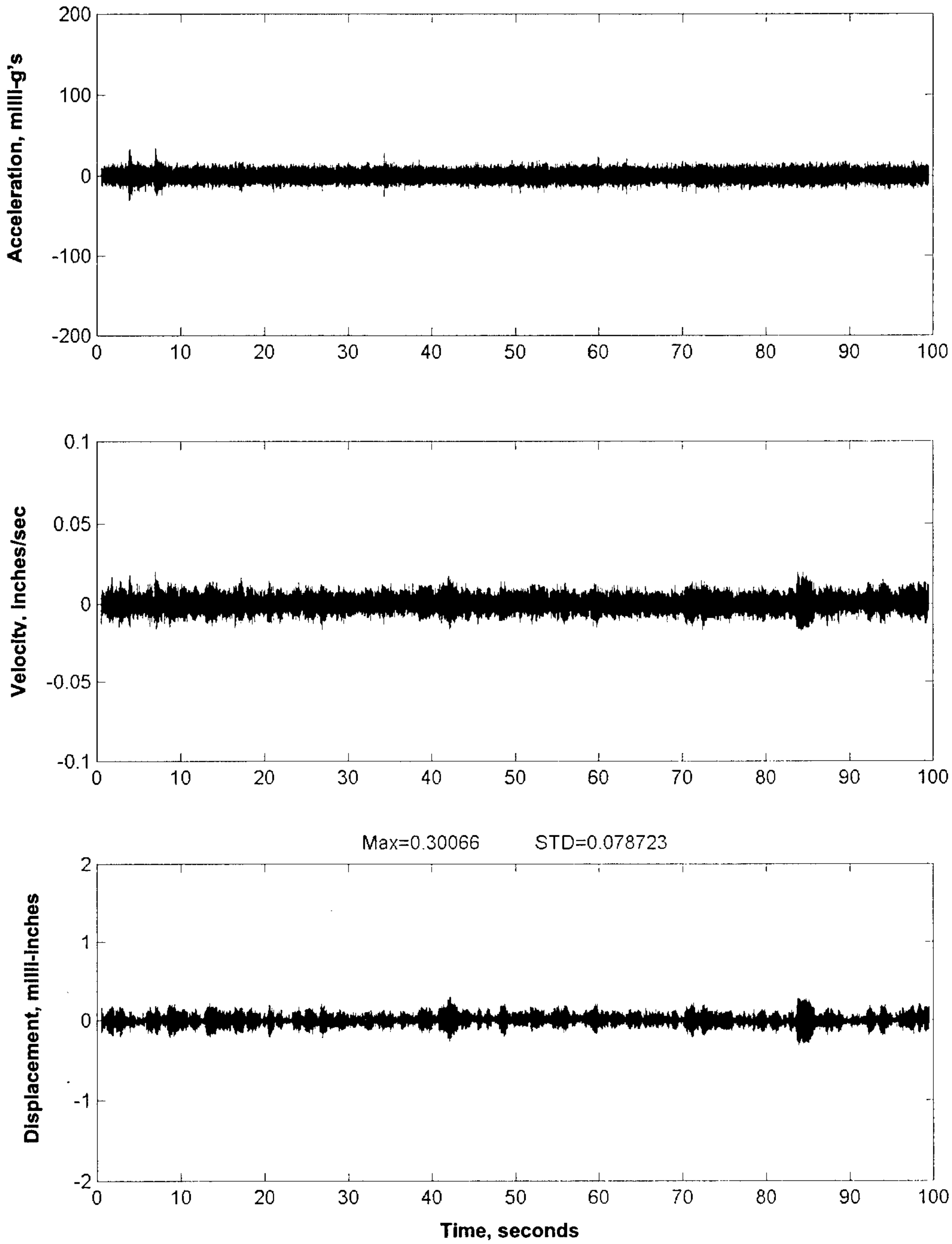


Figure 65. Vertical accelerations, Gate 5, raised position, 5.0-ft opening, 07/21/00

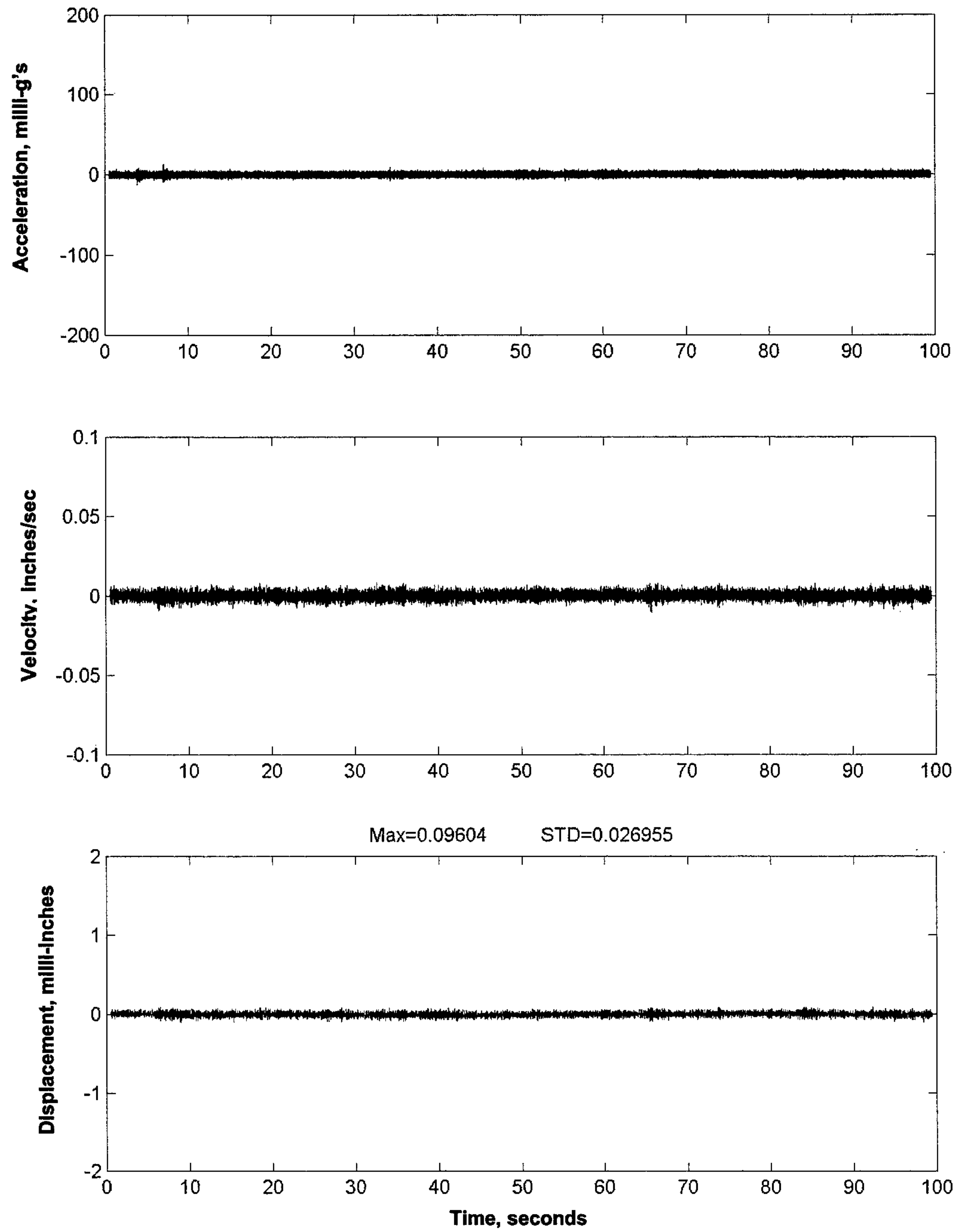


Figure 66. Radial accelerations, Gate 5, raised position, 5.0-ft opening, 07/11/00

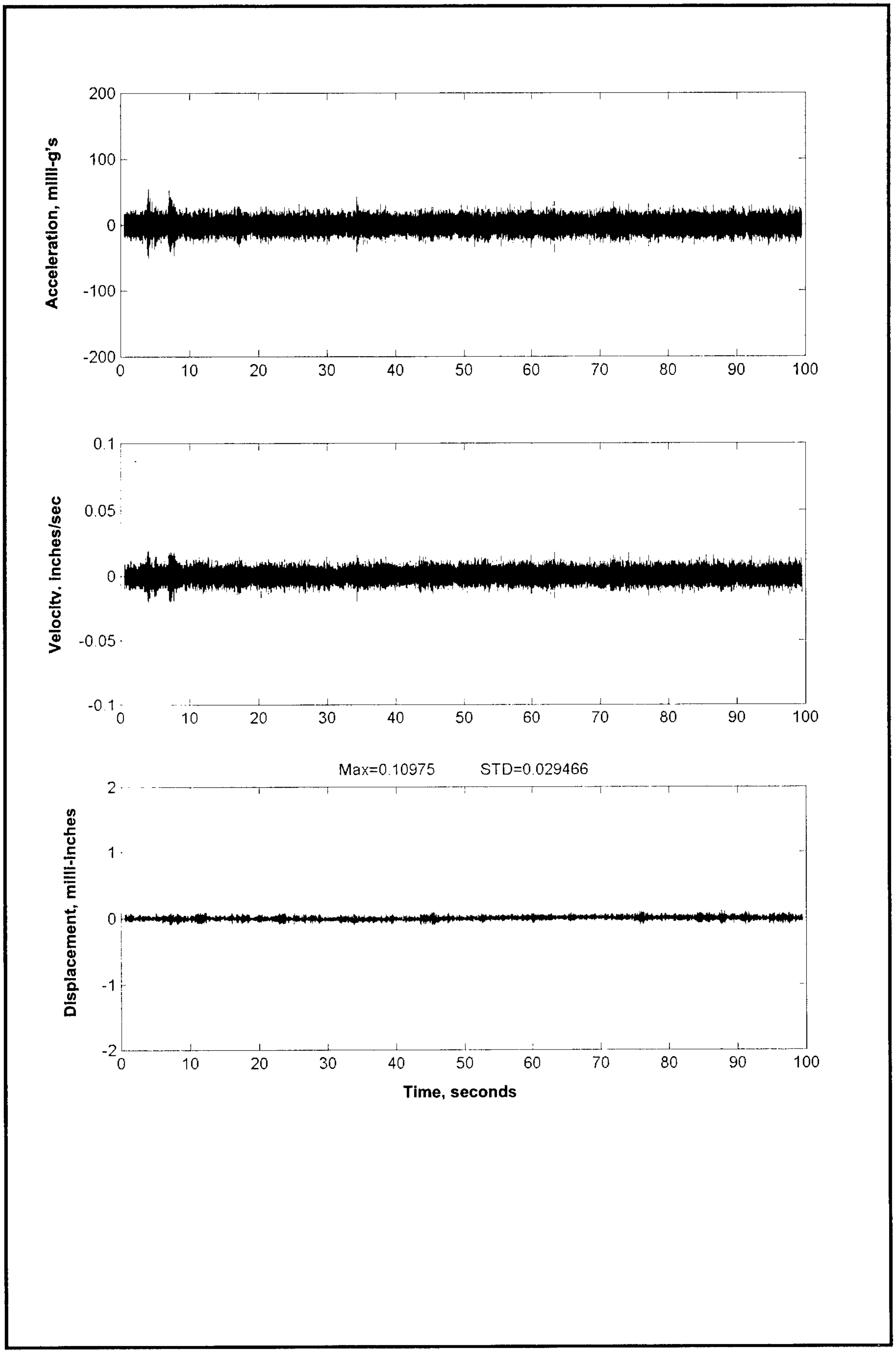


Figure 67. Transverse accelerations, Gate 5, raised position, 5.0-ft opening, 07/11/00

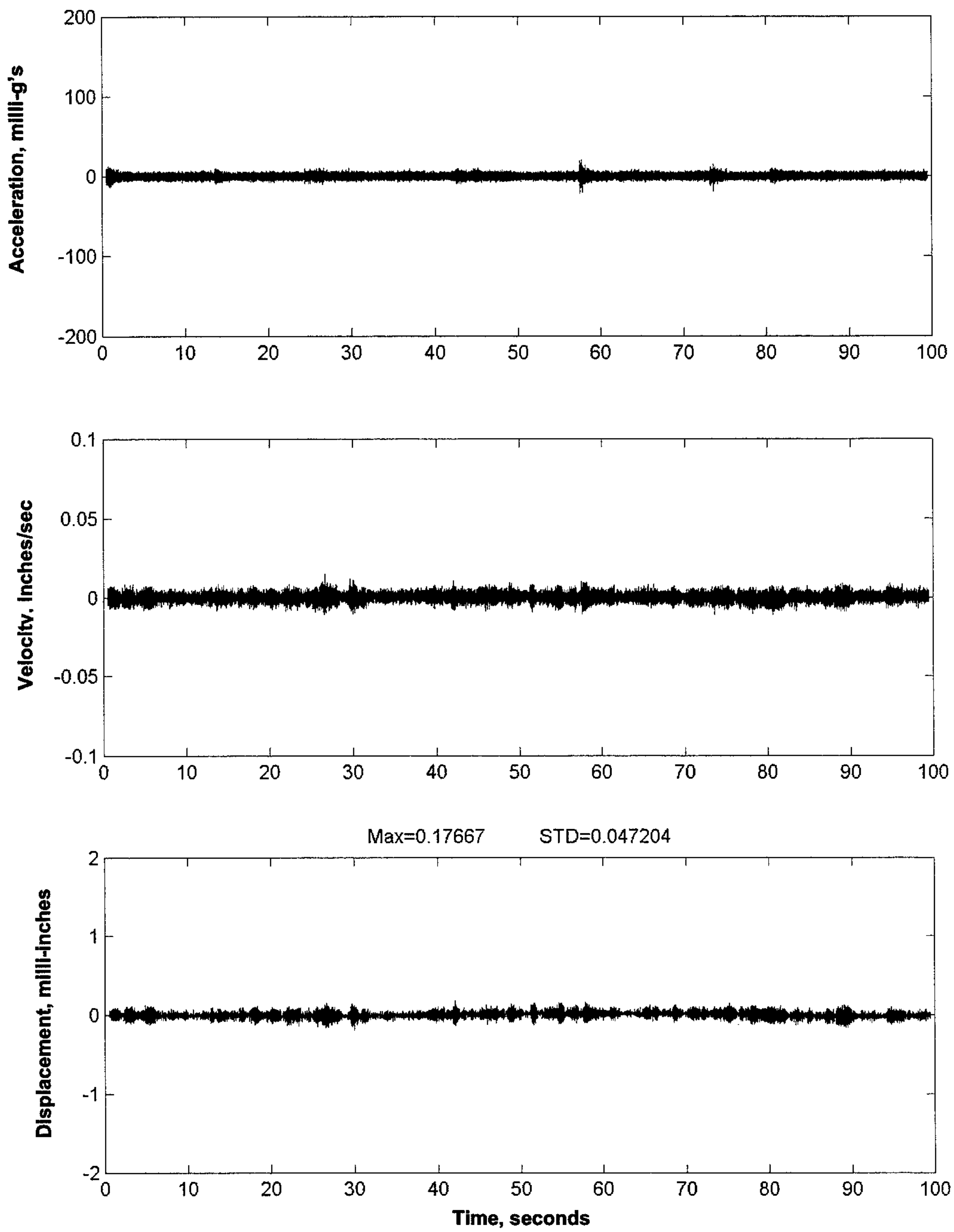


Figure 68. Vertical accelerations, Gate 7, raised position, 5.0-ft opening, 07/11/00

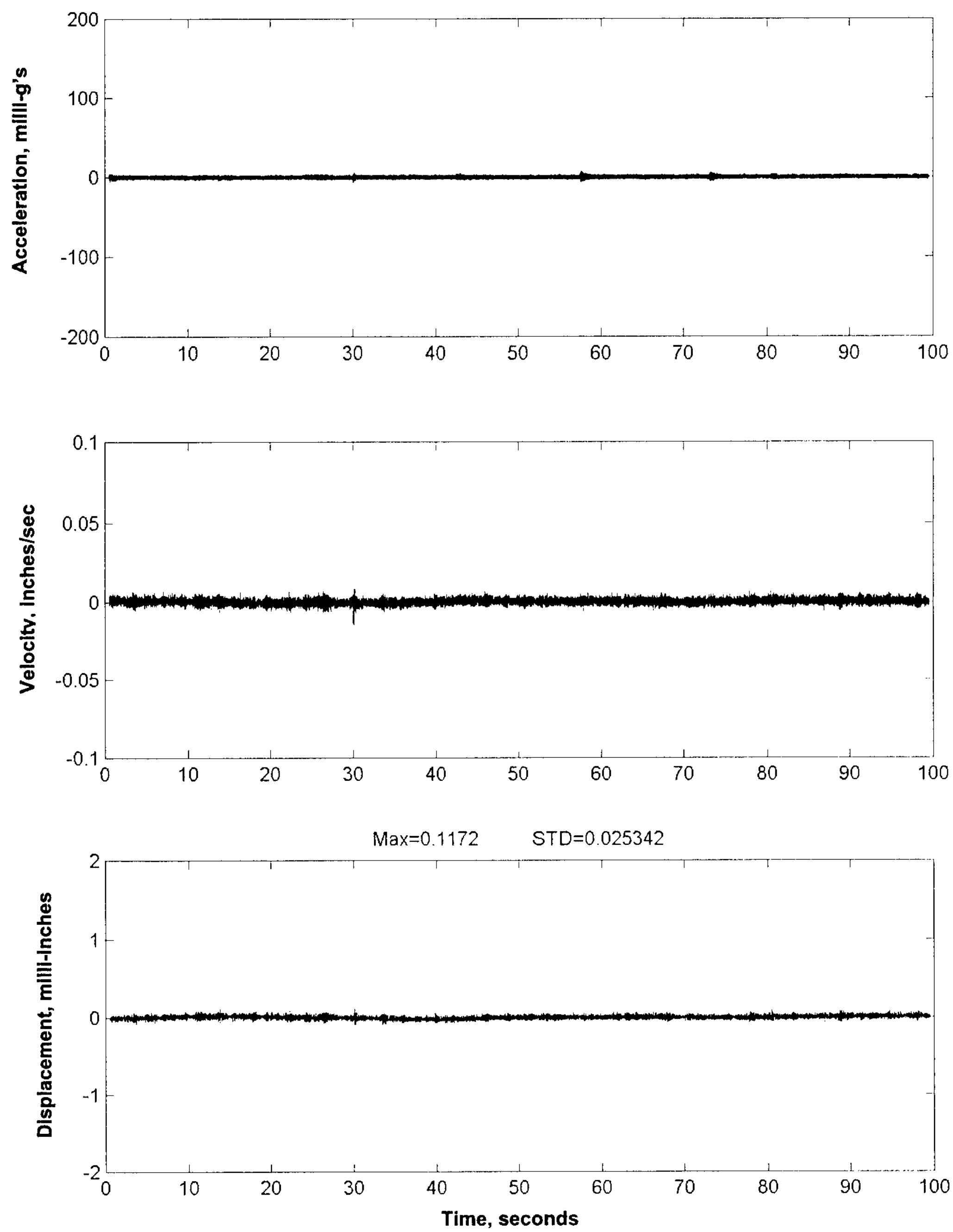


Figure 69. Radial accelerations, Gate 7, raised position, 5.0-ft opening, 07/11/00

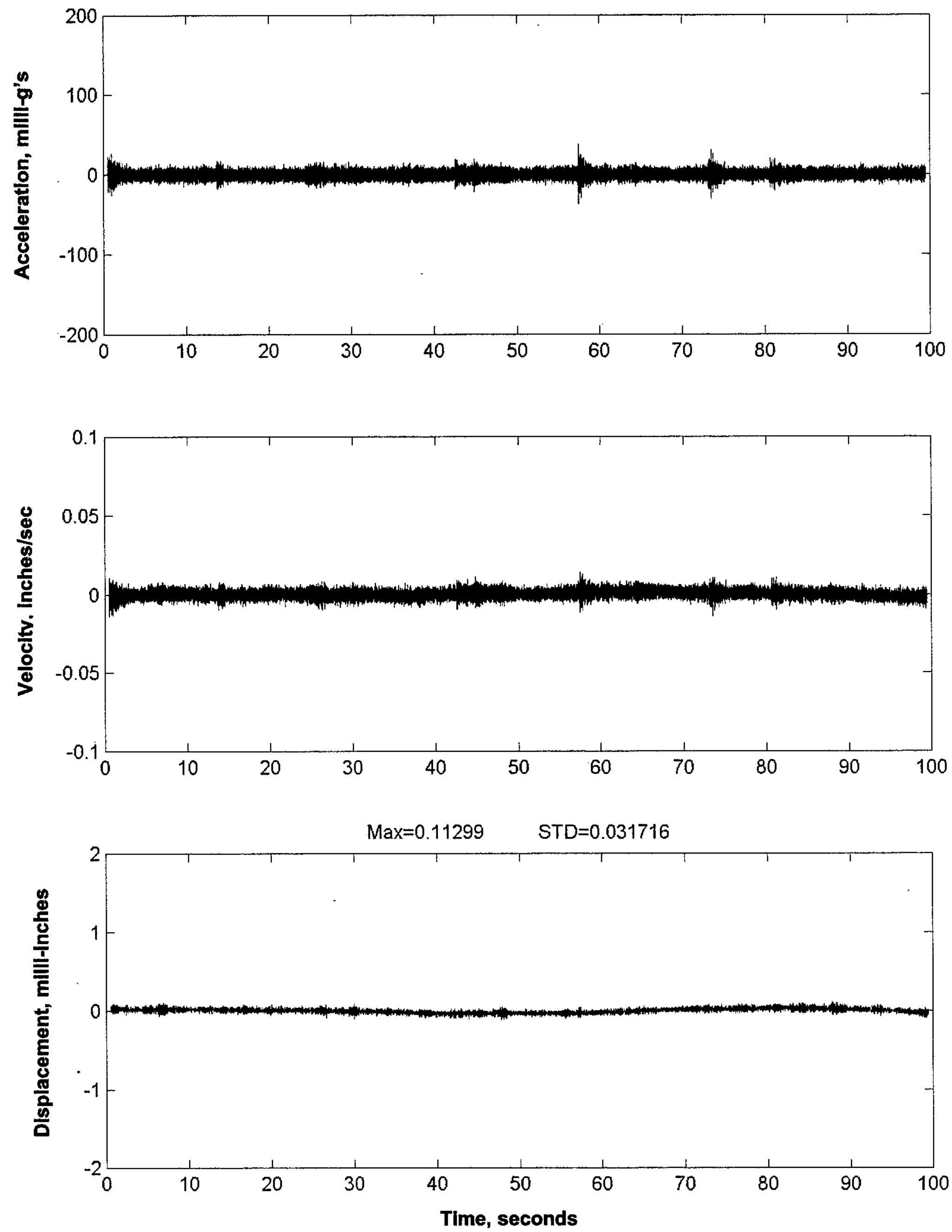


Figure 70. Transverse accelerations, Gate 7, raised position, 5.0-ft opening, 07/11/00

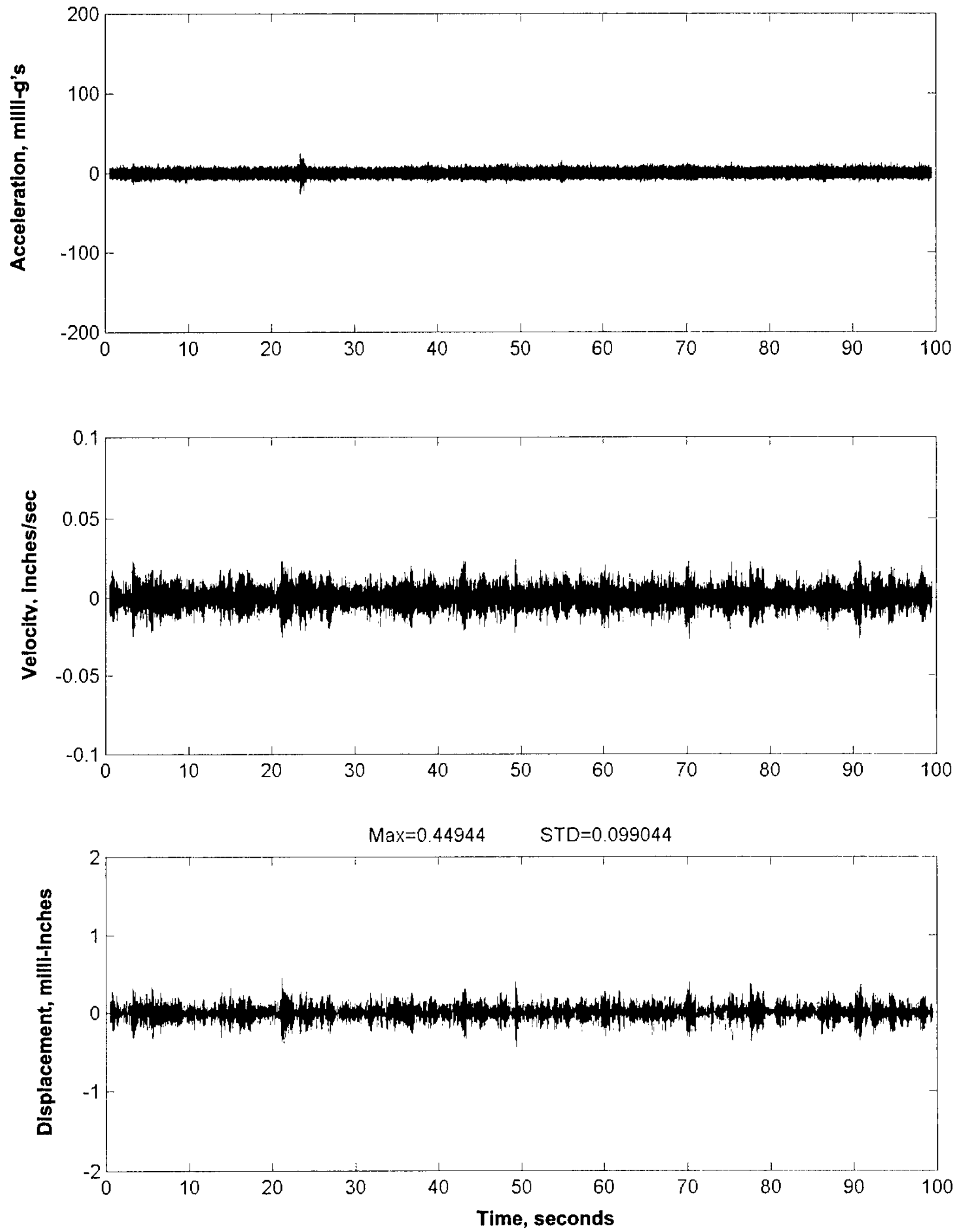


Figure 71. Vertical accelerations, Gate 3, raised position, 5.0-ft opening, 07/11/00

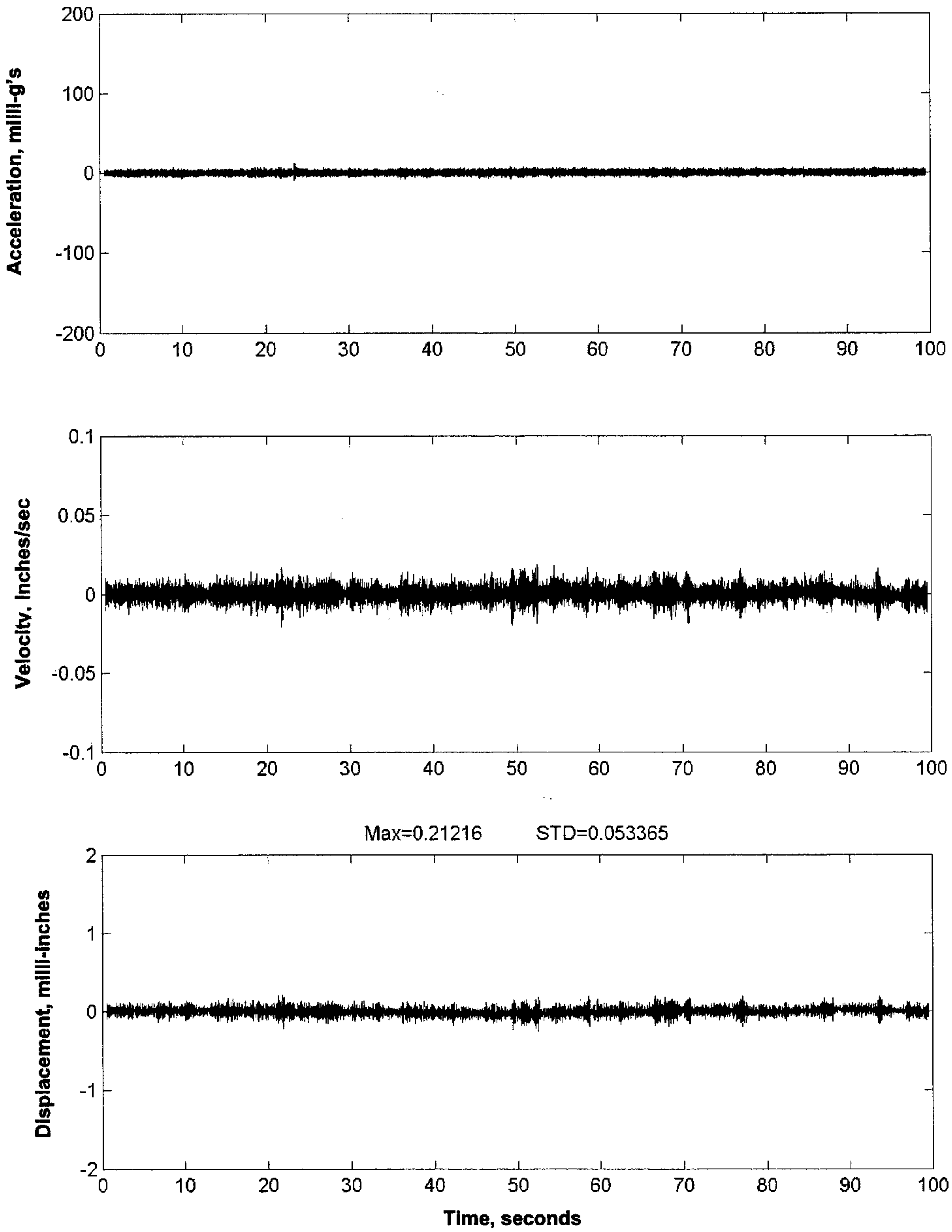


Figure 72. Radial accelerations, Gate 3, raised position, 5.0-ft opening, 07/11/00

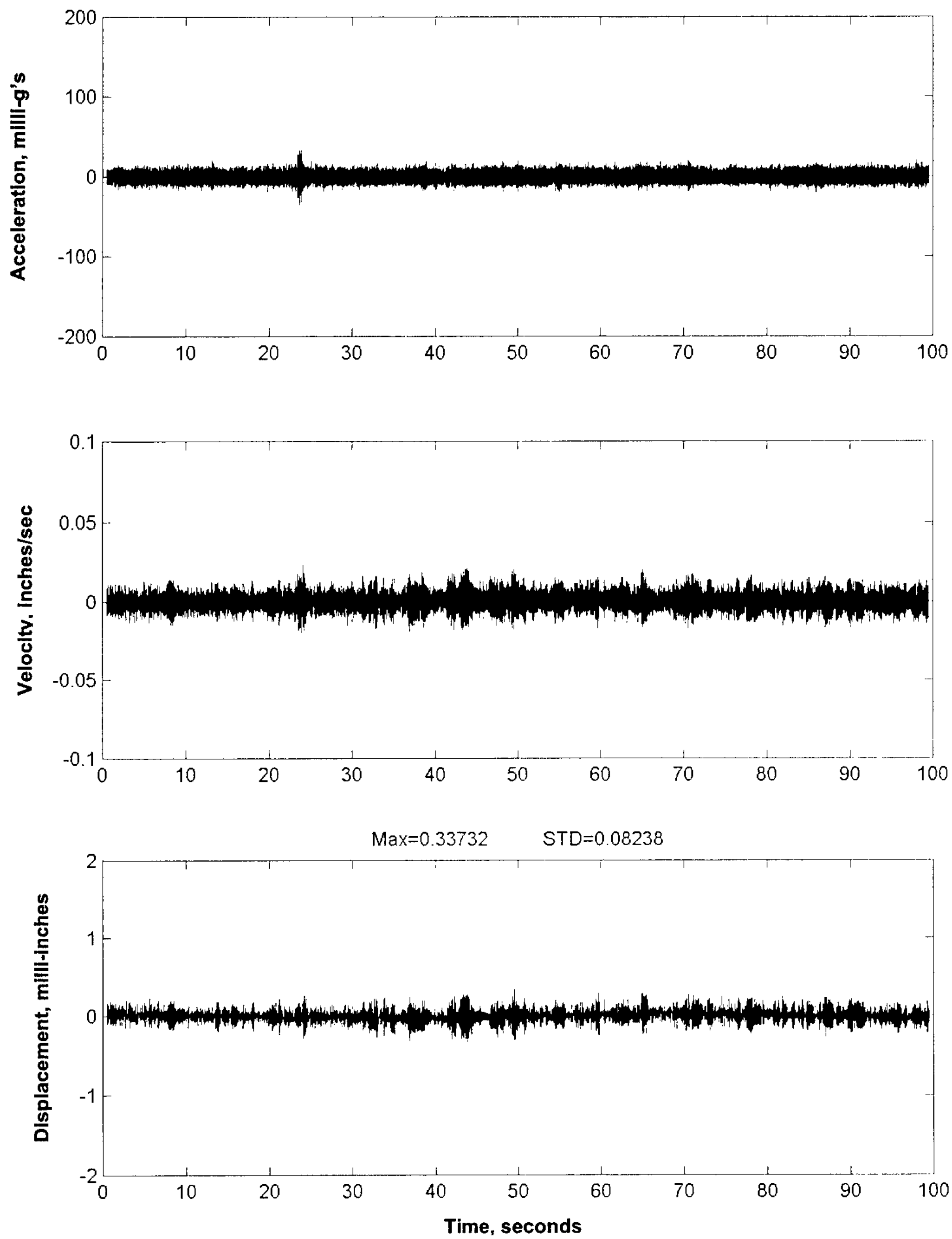


Figure 73. Transverse accelerations, Gate 3, raised position, 5.0-ft opening, 07/11/00

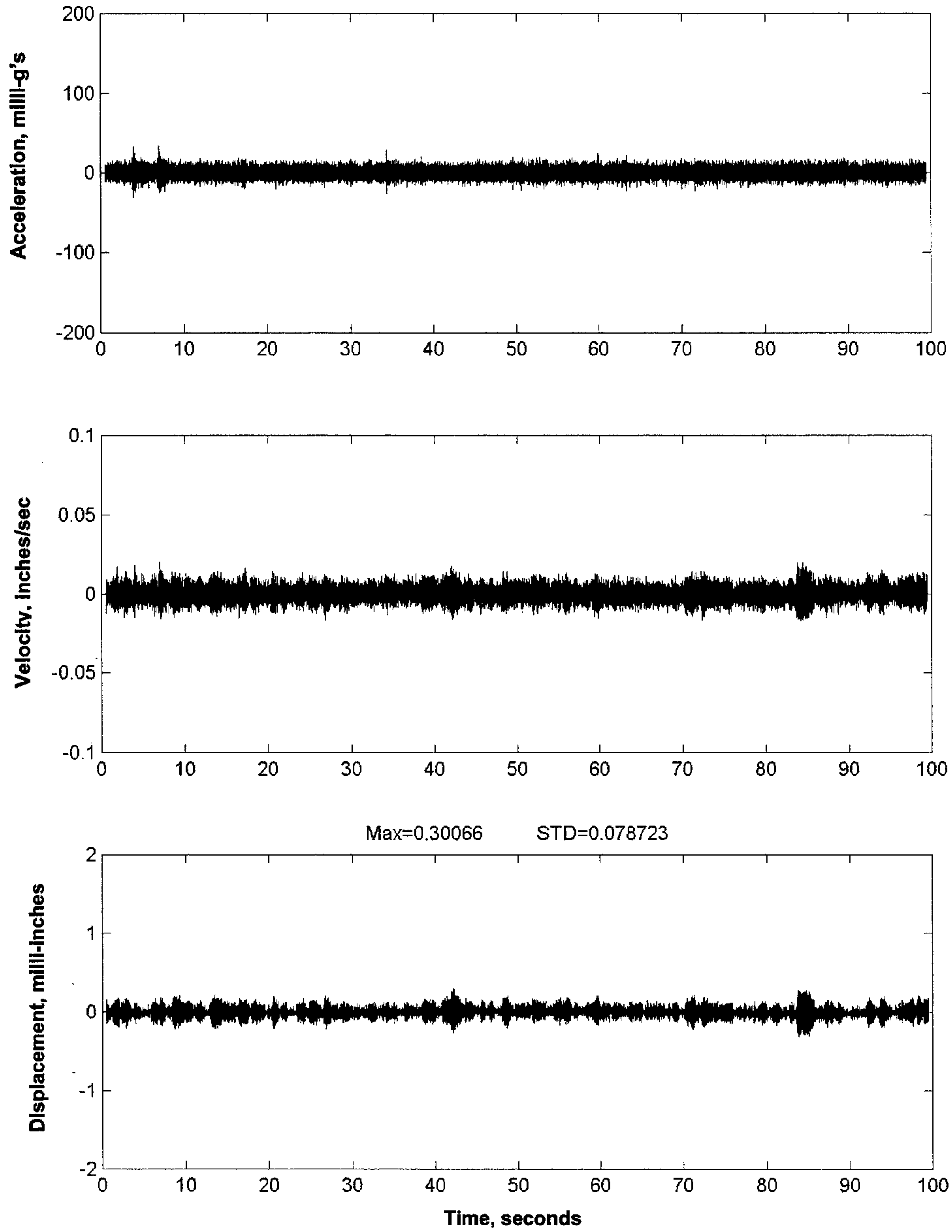


Figure 74. Vertical accelerations, Gate 5, raised position, 5.0-ft opening, 07/11/00

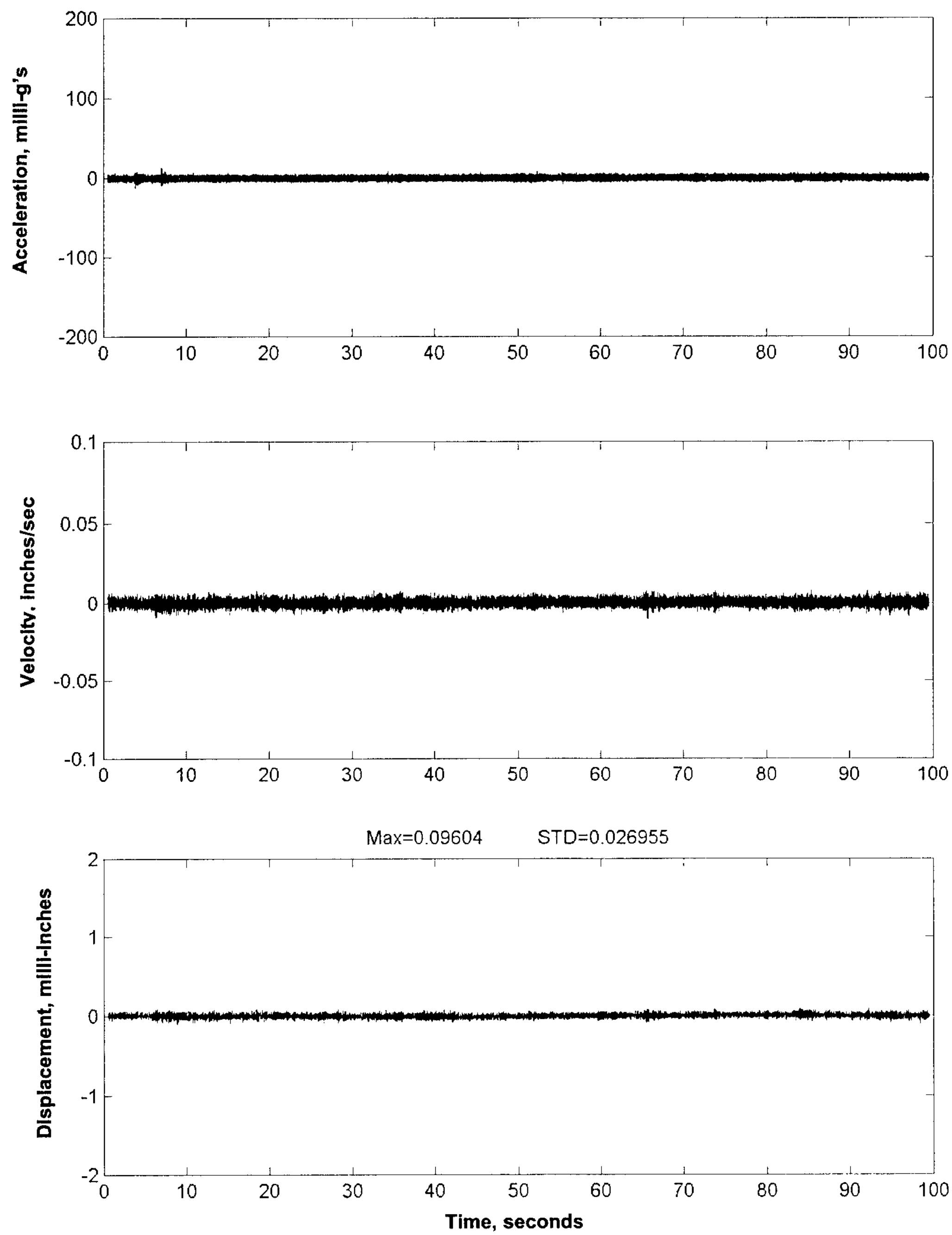


Figure 75. Radial accelerations, Gate 5, raised position, 5.0-ft opening, 07/11/00

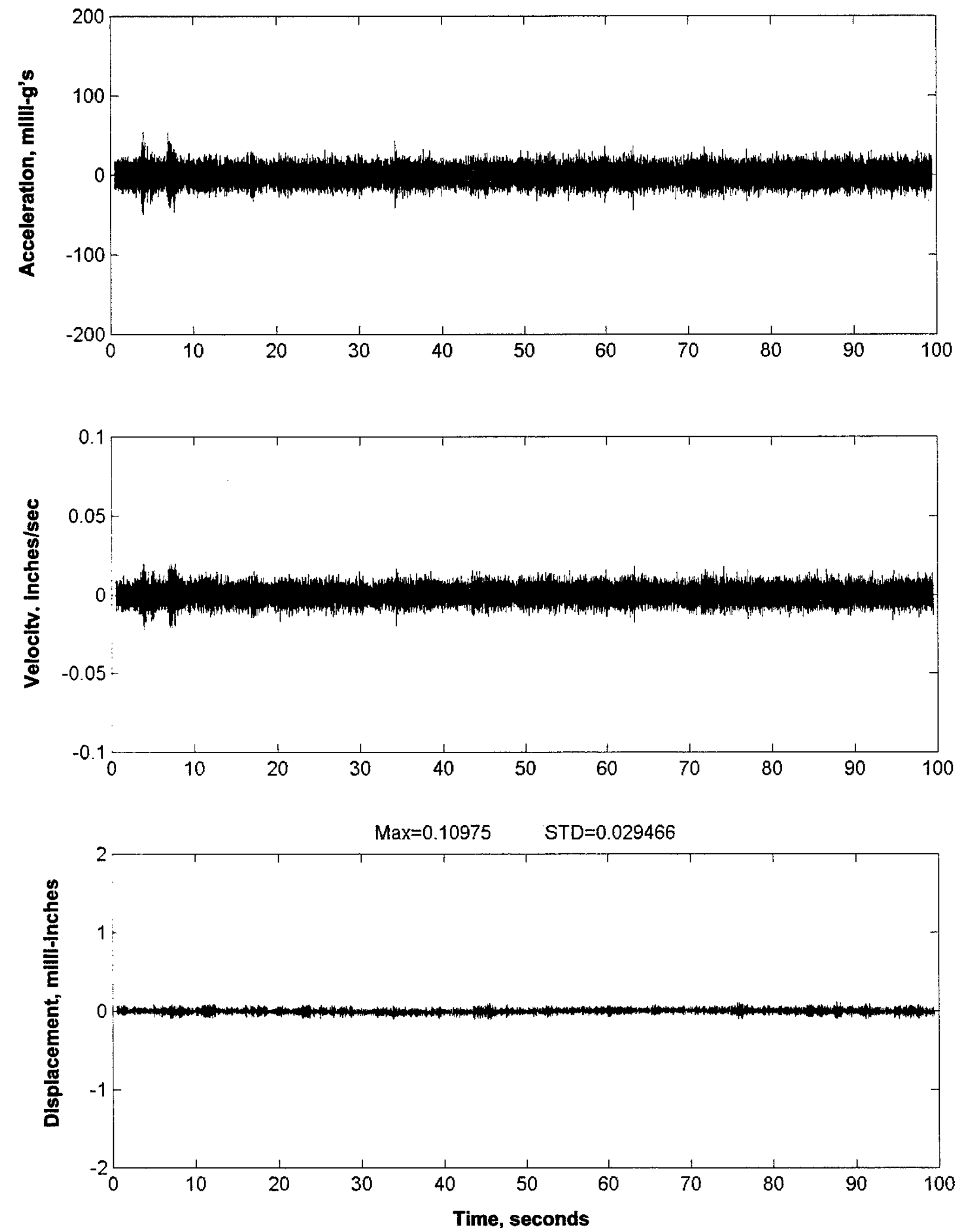


Figure 76. Transverse accelerations, Gate 5, raised position, 5.0-ft opening, 07/11/00

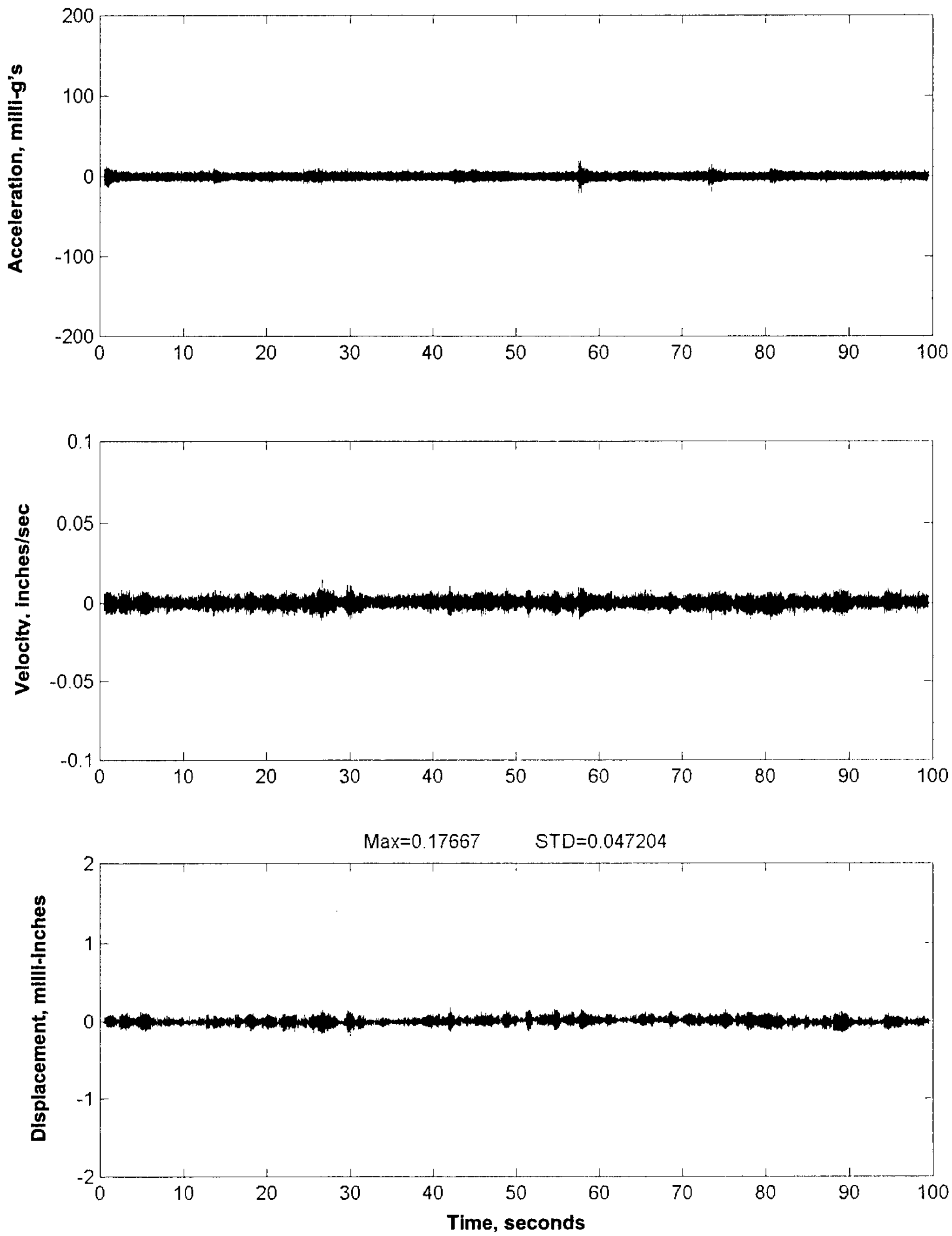


Figure 77. Vertical accelerations, Gate 7, raised position, 5.0-ft opening, 07/11/00

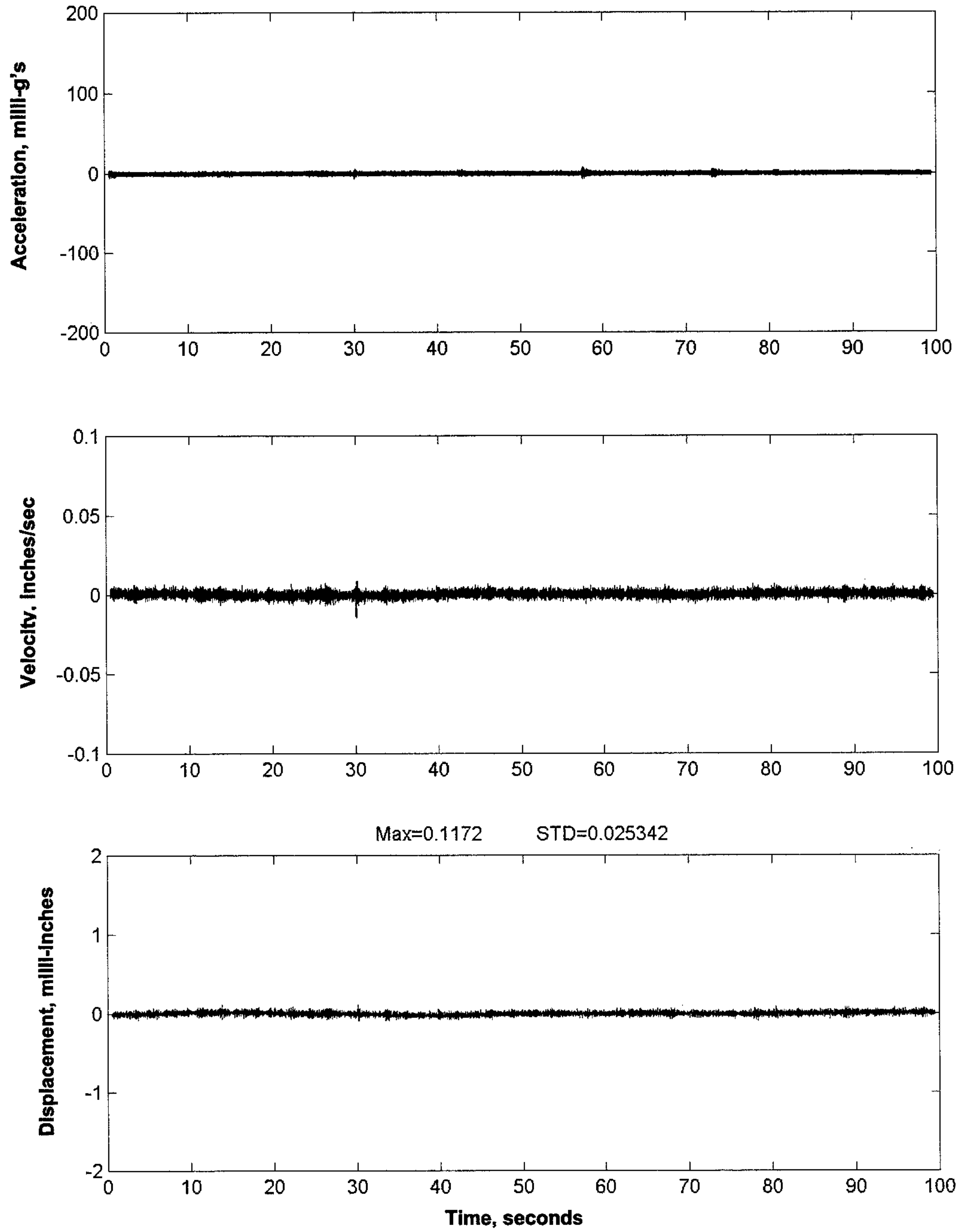


Figure 78. Radial accelerations, Gate 7, raised position, 5.0-ft opening, 07/11/00

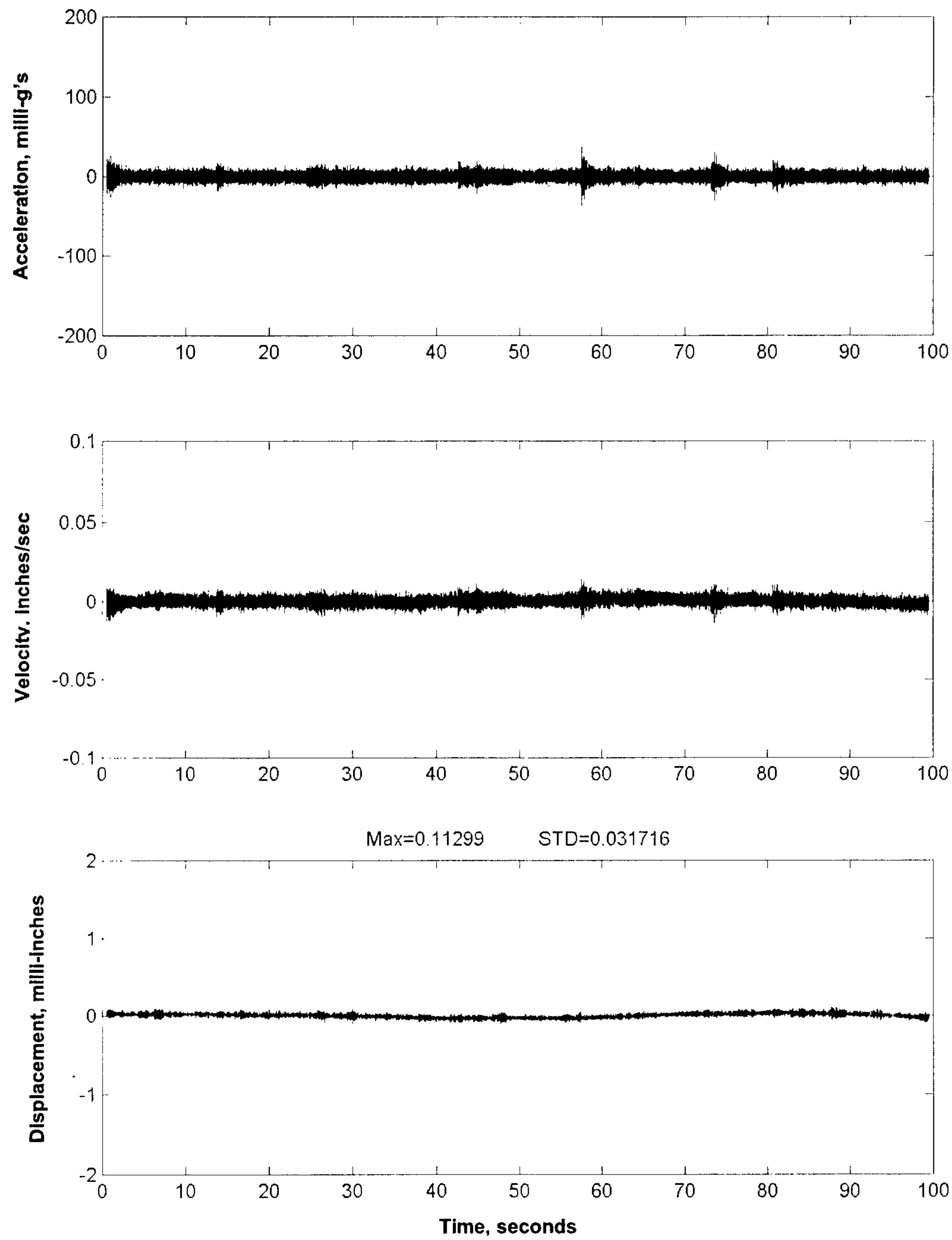


Figure 79. Transverse accelerations, Gate 7, raised position, 5.0-ft opening, 07/11/00

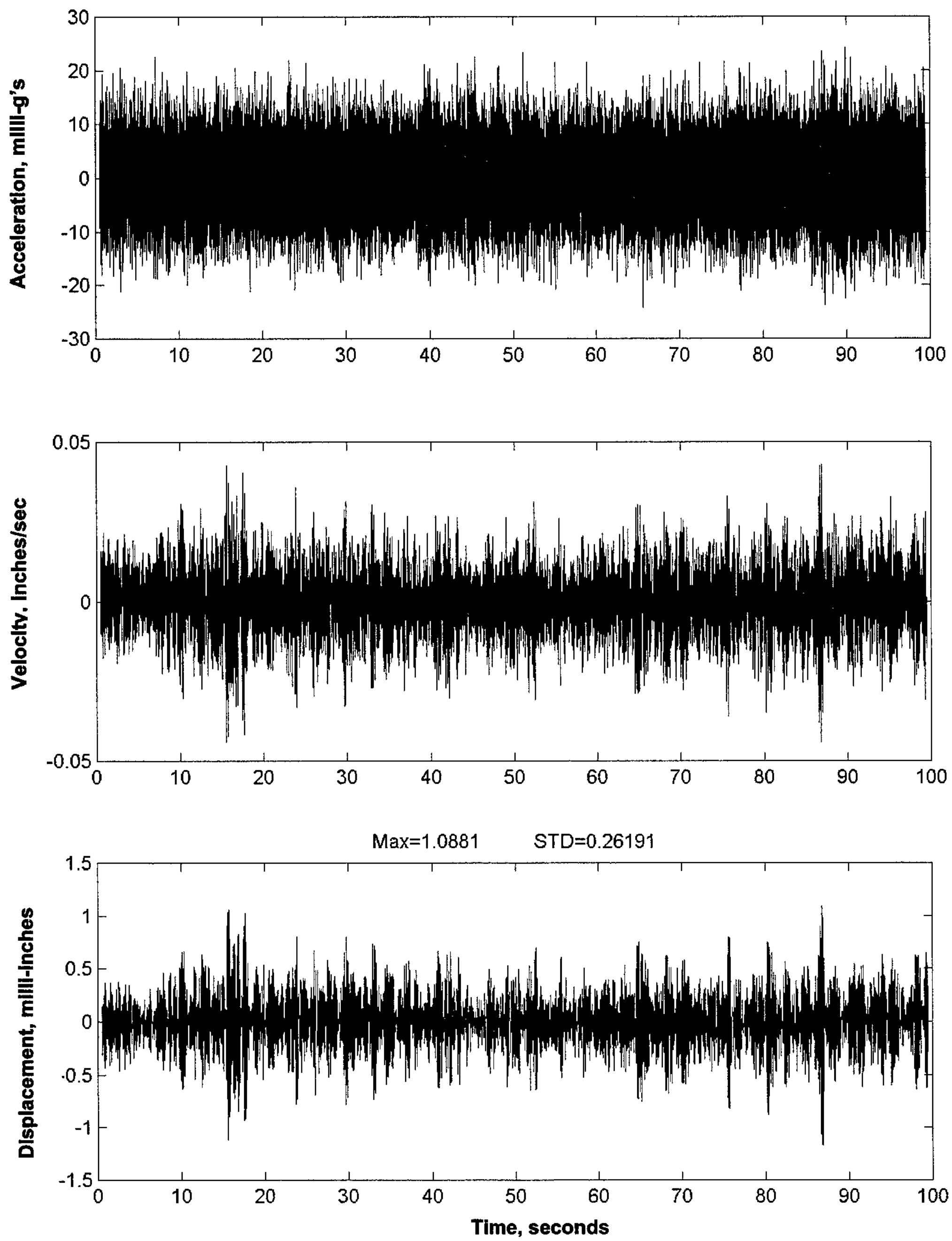


Figure 80. Vertical accelerations and displacements, Gate 5, submerged position, -2.0-ft submerged position, 02/14/00

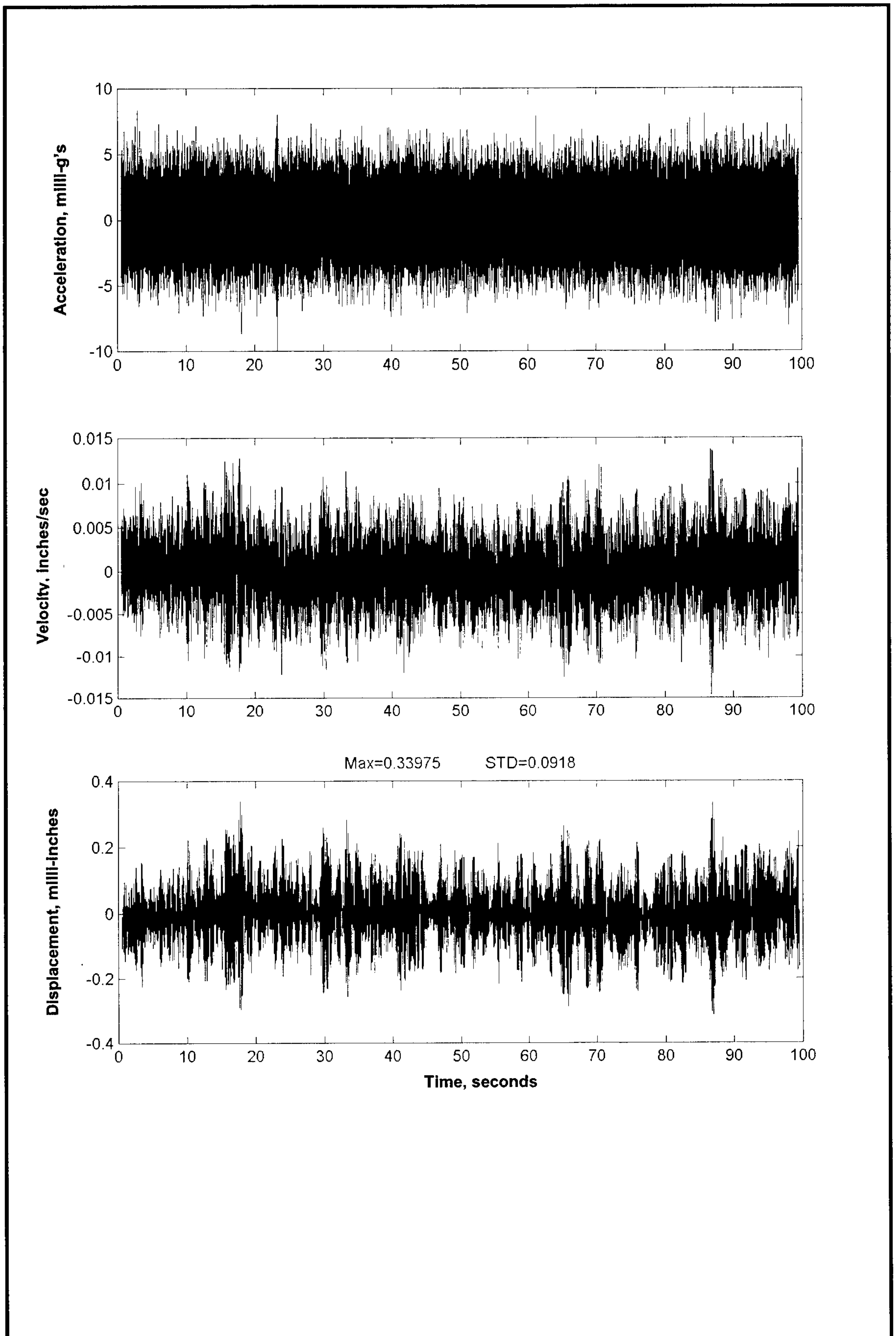


Figure 81. Radial accelerations and displacements, Gate 5, -2.0-ft submerged position, 02/14/00

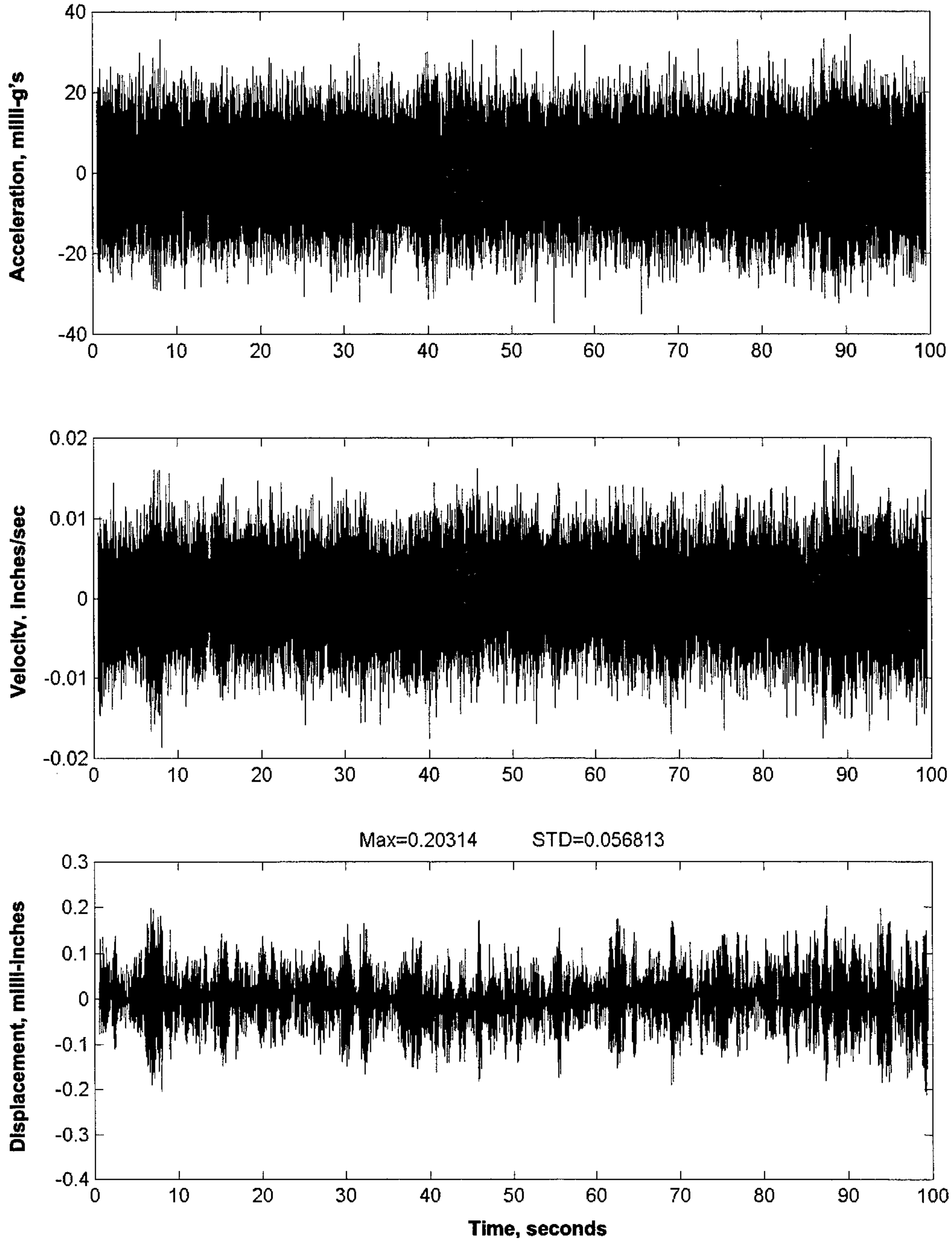


Figure 82. Transverse accelerations and displacements, Gate 5, -2.0-ft submerged position, 02/14/00

Table 1
Gate Cable Loads and Vibrations Type 1 (Original) Design Structure Flow Under Gate

G_o, ft	TW, el	F_2, lb	F_3, lb	F_4, lb	$F_{5_{max}}$, lb	$F_{5_{min}}$, lb	f, Hz	Δ_p, lb
1	470	0	115,300	153,200	37,900	36,400	RANDOM	1,500
1	473	5,200	110,100	164,800	54,700	54,100	RANDOM	600
1	474	7,400	107,900	161,900	54,000	54,000	RANDOM	0
2	470	0	115,300	156,100	40,800	39,300	RANDOM	1,500
2	472	800	114,500	166,200	51,700	54,100	RANDOM	600
2	474	5,200	110,100	164,800	54,700	54,100	RANDOM	600
2	475	7,400	107,900	141,500	33,600	33,000	RANDOM	600
4	470	0	115,300	156,200	40,900	39,400	RANDOM	1,500
4	472	0	115,300	164,800	49,500	48,000	RANDOM	1,500
4	474	800	114,500	163,300	48,800	47,300	RANDOM	1,500
4	476	5,200	110,100	156,200	46,100	44,600	RANDOM	1,500
5	470	0	115,300	162,000	46,700	43,700	RANDOM	3,000
5	474	0	115,300	161,800	46,500	45,000	RANDOM	1,500
5	478	7,400	107,900	161,500	53,600	52,700	RANDOM	900
5	480	10,100	105,200	157,700	52,500	51,600	RANDOM	900
6	470	0	115,300	163,300	48,000	45,400	RANDOM	2,600
6	474	0	115,300	161,800	46,500	45,000	RANDOM	1,500
6	476	800	114,500	163,300	48,800	47,900	RANDOM	900
6	480	9,100	106,200	161,800	55,600	55,600	0	0
7	470	0	115,300	163,800	48,500	47,700	RANDOM	800
7	473	0	115,300	162,100	46,800	46,000	RANDOM	800
7	476	2,900	112,400	162,000	49,600	48,800	RANDOM	800
7	479	5,200	110,100	164,700	54,600	53,700	RANDOM	900
7	481	9,100	106,200	161,600	55,400	53,900	RANDOM	1,500
8	470	0	115,300	163,300	48,000	46,500	RANDOM	1,500
8	473	0	115,300	166,300	51,000	51,000	0	0
8	479	2,900	112,400	158,900	46,500	46,500	0	0
8	482	9,100	106,200	141,300	35,100	35,100	0	0
9	470	0	115,300	164,900	49,600	46,600	RANDOM	3,000
9	472	0	115,300	163,300	48,000	46,500	RANDOM	1,500
9	480	2,900	112,400	163,300	50,900	50,900	0	0
9	483	9,100	106,200	144,300	38,100	38,100	0	0
10	470	0	115,300	163,300	48,000	46,500	RANDOM	1,500
10	472	0	115,300	167,800	52,500	51,000	RANDOM	1,500
10	478	0	115,300	166,300	51,000	51,000	0	0
10	483	7,400	107,900	147,300	39,400	39,400	0	0

Note: See Figures 16 and 17 for definitions of symbols. Dry weight of gate F_1 = 115,300 lb.

Table 2
Gate Cable Loads and Vibrations Type 1 (Original) Design Structure Flow Over Gate

Gate Submergence, ft	TW, el	F_2, lb	F_3, lb	F_4, lb	$F_{5_{max}}$, lb	$F_{5_{min}}$, lb	f, Hz	Δ_p, lb
1	470	2,900	112,400	132,900	20,500	19,100	3.4	1,400
1	471	5,200	110,100	127,000	16,900	15,500	3.4	1,400
2	470	5,200	110,100	141,600	31,500	30,100	3.1	1,400
2	472	9,100	106,200	132,900	26,700	23,800	2.7	2,900
2	473	10,100	105,200	130,000	24,800	22,800	2.7	2,000
2	475	11,300	104,000	128,500	24,500	22,500	2.2	2,000
3	470	7,400	107,900	144,600	36,700	33,700	2.9	3,000
3	472	10,100	105,200	138,700	33,500	29,500	2.5	4,000
3	474	11,300	104,000	145,800	41,800	38,800	2.5	3,000
3	476	12,450	102,850	131,400	28,550	24,550	2.5	4,000
4	470	9,100	106,200	141,700	35,500	31,500	2.5	4,000
4	472	10,700	104,600	143,100	38,500	34,500	2.5	4,000
4	474	11,850	103,450	138,700	35,250	32,250	2.2	3,000
4	476	13,000	102,300	124,200	21,900	18,900	2.2	3,000
5	470	10,100	105,200	147,100	41,900	38,100	2.2	3,800
5	472	11,300	104,000	145,900	41,900	38,300	2.2	3,600
5	475	13,000	102,300	134,300	32,000	28,500	1.8	3,500
5	478	14,800	100,500	113,800	13,300	9,900	1.8	3,400
6	470	10,700	104,600	144,400	39,800	32,600	1.6	7,200
6	472	11,850	103,450	132,800	29,350	25,850	2.0	3,500
6	476	14,200	101,100	110,800	9,700	8,100	RANDOM	1,600
7	470	11,300	104,000	154,600	50,600	47,100	2.0	3,500
7	472	12,450	102,850	165,000	62,150	56,250	2.0	5,900
7	476	14,800	100,500	117,600	17,100	11,200	1.8	5,900
7	477	15,300	100,000	109,500	9,500	8,100	1.8	1,400
8	470	11,850	103,450	122,700	19,250	16,250	RANDOM	3,000
8	473	13,600	101,700	122,700	21,000	15,100	RANDOM	5,900
8	478	15,300	100,000	58,300	-41,700	-41,700	0	0
8	483	15,300	100,000	49,700	-50,300	-50,300	0	0

Note: See Figures 16 and 17 for definitions of symbols. Dry weight of gate F_1 = 115,300 lb.

Table 3 Gate Cable Loads and Vibrations Type 2 Design Structure Flow Under Gate								
G_o, ft	TW, el	F_2, lb	F_3, lb	F_4, lb	$F_{5_{max}}$, lb	$F_{5_{min}}$, lb	f, Hz	Δ_p, lb
1	470	0	115,300	140,100	24,800	24,000	RANDOM	800
1	473	5,200	110,100	147,400	37,300	37,300	0	0
1	474	7,400	107,900	135,700	27,800	27,800	0	0
2	470	0	115,300	158,900	43,600	42,800	RANDOM	800
2	472	800	114,500	148,800	34,300	34,300	0	0
2	474	5,200	110,100	148,800	38,700	38,700	0	0
2	475	7,400	107,900	141,600	33,700	33,700	0	0
4	470	0	115,300	134,300	19,000	17,500	RANDOM	1,500
4	472	0	115,300	141,600	26,300	24,800	RANDOM	1,500
4	474	800	114,500	140,100	25,600	24,100	RANDOM	1,500
4	476	5,200	110,100	137,200	27,100	25,600	RANDOM	1,500
5	470	0	115,300	134,300	19,000	17,500	RANDOM	1,500
5	474	0	115,300	141,600	26,300	24,800	RANDOM	1,500
5	478	7,400	107,900	137,200	29,300	27,800	RANDOM	1,500
5	480	10,100	105,200	119,600	14,400	12,200	RANDOM	2,200
6	470	0	115,300	141,700	26,400	25,700	RANDOM	700
6	474	0	115,300	141,600	26,300	25,600	RANDOM	700
6	476	800	114,500	137,300	22,800	22,100	RANDOM	700
6	480	9,100	106,200	129,700	23,500	21,300	RANDOM	2,200
7	470	0	115,300	135,800	20,500	19,700	RANDOM	800
7	473	0	115,300	134,300	19,000	18,200	RANDOM	800
7	476	2,900	112,400	134,000	21,600	20,800	RANDOM	800
7	479	5,200	110,100	128,300	18,200	17,400	RANDOM	800
7	481	9,100	106,200	116,800	10,600	9,800	RANDOM	800
8	470	0	115,300	127,000	11,700	10,200	RANDOM	1,500
8	473	0	115,300	124,000	8,700	8,000	RANDOM	700
8	479	2,900	112,400	124,000	11,600	10,900	RANDOM	700
8	482	9,100	106,200	105,000	-1,200	-1,200	0	0
9	470	0	115,300	128,500	13,200	11,800	RANDOM	1,400
9	472	0	115,300	124,100	8,800	7,400	RANDOM	1,400
9	480	2,900	112,400	127,000	14,600	13,200	RANDOM	1,400
9	483	9,100	106,200	115,100	8,900	8,900	0	0
10	470	0	115,300	127,200	11,900	10,400	RANDOM	1,500
10	472	0	115,300	128,500	13,200	13,200	0	0
10	478	0	115,300	127,000	11,700	11,700	0	0
10	483	7,400	107,900	113,900	6,000	6,000	0	0

Note: See Figures 16 and 17 for definitions of symbols. Dry weight of gate F_1 = 115,300 lb.

Table 4
Gate Cable Loads and Vibrations Type 2 Design Structure Flow Over Gate

Gate Submergence, ft	TW, el	F_2, lb	F_3, lb	F_4, lb	$F_{5_{max}}$, lb	$F_{5_{min}}$, lb	f, Hz	Δ_p, lb
1	470	2,900	112,400	134,600	21,900	20,500	3.4	1,400
1	471	5,200	110,100	128,500	18,400	17,000	3.4	1,400
2	470	5,200	110,100	140,200	30,100	28,700	3.1	1,400
2	472	9,100	106,200	138,700	32,500	29,000	2.7	2,900
2	473	10,100	105,200	138,600	33,400	30,500	2.5	2,900
2	475	11,300	104,000	128,400	24,400	23,000	2.0	1,400
3	470	7,400	107,900	139,100	31,200	29,000	2.9	2,200
3	472	10,100	105,200	138,400	33,200	31,000	2.5	2,200
3	474	11,300	104,000	138,400	34,400	33,000	2.3	1,400
3	476	12,450	102,850	125,250	22,400	20,200	2.3	2,200
4	470	9,100	106,200	138,700	32,500	29,600	2.7	2,900
4	472	10,700	104,600	138,300	33,700	32,300	2.5	1,400
4	474	11,850	103,450	132,800	29,350	27,950	2.4	1,400
4	476	13,000	102,300	125,600	23,300	20,400	2.4	2,900
5	470	10,100	105,200	143,000	37,800	36,400	2.0	1,400
5	472	11,300	104,000	146,000	42,000	40,600	1.9	1,400
5	475	13,000	102,300	127,300	25,000	23,600	1.7	1,400
5	478	14,800	100,500	124,100	23,600	22,200	1.6	1,400
6	470	10,700	104,600	151,600	47,000	45,600	2.0	1,400
6	472	11,850	103,450	156,200	52,750	51,350	2.0	1,400
6	476	14,200	101,100	148,700	47,600	46,900	RANDOM	700
7	470	11,300	104,000	158,000	54,000	52,600	RANDOM	1,400
7	472	12,450	102,850	163,300	60,450	59,050	RANDOM	1,400
7	476	14,800	100,500	140,200	39,700	38,300	RANDOM	1,400
7	477	15,300	100,000	132,000	32,000	30,600	RANDOM	1,400
8	470	11,850	103,450	127,400	23,550	20,650	RANDOM	2,900
8	473	13,600	101,700	119,300	17,600	16,200	RANDOM	1,400
8	478	15,300	100,000	114,200	14,200	14,200	0	0
8	483	15,300	100,000	103,500	3,500	3,500	0	0

Note: See Figures 16 and 17 for definitions of symbols. Dry weight of gate F_1 = 115,300 lb.

Table 5
Gate Cable Loads and Vibrations Type 3 Design Structure Flow Under Gate

G_o, ft	TW, el	F_2, lb	F_3, lb	F_4, lb	$F_{5_{max}}$, lb	$F_{5_{min}}$, lb	f, Hz	Δ_p, lb
1	470	0	115,300	132,700	17,400	16,600	RANDOM	800
1	473	5,200	110,100	129,800	19,700	19,700	0	0
1	474	7,400	107,900	129,800	21,900	21,900	0	0
2	470	0	115,300	128,400	13,100	12,300	RANDOM	800
2	472	800	114,500	131,300	16,800	16,800	0	0
2	474	5,200	110,100	125,500	15,400	15,400	0	0
2	475	7,400	107,900	124,000	16,100	16,100	0	0
4	470	0	115,300	115,300	0	-1,500	RANDOM	1,500
4	472	0	115,300	118,200	2,900	1,400	RANDOM	1,500
4	474	800	114,500	125,500	11,000	9,500	RANDOM	1,500
4	476	5,200	110,100	129,000	18,900	17,400	RANDOM	1,500
5	470	0	115,300	123,900	8,600	7,100	RANDOM	1,500
5	474	0	115,300	125,400	10,100	8,600	RANDOM	1,500
5	478	7,400	107,900	126,700	18,800	17,300	RANDOM	1,500
5	480	10,100	105,200	115,300	10,100	10,100	0	0
6	470	0	115,300	125,600	10,300	9,500	RANDOM	800
6	474	0	115,300	128,400	13,100	12,300	RANDOM	800
6	476	800	114,500	127,000	12,500	11,700	RANDOM	800
6	480	9,100	106,200	113,600	4,700	7,400	0	0
7	470	0	115,300	131,200	15,900	15,100	RANDOM	800
7	473	0	115,300	131,200	15,900	15,100	RANDOM	800
7	476	2,900	112,400	131,200	18,800	17,300	RANDOM	1,500
7	479	5,200	110,100	131,200	21,200	19,700	RANDOM	1,500
7	481	9,100	106,200	131,200	25,100	24,300	RANDOM	800
8	470	0	115,300	131,200	16,000	14,500	RANDOM	1,500
8	473	0	115,300	136,400	21,100	19,600	RANDOM	1,500
8	479	2,900	112,400	133,200	20,800	20,000	RANDOM	800
8	482	9,100	106,200	131,300	25,100	25,100	0	0
9	470	0	115,300	132,000	16,700	15,200	RANDOM	1,500
9	472	0	115,300	131,500	16,200	14,700	RANDOM	1,500
9	480	2,900	112,400	133,400	21,000	20,200	RANDOM	800
9	483	9,100	106,200	103,500	-4,400	-4,400	0	0
10	470	0	115,300	132,100	16,800	15,300	RANDOM	1,500
10	472	0	115,300	131,400	16,100	15,300	RANDOM	800
10	478	0	115,300	126,000	10,700	10,700	0	0
10	483	7,400	107,900	123,000	15,100	15,100	0	0

Note: See Figures 16 and 17 for definitions of symbols. Dry weight of gate F_1 = 115,300 lb.

Table 6
Gate Cable Loads and Vibrations Type 3 Design Structure Flow Over Gate

Gate Submergence, ft	TW, el	F_2, lb	F_3, lb	F_4, lb	$F_{5_{max}}$, lb	$F_{5_{min}}$, lb	f, Hz	Δ_p, lb
1	470	2,900	112,400	137,100	24,700	24,700	0	0
1	471	5,200	110,100	132,800	22,700	22,700	0	0
2	470	5,200	110,100	128,400	18,300	17,500	RANDOM	800
2	472	9,100	106,200	131,300	25,400	25,100	0	0
2	473	10,100	105,200	128,400	23,200	23,200	0	0
2	475	11,300	104,000	115,200	11,200	11,200	0	0
3	470	7,400	107,900	123,900	16,000	16,000	0	0
3	472	10,100	105,200	121,000	15,800	15,800	0	0
3	474	11,300	104,000	113,700	9,700	9,700	0	0
3	476	12,450	102,850	112,850	10,000	10,000	0	0
4	470	9,100	106,200	156,100	49,900	49,900	0	0
4	472	10,700	104,600	148,800	44,200	44,200	0	0
4	474	11,850	103,450	144,400	40,950	40,950	0	0
4	476	13,000	102,300	138,500	36,200	36,200	0	0
5	470	10,100	105,200	141,500	36,300	36,300	0	0
5	472	11,300	104,000	132,700	28,700	27,200	RANDOM	1,500
5	475	13,000	102,300	122,500	20,200	20,200	0	0
5	478	14,800	100,500	120,000	19,500	19,500	0	0
6	470	10,700	104,600	126,900	22,300	21,500	RANDOM	800
6	472	11,850	103,450	118,100	14,650	14,650	0	0
6	476	14,200	101,100	107,900	6,800	6,800	0	0
7	470	11,300	104,000	116,100	12,100	12,900	RANDOM	800
7	472	12,450	102,850	118,250	15,400	15,400	0	0
7	476	14,800	100,500	83,000	-17,500	-17,500	0	0
7	477	15,300	100,000	78,700	-21,300	-21,300	0	0
8	470	11,850	103,450	150,400	46,950	46,950	0	0
8	473	13,600	101,700	138,600	36,900	36,900	0	0
8	478	15,300	100,000	131,000	31,000	31,000	0	0
8	483	15,300	100,000	61,300	-38,700	-38,700	0	0

Note: See Figures 16 and 17 for definitions of symbols. Dry weight of gate F_1 = 115,300 lb.

Table 7
Life-Cycle Cost Analysis Summary

Cost Item	Existing Remote Operation Plan 1	Manual Operation Plan 2	Replace Remote Operation Plan 3
Cost Estimate, Incl ED[1], SA[2], RE[3], PM[r]	$0	$0	$1,042,501
No. of Construction Years			1
Annual Maintenance Cost	5,819	0	5,819
Annual Labor Cost	12,074	185,869	12,074
Periodic Replacement Costs:			
None Identified	0	0	0
Project Life/Evaluation Period	5	5	25
Federal Discount Rate	6.875%	6.875%	6.875%
Cost Analysis:			
Capital Costs (Design and Const.)	0	0	1,042,501
Interest During Construction	0	0	35,836
Discounted Replacement Costs:			
Year Replaced	0	0	0
	―――――	―――――	―――――
Present Value of Total Life-Cycle Costs	$0	$0	$1,078,337
Annualized Life-Cycle Costs	$0	$0	$91,493
Annual Maintenance and Labor Costs	17,893	185,869	17,893
Total Annual Life-Cycle Costs	$17,893	$185,869	$109,386

[1] Engineering Division
[2] Supervision and Administration
[3] Real Estate
[4] Project Management

Table 8
Maintenance and Labor Cost Data

Remote Operation Maintenance and Labor Costs					Manual Operation Labor Costs	
Year	Maint./Servc.		Labor	Labor	No. Operators	4 full-time
			Non-icing	Icing	Annual Hours Reqd.	8320
1990	$7,923		(Mar-Nov)	(Dec-Feb)	(4 X 2080)	
1991	$5,695				Avg. Wage/Benefits	$22.34
1992	$8,838	rate[1]	22.36	22.36	Annual Oper. Cost	$185,869
1993	$6,537	hr/day	1	3		
1994	$8,050	days	270	90		
1995	$1,638					
1996	$4,136	cost	$6,037	$6,037		
1997	$6,378					
1998	$3,179					
Total	$52,374					
Average	$5,819					

[1]Rate includes wages and benefits

Table 9
Marseilles Dam Instrumented Gate Operation Log

Date	Time	Gate 1 Opening, ft	Gate 3 Opening, ft	Gate 5 Opening, ft	Gate 7 Opening, ft	Comment
9/16/99	1510	0.0	0.0	0.0	1.0	
9/16/99	1650	0.0	0.0	0.0	0.5	
9/16/99	1755	0.0	0.0	0.0	0.0	
9/17/99	1315	0.0	0.0	0.0	0.5	
9/17/99	1317	0.0	0.0	0.0	1.0	
9/17/99	1320	0.0	0.0	0.0	0.0	
9/22/99	600	0.0	0.0	0.0	0.5	
9/22/99	1500	0.0	0.0	0.0	0.0	
9/27/99	2345	0.0	0.0	0.0	1.0	
9/28/99	1000	0.0	0.0	0.0	2.0	
9/28/99	1115	0.0	0.0	0.0	3.0	
9/28/99	2215	0.0	0.0	0.0	0.0	
9/28/99	2215	0.0	0.0	0.0	3.0	
9/28/99	2215	2.0	2.0	0.0	3.0	
9/28/99	2215	0.0	0.0	0.0	3.0	
9/29/99	1420	0.0	0.0	0.0	2.0	
9/29/99	1710	0.0	0.0	0.0	0.0	
9/30/99	340	0.0	0.0	0.0	0.5	
9/30/99	455	0.0	0.0	0.0	2.0	
9/30/99	1235	0.0	0.0	0.0	1.5	
9/30/99	1330	0.0	0.0	0.0	0.5	
9/30/99	1455	0.0	0.0	0.0	0.0	
10/1/99	100	0.0	0.0	0.0	1.0	
10/1/99	105	0.0	0.0	0.0	2.0	
10/1/99	755	0.0	0.0	0.0	1.0	
10/1/99	1005	0.0	0.0	0.0	1.5	
10/1/99	1050	0.0	0.0	0.0	2.0	
10/1/99	1000	0.0	0.0	0.0	1.5	
10/1/99	1710	0.0	0.0	0.0	1.0	
10/1/99	1830	0.0	0.0	0.0	0.0	
10/2/99	910	0.0	0.0	0.0	1.0	
10/2/99	1110	0.0	0.0	0.0	1.5	
10/2/99	1130	0.0	0.0	0.0	2.0	
10/2/99	1625	0.0	0.0	0.0	1.5	
10/2/99	1705	0.0	0.0	0.0	1.0	
10/2/99	1800	0.0	0.0	0.0	0.0	
10/3/99	1230	0.5	0.0	0.0	0.0	
10/3/99	1305	1.0	0.0	0.0	0.0	
10/4/99	755	0.0	0.0	0.0	0.0	
10/4/99	1800	0.0	0.0	0.0	1.0	
4-Oct	2035	0.0	0.0	0.0	2.0	
10/4/99	2305	0.0	0.0	0.0	1.0	
10/5/99	540	0.0	0.0	0.0	0.5	

(Sheet 1 of 7)

Table 9 (Continued)						
Date	Time	Gate 1 Opening, ft	Gate 3 Opening, ft	Gate 5 Opening, ft	Gate 7 Opening, ft	Comment
10/5/99	805	0.0	0.0	0.0	0.0	
10/5/99	1420	0.0	0.0	0.0	1.0	
5-Oct	1630	0.0	0.0	0.0	0.5	
10/6/99	730	0.0	0.0	0.0	0.0	
10/6/99	1515	0.0	0.0	0.0	0.5	
10/7/99	200	0.0	0.0	0.0	1.0	
10/7/99	1030	0.0	0.0	0.0	0.5	
10/7/99	1230	0.0	0.0	0.0	0.0	
10/8/99	210	0.0	0.0	0.0	1.0	
10/8/99	1110	0.0	0.0	0.0	0.0	
10/9/99	750	0.0	0.0	0.0	1.0	
9-Oct	1325	0.0	0.0	0.0	0.5	
10/9/99	1350	0.0	0.0	0.0	0.0	
10/10/99	910	0.0	0.0	0.0	0.5	
10/13/99	1545	0.0	0.0	0.0	1.0	
10/13/99	2025	0.0	0.0	0.0	0.5	
10/13/99	2140	0.0	0.0	0.0	0.0	
10/15/99	1705	0.0	0.0	0.0	1.0	
10/15/99	2105	0.0	0.0	0.0	0.0	
10/17/99	1630	0.0	0.0	0.0	1.0	
10/17/99	1810	0.0	0.0	0.0	0.5	
10/17/99	2135	0.0	0.0	0.0	0.0	
10/19/99	1200	0.0	0.0	0.0	0.5	
10/19/99	1500	0.0	0.0	0.0	0.0	
10/29/99	1140	0.0	0.0	0.0	1.0	
10/29/99	1805	0.0	0.0	0.0	0.0	
11/23/99	1345	0.0	0.0	0.0	0.5	
11/23/99	1900	0.0	0.0	0.0	0.0	
11/26/99	735	0.0	0.0	0.0	1.0	
11/26/99	915	0.0	0.0	0.0	0.5	
11/26/99	1110	0.0	0.0	0.0	0.0	
12/4/99	2330	0.0	0.0	0.0	1.0	
12/4/99	2347	0.0	0.0	0.0	1.5	
12/5/99	300	0.0	0.0	0.0	2.0	
12/5/99	540	0.0	0.0	0.0	3.0	
12/5/99	1805	0.0	0.0	0.0	2.0	
12/5/99	1840	0.0	0.0	0.0	2.5	
12/5/99	1922	0.0	0.0	0.0	3.0	
12/5/99	2245	0.0	0.0	0.0	2.0	
12/6/99	150	0.0	0.0	0.0	1.0	
12/6/99	800	0.0	0.0	0.0	2.0	
12/6/99	1200	0.0	0.0	0.0	3.0	
12/6/99	1330	0.0	0.0	0.0	2.0	
12/6/99	1540	0.0	0.0	0.0	3.0	
12/6/99	2145	0.0	0.0	0.0	2.5	

Table 9 (Continued)						
Date	Time	Gate 1 Opening, ft	Gate 3 Opening, ft	Gate 5 Opening, ft	Gate 7 Opening, ft	Comment
12/6/99	2300	0.0	0.0	0.0	2.0	
12/7/99	1600	0.0	0.0	0.0	0.0	
12/8/99	920	0.0	0.0	0.0	1.5	
12/8/99	1645	0.0	0.0	0.0	1.0	
12/8/99	2000	0.0	0.0	0.0	0.5	
12/8/99	2045	0.0	0.0	0.0	0.0	
12/9/99	320	0.0	0.0	0.0	0.5	
12/9/99	900	0.0	0.0	0.0	1.5	
12/9/99	1130	0.0	0.0	0.0	1.0	
12/9/99	1735	0.0	0.0	0.0	0.5	
12/9/99	2315	0.0	0.0	0.0	1.0	
12/10/99	0	0.0	0.0	0.0	1.0	
12/10/99	300	0.0	0.0	0.0	0.0	
12/10/99	1626	0.0	0.0	0.0	0.5	
12/11/99	0	0.0	0.0	0.0	1.0	
12/11/99	400	0.0	0.0	0.0	0.0	
12/12/99	1340	0.0	0.0	0.0	1.0	
12/15/99	600	0.0	0.0	0.0	1.0	
12/15/99	1510	0.0	0.0	0.0	0.5	
12/15/99	1520	0.0	0.0	0.0	0.0	
12/17/99	735	0.0	0.0	0.0	1.0	
12/17/99	1210	0.0	0.0	0.0	0.0	
12/20/99	20	0.0	0.0	0.0	0.5	
12/20/99	130	0.0	0.0	0.0	0.0	
12/20/99	2350	0.0	0.0	0.0	0.5	
12/21/99	5	0.0	0.0	0.0	1.0	
12/21/99	400	0.0	0.0	0.0	0.0	
12/24/99	310	0.0	0.0	0.0	0.5	
12/24/99	345	0.0	0.0	0.0	1.0	
12/24/99	0510	0.0	0.0	0.0	0.5	
12/24/99	0600	0.0	0.0	0.0	0.0	
12/30/99	0030	0.0	0.0	0.0	0.5	
12/30/99	0300	0.0	0.0	0.0	0.0	
1/6/00	1315	0.0	0.0	0.0	1.0	
1/6/00	1832	0.0	0.0	0.0	1.0	
1/6/00	2030	0.0	0.0	0.0	0.5	
1/6/00	2230	0.0	0.0	0.0	1.0	
1/6/00	2355	0.0	0.0	0.0	0.0	
1/8/00	1615	0.0	0.0	0.0	0.5	
1/8/00	1900	0.0	0.0	0.0	1.0	
1/8/00	2155	0.0	0.0	0.0	0.5	
1/9/00	0425	0.0	0.0	0.0	0.0	
1/9/00	1630	0.0	0.0	0.0	1.0	
1/9/00	1850	0.0	0.0	0.0	1.5	
1/10/00	0200	0.0	0.0	0.0	-8.0	

Table 9 (Continued)

Date	Time	Gate 1 Opening, ft	Gate 3 Opening, ft	Gate 5 Opening, ft	Gate 7 Opening, ft	Comment
1/10/00	0215	0.0	0.0	0.0	0.0	
1/11/00	0715	0.0	0.0	0.0	0.5	
1/11/00	0950	0.0	0.0	0.0	1.0	
1/11/00	1000	0.0	0.0	0.0	2.0	
1/11/00	1205	0.0	0.0	0.0	1.5	
1/11/00	1240	0.0	0.0	0.0	1.0	
1/11/00	1920	0.0	0.0	0.0	0.5	
1/11/00	2100	0.0	0.0	0.0	0.0	
1/13/00	2345	0.0	0.0	0.0	1.0	
1/14/00	0320	0.0	0.0	0.0	0.5	
1/14/00	0355	0.0	0.0	0.0	0.0	
1/21/00	1220	0.0	0.0	-1.0	-1.0	
1/21/00	1305	0.0	-1.0	-1.0	-1.0	
1/21/00	1400	-1.0	-1.0	-1.0	0.0	
1/21/00	1435	-1.0	-1.0	-1.5	-1.5	
1/21/00	1515	-1.0	-1.5	-1.5	-1.5	
1/22/00	0001	-1.0	-1.0	-1.0	-1.0	
1/22/00	0130	-0.5	-0.5	-0.5	-0.5	
22-Jan	0200	-1.0	-1.0	-1.0	-1.0	
1/22/00	0300	-1.0	-1.0	-1.0	-1.0	
1/22/00	0400	-0.5	-0.5	-0.5	-0.5	
1/22/00	0530	-1.0	-1.0	-1.0	-1.0	
1/22/00	0700	-1.0	-1.5	-1.5	-1.5	
1/22/00	0835	-1.0	-1.0	-1.0	-1.5	
1/22/00	0915	-1.0	-1.0	-1.0	-1.0	
1/22/00	1045	-0.5	-0.5	-0.5	-0.5	
1/22/00	1155	0.0	0.0	0.0	0.0	
1/23/00	400	-1.0	-1.0	-1.0	-1.0	
1/23/00	0500	-1.0	-1.0	-0.5	-0.5	
1/23/00	0700	-1.0	-1.0	-1.0	-1.0	
1/23/00	0730	-0.5	-0.5	-1.0	-0.5	
1/23/00	0830	-0.5	-0.5	-0.5	-0.5	
1/23/00	1010	-3.0	0.0	0.0	0.0	
1/23/00	1105	-0.5	-0.5	-0.5	0.0	
1/23/00	1200	-0.5	-0.5	-0.5	-0.5	
1/23/00	1340	-0.3	-0.3	-0.3	0.0	
1/23/00	1400	-0.3	-0.3	-0.3	-0.3	
1/23/00	1800	-0.4	-0.4	-0.4	-0.4	
1/23/00	1925	-0.7	-0.7	-0.7	-0.7	
1/23/00	2135	-1.0	-1.0	-1.0	-1.0	
1/23/00	2145	-1.2	-1.2	-1.2	-1.2	
1/23/00	0001	-1.2	-1.2	-1.2	-1.2	
1/23/00	0100	-0.5	-0.5	-0.5	-0.5	
1/23/00	0230	-1.0	-1.0	-1.0	-1.0	
1/23/00	0400	-1.0	-1.0	-1.0	-1.0	

Table 9 (Continued)

Date	Time	Gate 1 Opening, ft	Gate 3 Opening, ft	Gate 5 Opening, ft	Gate 7 Opening, ft	Comment
1/24/00	0800	-1.0	-1.0	-1.0	-1.0	
1/24/00	0820	-1.0	-1.0	-1.0	-1.0	
1/24/00	1330	0.5	0.5	-1.0	-1.0	
1/24/00	1610	0.5	0.5	-0.5	-1.0	
1/24/00	1830	0.5	0.5	-0.5	-0.5	
1/25/00	0200	-0.5	-0.5	-0.5	-0.5	
1/25/00	0800	1.5	1.0	1.0	-2.0	
1/25/00	0915	-0.5	-0.5	-0.5	-2.0	
1/25/00	1150	0.0	0.0	0.0	-5.0	
1/25/00	1200	0.0	0.0	0.0	0.0	
1/25/00	1240	1.0	0.5	0.5	0.5	
1/25/00	1400	-0.5	0.5	0.5	0.0	
1/25/00	1435	0.0	0.0	0.0	0.0	
1/25/00	2205	-0.5	-0.5	-0.5	-0.5	
1/26/00	0200	-1.0	-1.0	-1.0	-1.0	
1/26/00	0815	-1.0	-1.0	-1.0	-1.5	
1/26/00	1900	-1.0	-1.0	-0.5	-0.5	
1/27/00	0920	-1.0	-1.0	-0.5	-1.0	
1/27/00	0932	-1.0	-1.0	-0.5	-2.0	
1/27/00	1400	-1.0	-1.0	-1.0	-2.0	
1/27/00	1530	-2.0	-2.0	-2.0	-2.0	
1/27/00	1640	-1.5	-1.5	-1.5	-1.5	
1/28/00	0105	-1.5	-1.5	-1.0	-1.0	
1/28/00	0340	-1.0	-1.0	-1.0	-0.5	
1/28/00	0615	-1.0	-1.0	-0.5	-0.5	
1/28/00	0740	-1.0	-0.5	-0.5	-0.5	
1/28/00	0940	-1.0	-0.5	-0.5	-0.5	
1/28/00	1200	-0.5	-0.5	-0.5	-0.5	
1/28/00	1720	-1.0	-1.0	-1.0	-1.0	
1/28/00	1750	-1.5	-1.5	-1.5	-1.5	
1/28/00	2005	-1.0	-1.0	-1.0	-1.0	
1/28/00	2050	-0.5	-0.5	-0.5	-0.5	
1/28/00	2315	0.0	-0.5	-0.5	-0.5	
1/29/00	0400	0.0	0.0	-0.5	-0.5	
1/29/00	0846	-0.5	-0.5	-0.5	-0.5	
1/29/00	0900	-0.5	-0.5	-0.5	-1.0	
1/29/00	1005	-0.5	-0.5	-1.0	-1.0	
1/29/00	1100	-1.0	-1.0	-1.0	-1.0	
1/29/00	1200	-1.0	-1.0	-1.5	-1.5	
1/29/00	1330	-1.5	-1.5	-2.0	-2.0	
1/29/00	1753	-1.0	-1.0	-2.0	-2.0	
1/30/00	0730	-1.0	-1.0	-1.0	-2.0	
1/30/00	1350	-0.5	-1.0	-1.0	-1.0	
1/30/00	1410	-0.5	-0.5	-0.5	-0.5	
1/31/00	0020	-0.5	-0.5	-1.0	-1.0	

Table 9 (Continued)						
Date	Time	Gate 1 Opening, ft	Gate 3 Opening, ft	Gate 5 Opening, ft	Gate 7 Opening, ft	Comment
1/31/00	0110	-1.0	-1.0	-1.0	-1.0	
1/31/00	0335	-1.5	-1.5	-1.5	-1.5	
1/31/00	1500	0.0	0.0	0.0	0.0	
1/31/00	1950	-0.5	-0.5	-0.5	-0.5	
1/31/00	2300	-1.0	-1.0	-1.0	-1.0	
2/1/00	0005	-1.0	-1.5	-1.5	-1.5	
2/1/00	0020	-1.5	-1.5	-1.5	-1.5	
2/1/00	1130	-1.0	-1.0	-1.5	-1.5	
2/1/00	1430	-1.0	-1.0	-1.0	-1.0	
2/1/00	2245	-0.5	-0.5	-0.5	-0.5	
2/1/00	2305	0.0	0.0	0.0	0.0	
2/2/00	0250	0.0	-0.5	-0.5	-0.5	
2/2/00	0400	-1.0	-1.0	-1.0	-1.0	
2/2/00	0635	-1.5	-1.5	-1.5	-1.5	
2/2/00	1515	-1.0	-1.0	-1.5	-1.5	
2/2/00	1700	-1.0	-1.0	-1.0	-1.0	
2/2/00	1915	-0.5	-0.5	-1.0	-1.0	
2/2/00	2120	-0.5	-0.5	-0.5	-0.5	
2/2/00	2210	0.0	0.0	0.0	0.0	
2/3/00	0640	0.0	0.0	-0.5	-0.5	
2/3/00	0830	-0.5	-0.5	-1.0	-1.0	
2/3/00	0935	-1.0	-1.0	-1.0	-1.0	
2/3/00	1105	-1.5	-1.5	-1.5	-1.0	
2/4/00	0225	-1.0	-1.0	-1.0	-1.0	
2/4/00	0530	-1.0	-1.0	-0.5	-0.5	
2/4/00	0635	-0.5	-0.5	-0.5	-0.5	
2/4/00	1430	-1.0	-1.0	-1.0	-1.0	
2/4/00	1600	-1.0	-1.5	-1.5	-1.5	
2/4/00	1700	-1.5	-1.5	-1.5	-1.5	
2/5/00	0230	-1.5	-2.5	-1.0	-1.0	
2/5/00	0850	-1.0	-1.0	-1.0	-1.0	
2/5/00	0900	-0.5	-0.5	-0.5	-0.5	
2/5/00	1300	-0.5	0.5	0.0	0.0	
2/5/00	1745	-0.5	-0.5	-0.5	0.0	
2/5/00	1940	-1.0	-0.5	-0.5	-0.5	
2/6/00	0225	-1.0	-0.5	-0.5	-0.5	
2/6/00	0250	-1.0	-1.0	-1.0	-1.0	
2/7/00	2000	-1.0	-1.0	-1.0	0.0	
2/7/00	2100	-1.0	-1.0	0.0	0.0	
2/7/00	2200	-1.0	0.0	0.0	0.0	
2/7/00	2300	0.0	0.0	0.0	0.0	
2/8/00	1800	0.0	0.0	0.0	-1.5	
2/8/00	1900	0.0	0.0	-1.5	-1.5	
2/8/00	2100	0.0	-1.5	-1.5	-1.5	
2/8/00	2130	-1.5	-1.5	-1.5	-1.5	

Table 9 (Concluded)						
Date	Time	Gate 1 Opening, ft	Gate 3 Opening, ft	Gate 5 Opening, ft	Gate 7 Opening, ft	Comment
2/9/00	0115	-1.5	-1.5	-1.0	-1.0	
2/9/00	0200	-1.0	-1.0	-1.0	-1.0	
2/9/00	0700	0.0	0.0	-1.0	-1.0	
2/9/00	0930	-0.5	-0.5	-0.5	-1.0	
2/9/00	1245	-1.0	-1.0	-1.0	-1.0	
2/9/00	1400	-1.5	-1.5	-1.5	-1.5	
2/9/00	2310	-1.0	-1.0	-1.0	-1.0	
2/10/00	0115	-0.5	-0.5	-0.5	-0.5	
2/10/00	1000	-0.5	-1.0	-1.0	-1.0	
2/10/00	1110	-1.0	-1.0	-1.0	-1.0	
2/10/00	1150	-1.0	-1.0	-1.5	-1.5	
2/10/00	1400	-1.5	-1.5	-1.5	-1.5	
2/11/00	2400	-1.5	-1.5	-1.0	-1.0	
2/11/00	0415	-1.0	-1.0	-1.0	-1.0	
2/11/00	1455	-1.0	-1.0	-1.0	-1.0	
2/12/00	0045	-1.5	-1.5	-1.5	-1.5	
2/12/00	0400	-1.5	-1.5	-2.0	-2.0	
2/12/00	1320	-1.5	-1.5	-1.5	-2.0	
						(Sheet 7 of 7)

Table 10
Summary of Ice Conditions on Marseilles Pool 1 January - 18 February 2000

Date	Average Air Temp. (°F)	Average W Wind Speed (mph)	Wind Dir.	Ice Cover & Ice Activity
1 - 20 Jan.				Open water
21-Jan-00	36.0	11.1	NW	Thin, black sheet ice cover on pool
22-Jan-00	30.2	12.8		Gray sheet ice, flooded at edges and in front of dam gates
23-Jan-00	29.7	8.2	NW	At dawn, sheet ice intact Between 09:47-10:09 wind pushes sheet ice upstream and out of view
24-Jan-00	19.6	4.2	W	Gray sheet ice re-formed pool, except for (20-ft-)width of open water in front of dam gates
25-Jan-00	311.5	122.6	NW	At dawn, show-dusted ice cover with longitudinal cracks At 11:40 towboat breaks out sheet ice. By 13:00 most of the ice has passed the dam. By 15:50, pool clear of ice
26-Jan-00	31.8	7.8		Thin black ice re-formed on pool
27-Jan-00	22.8	6.1		No-record, assume thin sheet ice
28-Jan-00	24.6	10.9	E	Throughout morning, gray sheet ice on pool 12:57, ice starts to shift neat Gate 1 13:07 floods the upper edge of the sheet ice 13:17 entire sheet moves towards dam 13:31 ice sheet pushes through central dam gates By 13:35 most of the sheet ice has passed the dam Until 14:20 intermittent disperse floes continue to arrive at dam After 14:20 open water
29-Jan-00	23.0	8.0		Disperse flows pass central and right-side dam gates
30-Jan-00	14.6	10.8		Open water, disperse small floes early
31-Jan-00	3.4	12.1	06:38	06:38, pool filled with accumulation of small floes 07:17, left side of accumulation shifts upstream 07:27, left half begins to move d/s past gates 07:30-0750 right half moves past gates 07:50, ice stalls on right, center ice moves, some through Gate 2 After 08:04 pool clear of ice, except for some floes on right side
1-Feb-00	12.8	7.1		Open water, with minor floes passing 1, 2 3 early in day
2-Feb-00	17.2	4.4	W	Open water
3-Feb-00	5	8.8		Open water
4-Feb-00	14.8	5.8	NW	Open water
5-Feb-00	14	10.2	W	Open water
6-Feb-00	19.6	9.6		Open water, minor small floes
7-Feb-00	21.6	8.2		Open water
8-Feb-00	23.7	11.3	W	Open water
9-Feb-00	26.5	13.5	W	Open water
10-Feb-00	22	10.8		Open water
11-Feb-00	25.3	5.6	NW	Open water
12-Feb-00	17.6	7.2	E	Open water
13-Feb-00	31.1	7.7	E	Open water
14-Feb-00	28.4	10.2	W	Open water
15-Feb-00	21.2	8.3		Open water
16-Feb-00	24.1	10.8		No-record, Assume open water
17-Feb-00 And after	29.7	5.3		No-record, Assume open water

Table 11
Marseilles Dam; Raised Gate Positions; No Gates Operating; Background Vibration Statistics

Data Collected on 11/26/1999 at 1134 hrs
Instrumented Gates: 1, 3, 5, 7
Gate Settings: 0, 0, 0, 0

Channel No.	Minimum	Average	Maximum	Std Dev	RMS	Units	Gate No/ Sensor
1	-0.41	-0.232	0.011	0.013	0.232	Degrees	Gate 1/ Tilt
2	-36.261	18.219	71.536	11.274	21.425	Milli-g's	Gate 1/ Vertical Acceleration
3	-8.771	16.056	38.658	5.274	16.9	Milli-g's	Gate 1/ Radial Acceleration
4	-59.787	16.987	89.74	15.797	23.197	Milli-g's	Gate1/ Transverse Acceleration
5	-0.808	-0.63	-0.493	0.01	0.63	Degrees	Gate 3/ Tilt
6	6.383	24.35	41.217	2.088	24.439	Milli-g's	Gate 3/ Vertical Acceleration
7	15.349	22.707	29.56	1.302	22.745	Milli-g's	Gate 3/ Radial Acceleration
8	-3.473	13.545	29.458	2.45	13.765	Milli-g's	Gate 3/ Transverse Acceleration
9	-0.764	-0.654	-0.552	0.008	0.654	Degrees	Gate 5/ Tilt
10	3.843	14.4	24.232	2.047	14.545	Milli-g's	Gate 5/ Vertical Acceleration
11	6.431	12.57	19.572	1.371	12.644	Milli-g's	Gate 5/ Radial Acceleration
12	-3.242	10.985	23.81	2.749	11.324	Milli-g's	Gate 5/ Transverse Acceleration
13	-1.689	-1.523	-1.381	0.009	1.523	Degrees	Gate 7/ Tilt
14	-21.255	21.868	67.691	3.269	22.111	Milli-g's	Gate 7/ Vertical Acceleration
15	-2.671	15.925	37.518	1.446	15.99	Milli-g's	Gate 7/ Radial Acceleration
16	-92.128	-13.201	59.278	5.542	14.317	Milli-g's	Gate 7/ Transverse Acceleration

Table 12
Marseilles Dam; Raised Gate Positions; Single Gate Operation; Vibration Statistics

Data Collected on 12/04/1999 at 2351 hrs
Instrumented Gates: 1, 3, 5, 7
Gate Settings : 0, 0, 0, 1.5

Channel No.	Minimum	Average	Maximum	Std Dev	RMS	Units	Gate No/ Sensor
1	-1.106	-0.968	-0.781	0.012	0.968	Degrees	Gate 1/ Tilt
2	-31.446	18.131	61.644	9.59	20.511	Milli-g's	Gate 1/ Vertical Acceleration
3	-5.617	16.204	36.225	4.389	16.788	Milli-g's	Gate 1/ Radial Acceleration
4	-46.831	16.952	84.302	13.562	21.709	Milli-g's	Gate1/ Transverse Acceleration
5	-1.584	-1.498	-1.334	0.012	1.498	Degrees	Gate 3/ Tilt
6	4.59	24.357	43.041	1.883	24.429	Milli-g's	Gate 3/ Vertical Acceleration
7	14.451	22.743	30.966	1.142	22.771	Milli-g's	Gate 3/ Radial Acceleration
8	-24.691	13.519	45.438	2.382	13.727	Milli-g's	Gate 3/ Transverse Acceleration
9	-1.539	-1.44	-1.361	0.008	1.44	Degrees	Gate 5/ Tilt
10	-4.69	14.513	34.035	3.249	14.872	Milli-g's	Gate 5/ Vertical Acceleration
11	4.607	12.454	20.531	1.818	12.586	Milli-g's	Gate 5/ Radial Acceleration
12	-15.608	10.959	37.543	4.359	11.794	Milli-g's	Gate 5/ Transverse Acceleration
13	5.784	6.632	7.534	0.771	6.677	Degrees	Gate 7/ Tilt
14	-2.239	21.939	48.613	5.078	22.519	Milli-g's	Gate 7/ Vertical Acceleration
15	6.939	15.858	26.342	2.039	15.989	Milli-g's	Gate 7/ Radial Acceleration
16	-52.695	-13.162	26.683	8.783	15.824	Milli-g's	Gate 7/ Transverse Acceleration

Table 13
Marseilles Dam; Raised Gate Positions; Single Gate Operation; Vibration Statistics

Data Collected on 12/05/1999 at 0323 hrs
Instrumented Gates: 1, 3, 5, 7
Gate Settings: 0, 0, 0, 2.0

Statistics							
Channel No.	**Minimum**	**Average**	**Maximum**	**Std Dev**	**RMS**	**Units**	**Gate No/ Sensor**
1	-1.091	-0.963	-0.791	0.013	0.963	Degrees	Gate 1/ Tilt
2	-29.27	18.072	61.818	9.655	20.489	Milli-g's	Gate 1/ Vertical Acceleration
3	-3.935	16.185	37.937	4.359	16.762	Milli-g's	Gate 1/ Radial Acceleration
4	-45.137	16.908	81.271	13.556	21.672	Milli-g's	Gate1/ Transverse Acceleration
5	-1.579	-1.485	-1.359	0.012	1.485	Degrees	Gate 3/ Tilt
6	15.532	24.347	34.986	1.68	24.405	Milli-g's	Gate 3/ Vertical Acceleration
7	17.622	22.653	28.124	1.09	22.679	Milli-g's	Gate 3/ Radial Acceleration
8	2.855	13.605	27.339	2.031	13.756	Milli-g's	Gate 3/ Transverse Acceleration
9	-1.52	-1.441	-1.38	0.008	1.441	Degrees	Gate 5/ Tilt
10	-0.358	14.577	28.726	2.938	14.87	Milli-g's	Gate 5/ Vertical Acceleration
11	4.329	12.519	20.592	1.856	12.656	Milli-g's	Gate 5/ Radial Acceleration
12	-12.43	10.881	33.665	3.879	11.552	Milli-g's	Gate 5/ Transverse Acceleration
13	8.981	9.177	9.332	0.008	9.177	Degrees	Gate 7/ Tilt
14	-11.318	21.982	53.49	5.704	22.71	Milli-g's	Gate 7/ Vertical Acceleration
15	4.759	15.877	28.461	2.242	16.034	Milli-g's	Gate 7/ Radial Acceleration
16	-61.131	-13.14	38.475	9.928	16.469	Milli-g's	Gate 7/ Transverse Acceleration

Table 14
Marseilles Dam; Raised Gate Positions; Single Gate Operation; Vibration Statistics

Data Collected on 12/5/1999 at 0557 hrs
Instrumented Gates: 1, 3, 5, 7
Gate Settings: 0, 0, 0, 3.0

Statistics							
Channel No.	**Minimum**	**Average**	**Maximum**	**Std Dev**	**RMS**	**Units**	**Gate No/ Sensor**
1	-1.091	-0.962	-0.189	0.054	0.963	Degrees	Gate 1/ Tilt
2	-22.859	18.136	63.617	9.102	20.292	Milli-g's	Gate 1/ Vertical Acceleration
3	-2.073	16.258	36.285	4.062	16.757	Milli-g's	Gate 1/ Radial Acceleration
4	-47.515	16.937	93.217	13.356	21.57	Milli-g's	Gate1/ Transverse Acceleration
5	-1.574	-1.472	-1.419	0.01	1.472	Degrees	Gate 3/ Tilt
6	14.803	24.4	33.466	1.761	24.464	Milli-g's	Gate 3/ Vertical Acceleration
7	17.592	22.654	27.765	1.139	22.683	Milli-g's	Gate 3/ Radial Acceleration
8	2.207	13.648	25.191	2.146	13.816	Milli-g's	Gate 3/ Transverse Acceleration
9	-1.544	-1.443	-1.38	0.008	1.443	Degrees	Gate 5/ Tilt
10	-2.475	14.611	35.11	2.518	14.827	Milli-g's	Gate 5/ Vertical Acceleration
11	4.916	12.547	20.685	1.73	12.665	Milli-g's	Gate 5/ Radial Acceleration
12	-16.689	10.871	39.132	3.22	11.338	Milli-g's	Gate 5/ Transverse Acceleration
13	11.827	11.938	12.092	0.008	11.938	Degrees	Gate 7/ Tilt
14	-9.692	21.99	47.233	5.852	22.756	Milli-g's	Gate 7/ Vertical Acceleration
15	5.925	15.985	26.342	2.294	16.149	Milli-g's	Gate 7/ Radial Acceleration
16	-62.026	-13.123	32.882	10.295	16.679	Milli-g's	Gate 7/ Transverse Acceleration

Table 15
Marseilles Dam; Raised Gate Positions; 2 Gate Operation; Vibration Statistics

Data Collected on 06/02/2000 at 0130 hrs
Instrumented Gates : 1, 3, 5, 7
Gate Openings: 0.0, 0.0, 2.0, 5.0

Statistics							
Channel No.	**Minimum**	**Average**	**Maximum**	**Std. Dev**	**RMS**	**Units**	**Gate No. Sensor**
1	0.001	0.162	0.357	0.034	0.166	degrees	Gate 1/ Tilt
2	-62.834	18.346	96.629	4.88	18.984	Milli-g's	Gate 1/ Vertical Acceleration
3	-14.508	14.032	38.027	2.509	14.254	Milli-g's	Gate 1/ Radial Acceleration
4	-93.692	19.656	147.12	7.589	21.071	Milli-g's	Gate1/ Transverse Acceleration
5	0.629	0.778	0.889	0.009	0.778	degrees	Gate 3/ Tilt
6	-25.989	26.037	80.914	2.997	26.209	Milli-g's	Gate 3/ Vertical Acceleration
7	1.675	22.545	38.297	1.566	22.599	Milli-g's	Gate 3/ Radial Acceleration
8	-64.831	17.749	111.093	4.137	18.224	Milli-g's	Gate 3/ Transverse Acceleration
9	8.683	8.803	8.876	0.008	8.803	degrees	Gate 5/ Tilt
10	-7.002	17.252	42.275	5.516	18.113	Milli-g's	Gate 5/ Vertical Acceleration
11	5.071	13.927	23.499	1.896	14.056	Milli-g's	Gate 5/ Radial Acceleration
12	-28.133	9.801	54.073	8.993	13.302	Milli-g's	Gate 5/ Transverse Acceleration
13	17.071	17.253	17.443	0.008	17.253	degrees	Gate 7/ Tilt
14	-6.073	21.804	51.987	3.778	22.128	Milli-g's	Gate 7/ Vertical Acceleration
15	-0.675	19.148	37.364	1.547	19.21	Milli-g's	Gate 7/ Radial Acceleration
16	-51.257	-11.448	47.358	6.78	13.305	Milli-g's	Gate 7/ Transverse Acceleration

Table 16
Marseilles Dam; Raised Gate Positions; 2 Gate Operation; Vibration Statistics

Data Collected on 04/21/2000 at 1407 hrs
Instrumented Gates: 1, 3, 5, 7
Gate Openings: 0.0, 0.0, 5.0, 5.0

Statistics							
Channel No.	**Minimum**	**Average**	**Maximum**	**Std Dev**	**RMS**	**Units**	**Gate No./ Sensor**
1	0.888	1.034	1.179	0.02	1.034	degrees	Gate 1/ Tilt
2	-35.188	17.844	67.736	3.966	18.279	Milli-g's	Gate 1/ Vertical Acceleration
3	-0.841	16.58	34.903	3.285	16.902	Milli-g's	Gate 1/ Radial Acceleration
4	-64.779	17.093	99.932	6.331	18.227	Milli-g's	Gate1/ Transverse Acceleration
5	0.729	0.812	0.924	0.011	0.812	degrees	Gate 3/ Tilt
6	-30.852	24.423	71.978	2.364	24.538	Milli-g's	Gate 3/ Vertical Acceleration
7	10.771	22.534	32.073	1.477	22.582	Milli-g's	Gate 3/ Radial Acceleration
8	-87.08	13.436	106.826	3.53	13.892	Milli-g's	Gate 3/ Transverse Acceleration
9	17.413	17.458	17.557	0.008	17.458	degrees	Gate 5/ Tilt
10	-33.872	14.563	64.52	5.255	15.482	Milli-g's	Gate 5/ Vertical Acceleration
11	-1.268	12.71	31.847	1.811	12.838	Milli-g's	Gate 5/ Radial Acceleration
12	-90.186	10.619	91.076	8.7	13.728	Milli-g's	Gate 5/ Transverse Acceleration
13	17.346	17.454	17.551	0.008	17.454	degrees	Gate 7/ Tilt
14	-14.599	22.014	60.146	5.373	22.66	Milli-g's	Gate 7/ Vertical Acceleration
15	1.32	16.105	33.189	2.053	16.235	Milli-g's	Gate 7/ Radial Acceleration
16	-90.498	-12.761	54.069	9.629	15.986	Milli-g's	Gate 7/ Transverse Acceleration

Table 17 Marseilles Dam; Raised Gate Positions; 3 Gate Operation; Vibration Statistics							
Data Collected on 04/22/2000 at 0536 hrs Instrumented Gates: 1, 3, 5, 7 Gate Openings: 0.0, 1.0, 5.0, 5.0							
Statistics							
Channel No.	Minimum	Average	Maximum	Std. Dev	RMS	Units	Gate No./ Sensor
1	0.788	1.03	1.219	0.038	1.031	degrees	Gate 1/ Tilt
2	-18.74	17.815	53.696	3.192	18.098	Milli-g's	Gate 1/ Vertical Acceleration
3	3.034	17.014	30.878	1.766	17.106	Milli-g's	Gate 1/ Radial Acceleration
4	-38.778	16.731	61.659	4.955	17.449	Milli-g's	Gate1/ Transverse Acceleration
5	6.011	6.123	6.281	0.01	6.123	degrees	Gate 3/ Tilt
6	8.48	24.242	39.241	3.425	24.483	Milli-g's	Gate 3/ Vertical Acceleration
7	15.199	22.468	29.71	1.387	22.511	Milli-g's	Gate 3/ Radial Acceleration
8	-11.595	12.862	41.524	5.198	13.872	Milli-g's	Gate 3/ Transverse Acceleration
9	17.148	17.238	17.34	0.008	17.238	degrees	Gate 5/ Tilt
10	-36.348	14.24	63.022	5.132	15.136	Milli-g's	Gate 5/ Vertical Acceleration
11	-16.882	12.615	40.968	1.628	12.72	Milli-g's	Gate 5/ Radial Acceleration
12	-54.455	10.859	71.017	8.308	13.672	Milli-g's	Gate 5/ Transverse Acceleration
13	17.405	17.503	17.594	0.008	17.503	degrees	Gate 7/ Tilt
14	-18.832	21.903	68.672	3.216	22.137	Milli-g's	Gate 7/ Vertical Acceleration
15	-9.794	15.75	37.088	1.378	15.81	Milli-g's	Gate 7/ Radial Acceleration
16	-68.864	-12.955	50.49	5.71	14.157	Milli-g's	Gate 7/ Transverse Acceleration

Table 18 Marseilles Dam; Raised Gate Positions; 3 Gate Operation; Vibration Statistics							
Data Collected on 07/11/2000 at 2117 hrs Instrumented Gates : 1, 3, 5, 7 Gate Openings: 0.0, 5.0, 5.0, 5.0							
Statistics							
Channel No.	Minimum	Average	Maximum	Std. Dev	RMS	Units	Gate No./ Sensor
1	0.121	0.364	0.643	0.058	0.369	degrees	Gate 1/ Tilt
2	0.986	18.47	36.319	1.821	18.56	Milli-g's	Gate 1/ Vertical Acceleration
3	1.532	12.433	24.09	1.322	12.503	Milli-g's	Gate 1/ Radial Acceleration
4	0.505	20.375	43.236	2.451	20.522	Milli-g's	Gate1/ Transverse Acceleration
5	17.051	17.136	17.261	0.01	17.136	degrees	Gate 3/ Tilt
6	-224.2	26.467	300.464	3.707	26.726	Milli-g's	Gate 3/ Vertical Acceleration
7	-65.074	22.276	116.954	1.847	22.353	Milli-g's	Gate 3/ Radial Acceleration
8	-170.8	19.301	223.276	5.166	19.98	Milli-g's	Gate 3/ Transverse Acceleration
9	17.066	17.116	17.205	0.009	17.116	degrees	Gate 5/ Tilt
10	-23.255	18.411	62.696	5.175	19.125	Milli-g's	Gate 5/ Vertical Acceleration
11	-5.194	14.378	34.413	1.756	14.485	Milli-g's	Gate 5/ Radial Acceleration
12	-67.488	9.097	94.318	8.53	12.47	Milli-g's	Gate 5/ Transverse Acceleration
13	17.114	17.175	17.227	0.009	17.175	degrees	Gate 7/ Tilt
14	-14.875	21.722	51.957	2.444	21.859	Milli-g's	Gate 7/ Vertical Acceleration
15	5.864	20.084	34.11	1.058	20.112	Milli-g's	Gate 7/ Radial Acceleration
16	-62.313	-11.168	40.647	4.351	11.985	Milli-g's	Gate 7/ Transverse Acceleration

Table 19
Marseilles Dam; Raised Gate Positions; 3 Gate Operation; Vibration Statistics

Data Collected on 07/11/2000 at 2017 hrs
Instrumented Gates: 1, 3, 5, 7
Gate Openings: 0.0, 5.0, 5.0, 7.0

Statistics

Channel No.	Minimum	Average	Maximum	Std. Dev	RMS	Units	Gate No. Sensor
1	-0.129	0.024	0.262	0.051	0.057	degrees	Gate 1/ Tilt
2	10.008	18.409	30.256	1.474	18.468	Milli-g's	Gate 1/ Vertical Acceleration
3	8.26	12.342	16.22	0.799	12.368	Milli-g's	Gate 1/ Radial Acceleration
4	6.835	20.459	35.777	1.998	20.556	Milli-g's	Gate1/ Transverse Acceleration
5	16.975	17.044	17.166	0.01	17.044	degrees	Gate 3/ Tilt
6	-93.225	26.501	138.241	3.667	26.754	Milli-g's	Gate 3/ Vertical Acceleration
7	-18.64	22.234	58.402	1.801	22.306	Milli-g's	Gate 3/ Radial Acceleration
8	-108.74	19.427	113.713	5.108	20.087	Milli-g's	Gate 3/ Transverse Acceleration
9	17.08	17.127	17.186	0.008	17.127	degrees	Gate 5/ Tilt
10	-47.356	18.484	75.366	5.01	19.151	Milli-g's	Gate 5/ Vertical Acceleration
11	-6.277	14.453	34.784	1.73	14.556	Milli-g's	Gate 5/ Radial Acceleration
12	-115.78	8.977	130.526	8.125	12.108	Milli-g's	Gate 5/ Transverse Acceleration
13	21.531	21.585	21.65	0.009	21.585	degrees	Gate 7/ Tilt
14	-39.566	21.677	84.222	4.18	22.076	Milli-g's	Gate 7/ Vertical Acceleration
15	-9.272	20.129	43.167	1.645	20.196	Milli-g's	Gate 7/ Radial Acceleration
16	-122.52	-11.082	79.537	7.669	13.477	Milli-g's	Gate 7/ Transverse Acceleration

Table 20
Marseilles Dam Submerged Gate Positions; No Gates Open; Background Vibration Statistics

Data Collected on 02/7/2000 at 2320 hrs
Instrumented Gates : 1, 3, 5,7
Gate Settings 0, 0, 0, 0

Statistics

Channel No.	Min	Ave	Max	Std Dev	RMS	Units	Gate/Sensor
1	0.292	0.443	0.613	0.013	0.443	Degrees	Gate 1/ Tilt
2	5.918	18.408	31.417	2.878	18.631	Milli-g's	Gate 1/ Vertical Acceleration
3	11.264	17.474	24.3	1.334	17.525	Milli-g's	Gate 1/ Radial Acceleration
4	-6.418	16.107	38.392	4.825	16.814	Milli-g's	Gate1/ Transverse Acceleration
5	0.148	0.277	0.438	0.009	0.277	Degrees	Gate 3/ Tilt
6	14.803	23.998	32.493	1.771	24.063	Milli-g's	Gate 3/ Vertical Acceleration
7	18.759	23.056	27.496	0.924	23.075	Milli-g's	Gate 3/ Radial Acceleration
8	-0.471	12.213	24.102	2.382	12.443	Milli-g's	Gate 3/ Transverse Acceleration
9	0.108	0.187	0.291	0.007	0.188	Degrees	Gate 5/ Tilt
10	-4.039	13.584	31.071	3.317	13.983	Milli-g's	Gate 5/ Vertical Acceleration
11	6.308	12.583	19.417	1.279	12.647	Milli-g's	Gate 5/ Radial Acceleration
12	-13.065	11.618	34.682	4.868	12.596	Milli-g's	Gate 5/ Transverse Acceleration
13	-0.712	-0.515	-0.328	0.006	0.515	Degrees	Gate 7/ Tilt
14	9.631	22.301	34.259	2.644	22.458	Milli-g's	Gate 7/ Vertical Acceleration
15	8.934	14.815	20.232	1.155	14.86	Milli-g's	Gate 7/ Radial Acceleration
16	-34.384	-13.468	6.711	4.564	14.22	Milli-g's	Gate 7/ Transverse Acceleration

Table 21
Marseilles Dam Submerged Gate Positions; 4 Gate Operation; Vibration Statistics

Data Collected on 02/06/2000 at 0225 hrs
Instrumented Gates: 1, 3, 5, 7
Gate Settings: -1.0, -1.0, -1.0, -1.0

Statistics

Channel No.	Min	Ave	Max	Std Dev	RMS	Units	Gate/Sensor
1	-4.835	-4.697	-4.465	0.035	4.697	Degrees	Gate 1/ Tilt
2	-2.495	18.472	38.205	4.475	19.006	Milli-g's	Gate 1/ Vertical Acceleration
3	8.651	17.452	26.162	1.837	17.548	Milli-g's	Gate 1/ Radial Acceleration
4	-17.651	15.979	48.198	6.465	17.237	Milli-g's	Gate1/ Transverse Acceleration
5	-5.454	-5.233	-5.059	0.009	5.233	Degrees	Gate 3/ Tilt
6	8.724	23.868	40.062	3.506	24.124	Milli-g's	Gate 3/ Vertical Acceleration
7	17.383	22.886	28.304	1.226	22.919	Milli-g's	Gate 3/ Radial Acceleration
8	-9.888	11.872	34.638	4.816	12.812	Milli-g's	Gate 3/ Transverse Acceleration
9	-5.08	-5.025	-4.955	0.008	5.025	Degrees	Gate 5/ Tilt
10	-68.428	13.426	110.866	5.606	14.55	Milli-g's	Gate 5/ Vertical Acceleration
11	-37.444	12.385	52.687	1.979	12.542	Milli-g's	Gate 5/ Radial Acceleration
12	-119.59	11.601	174.427	8.078	14.136	Milli-g's	Gate 5/ Transverse Acceleration
13	-4.514	-4.316	-4.217	0.007	4.316	Degrees	Gate 7/ Tilt
14	-29.015	22.155	69.991	3.43	22.419	Milli-g's	Gate 7/ Vertical Acceleration
15	-7	14.554	34.785	1.565	14.638	Milli-g's	Gate 7/ Radial Acceleration
16	-106.41	-13.605	71.005	5.571	14.701	Milli-g's	Gate 7/ Transverse Acceleration

Table 22
Marseilles Dam Submerged Gate Positions; 4 Gate Operation; Vibration Statistics

Data Collected on 02/03/2000 1123 hrs
Instrumented Gates: 1, 3, 5, 7
Gate Settings -1.5, -1.5, -1.5, -1.5

Statistics

Channel No.	Min	Ave	Max	Std Dev	RMS	Units	Gate/Sensor
1	-5.898	-5.784	-5.597	0.018	5.784	Degrees	Gate 1/ Tilt
2	-3.365	18.462	40.091	4.311	18.959	Milli-g's	Gate 1/ Vertical Acceleration
3	10.032	17.332	25.561	1.68	17.413	Milli-g's	Gate 1/ Radial Acceleration
4	-14.055	16.068	45.316	6.175	17.214	Milli-g's	Gate1/ Transverse Acceleration
5	-6.356	-6.234	-6.11	0.009	6.234	Degrees	Gate 3/ Tilt
6	3.465	23.928	45.624	3.911	24.246	Milli-g's	Gate 3/ Vertical Acceleration
7	16.186	22.967	30.129	1.409	23.01	Milli-g's	Gate 3/ Radial Acceleration
8	-15.627	12.225	41.759	5.021	13.215	Milli-g's	Gate 3/ Transverse Acceleration
9	-6.337	-6.276	-6.164	0.01	6.276	Degrees	Gate 5/ Tilt
10	-19.802	13.504	44.327	5.723	14.667	Milli-g's	Gate 5/ Vertical Acceleration
11	-0.928	12.496	29.188	2.162	12.681	Milli-g's	Gate 5/ Radial Acceleration
12	-32.266	11.507	55.822	7.696	13.843	Milli-g's	Gate 5/ Transverse Acceleration
13	-5.685	-5.616	-5.561	0.007	5.616	Degrees	Gate 7/ Tilt
14	-13.741	22.162	59.778	3.855	22.494	Milli-g's	Gate 7/ Vertical Acceleration
15	-4.145	14.658	34.57	1.871	14.777	Milli-g's	Gate 7/ Radial Acceleration
16	-77.205	-13.621	54.612	5.671	14.754	Milli-g's	Gate 7/ Transverse Acceleration

Table 23
Marseilles Dam Submerged Gate Positions; 4 Gate Operation; Vibration Statistics

Data Collected on 02/14/2000 at 0130 hrs
Instrumented Gates: 1, 3, 5, 7
Gate Settings: -1.5, -2.0, -2.0, -2.0

	Statistic						
Channel No.	**Min**	**Ave**	**Max**	**Std Dev**	**RMS**	**Units**	**Gate/Sensor**
1	-5.988	-5.85	-5.657	0.011	5.85	Degrees	Gate 1/ Tilt
2	-5.628	18.459	39.888	4.414	18.98	Milli-g's	Gate 1/ Vertical Acceleration
3	9.672	17.573	26.102	1.725	17.657	Milli-g's	Gate 1/ Radial Acceleration
4	-14.085	16.105	48.733	6.375	17.32	Milli-g's	Gate1/ Transverse Acceleration
5	-7.557	-7.467	-7.397	0.01	7.467	Degrees	Gate 3/ Tilt
6	2.796	23.997	46.172	3.983	24.325	Milli-g's	Gate 3/ Vertical Acceleration
7	15.708	23.092	32.283	1.428	23.136	Milli-g's	Gate 3/ Radial Acceleration
8	-20.159	12.099	41.906	5.637	13.348	Milli-g's	Gate 3/ Transverse Acceleration
9	-7.73	-7.648	-7.595	0.008	7.648	Degrees	Gate 5/ Tilt
10	-20.942	13.425	46.021	5.583	14.54	Milli-g's	Gate 5/ Vertical Acceleration
11	1.113	12.425	24.736	1.971	12.58	Milli-g's	Gate 5/ Radial Acceleration
12	-25.813	11.554	52.643	8.077	14.097	Milli-g's	Gate 5/ Transverse Acceleration
13	-8.267	-8.204	-8.067	0.008	8.204	Degrees	Gate 7/ Tilt
14	2.699	22.221	41.927	4.07	22.591	Milli-g's	Gate 7/ Vertical Acceleration
15	5.465	14.747	23.272	1.871	14.865	Milli-g's	Gate 7/ Radial Acceleration
16	-45.984	-13.539	20.292	6.11	14.854	Milli-g's	Gate 7/ Transverse Acceleration

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14. ABSTRACT
In 1998, Marseilles Dam, IL, was approved for inclusion in the Monitoring Completed Navigation Projects Program. The object of the monitoring plan for Marseilles Dam was to determine if the dam gates were performing (both functionally and structurally) as predicted by model studies used in the project design. Monitoring of the dam was conducted during the period June 1999 through June 2001. Elements of the monitoring program included a Life-Cycle Cost analysis. Vibration data obtained from instruments on the gates appeared to validate a previous three-dimensional model study. A videotape analysis used to analyze gate efficiency for ice passage was successful. Trends in vibration data correlated well with model data. The Marseilles Dam submersible gates are currently functioning vibration-free and are in good structural condition. The Remote Operation System eliminated the need for 24-hr staffing of the dam and provides for operation of the dam at the lock, (2.4 mi) away and allows for relatively easy maintenance of strict pool tolerances. The submersible gates provide a safer mechanism for passing ice at lower discharged during winter conditions.

15. SUBJECT TERMS

Ice passage	Monitoring Completed Navigation Projects Program
Life-Cycle Cost analysis	Submergible gates
Marsseilles Dam, IL	Vibrations

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