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Physical Data Collection
for Lock Wall Deterioration

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Preface

The Waterways Experiment Station of the U.S. Army Engineer Research and Development Center (ERDC) was tasked by the Engineering Work Group for the Upper Mississippi River-Illinois Waterways Navigation Study to collect physical data for use in a reliability model for the deterioration of concrete in lock walls due to freeze-thaw and abrasion. This work effort was accomplished by Mr. Robert C. Patev, formerly of the Computer-Aided Engineering Division (CAED), Information Technology Laboratory (ITL), ERDC, with assistance from Dr. Mary Ann Leggett, CAED, ITL, ERDC, and Mr. Ron Wooley, Navigation Branch (NB), Waterways Division (WD), Hydraulics Laboratory (now the Coastal and Hydraulics Laboratory), ERDC. The report was prepared and written by Mr. Patev and Mr. Paul F. Mlakar and Mr. Larry M. Bryant, formerly of JAYCOR. The work was performed under the general supervision of Mr. H. Wayne Jones, Chief, CAED, ITL, and Dr. N. Radhakrishnan, former Director, ITL. Mr. Timothy D. Ables is Acting Director, ITL.

At the time of publication of this report, Director of ERDC was Dr. James R. Houston. Commander was COL James S. Weller, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units by applying the following factors as follows:

Multiply	By	To Obtain
feet	0.3048	meters
inches	0.0254	millimeters
miles (U.S. statute)	1.609347	kilometers

1 Introduction

The collection of physical data from lock chambers was required to properly develop the concrete deterioration model used for the Upper Mississippi River–Illinois Waterways Navigation Study (UMR-IWW). Statistical data needed for the model were collected from the measurements of concrete loss from four lock chambers and the time-lapse videotape monitoring of three lock chambers. Each item was crucial in developing the proper constraints to be used in the deterioration model.

Since the loss of concrete in lock chambers has not been typically measured during concrete inspections, it was necessary to measure the amount of loss attributable to freeze-thaw and abrasion. These measurements of loss would be the basis for developing a function that could predict the shape of concrete loss centered at the elevation of maximum loss. This loss of concrete from lock walls creates uneven surfaces that cause the exposure of embedded metals such as line hooks, check posts, or ladders that may cause barges to be impeded in transiting the lock or during lock filling or emptying.

The time-lapse videotape monitoring assisted with determining statistical values of previously unknown or estimated variables that were used in the UMR-IWW model. Since the field collection of physical data is often an expensive and time-consuming task, time-lapse monitoring was implemented to assist with physically cataloging hours of field data at a minimal cost. The collected data characterized the values for the number of impacts on lock walls that occur during a lockage, the velocity of a barge in different locations in a lock chamber, and the fluctuation of chamber pools with time. The data were used as a basis in the successful implementation of the model since the constraints of the model were parameters that were directly input as variables or constants in the probabilistic concrete deterioration model.

2 Vertical Surface Losses in Lock Chambers

Introduction

Loss of concrete from lock walls may delay tows in transiting the lock by creating uneven surfaces that may cause a barge to "hangup" during lock filling or emptying. This effect may be more significant than any structural deficiencies and historically is often the primary motivation for resurfacing of lock walls. A model for assessing lock wall vertical surfaces for this operational problem is developed in the following paragraphs.

Previous Study

The basic model for vertical surfaces was developed in a previous study.[1] In that study, the barge geometry was totally characterized by the radius, R_1, at the barge corner, which is assumed to be small relative to the concavity of the lock wall. The shape of the deteriorated surface was approximated by a parabola with zero concrete loss near the top and bottom of the lock wall with maximum loss near midpool, as illustrated in Figure 1. This deterioration function was

$$x = \alpha y^n \tag{1}$$

where:

x = horizontal component of concrete loss

α = constant reflecting *magnitude* of concrete loss

y = vertical distance measured from center of surface

n = exponent reflecting the *shape* (concavity) of the loss

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[1] Larry M. Bryant and Paul F. Mlakar. (1991). "Predicting concrete service life in cases of deterioration due to freezing and thawing," Technical Report REMR-CS-35, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

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a. DETERIORATED SURFACE   b. FREE BODY DIAGRAM
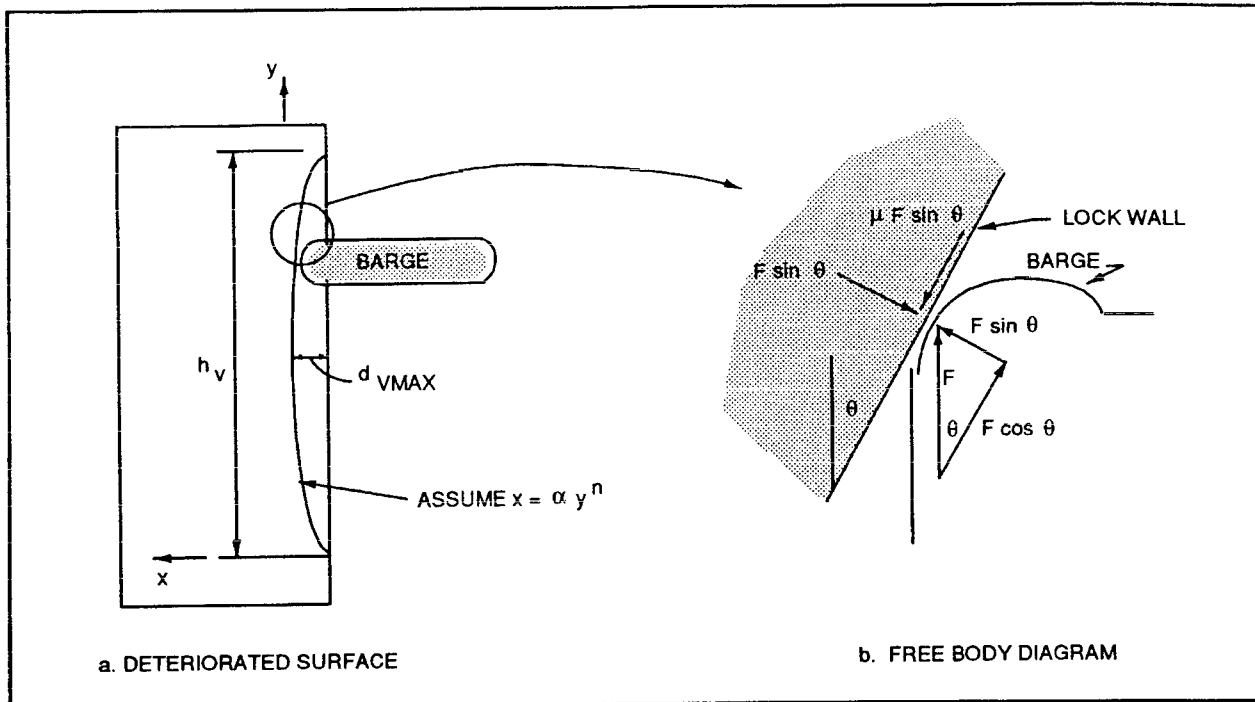
Figure 1. Vertical surfaces model (from Bryant and Mlakar 1991)[1]

For a symmetric deterioration function with a maximum concrete loss of d_{vmax} and a total height of deteriorated surface of h_v, then

$$x = \frac{d_{vmax}}{\left(\frac{h_v}{2}\right)^n} \times y^n \qquad (2)$$

With these geometric parameters, the model considered the frictional force developed between the rounded corner of the barge and the concave surface of the deteriorated lock wall.

For a resultant vertical force, F, on the barge due to filling of the chamber, the equal and opposite normal forces developed between the barge and the lock wall are $F(\sin \theta)$, where θ is the angle of the lock wall surface with the vertical. The frictional force developed is thus $\mu F(\sin \theta)$, where μ is the apparent coefficient of friction between the barge and the lock wall. If this friction force is greater than the collinear acting force, $F(\cos \theta)$, the barge will hang up on the wall, creating an operational problem. Therefore, factor of safety against this operational problem may be defined as

$$F = \frac{F(\cos\theta)}{\mu F(\sin\theta)} = \frac{1}{\mu(\tan\theta)} \qquad (3)$$

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[1] Ibid.

where

$$tan\theta = ny^{n-1} \frac{d_{v\,max}}{h_v^n}$$ (4)

The minimum factor of safety occurs for maximum angle, θ, which occurs for $y = h_v/2$, i.e.,

$$F = \frac{h_v}{2n\mu d_{v\,max}}$$ (5)

This earlier model proved useful and indicated promise with subsequent improvement. In fact, a recommendation from the previous study by Bryant and Mlakar was made to refine the (dimensional stability) model for the lock wall limit state by investigating and calibrating to more field structures. This recommendation was addressed in the development of the refined model used in this study.

Refinement of Model

In the current study, the model has been improved based on a more extensive investigation of actual concrete loss for lock wall vertical surfaces. Using detailed measurements from two locks, the description of the concrete loss (as a function of wall elevation) has been further generalized. The measurements from these two locks were scrutinized to determine any underlying pattern of deterioration that could be generalized for other locations. From this investigation, several analytical functions for the loss function were considered and evaluated using linear regression. The most promising of these functions, that also could be rationally explained from physical phenomena, was generalized for use in the loss model.

Loss Measurements Data

Measurements of the vertical faces of lock chambers were made and evaluated to examine the patterns of deterioration of lock wall concrete. The measurements were taken at locks on different river systems and under distinct winter operation patterns to investigate the range of deterioration that may occur. The locks selected for the study were Lockport Lock and Dam on the Chicago Ship and Sanitary Canal, Point Marion Lock and Dam on the Monongahela River, and Locks and Dams 13 and 15 on the Mississippi River (Appendixes A, B, C, and D, respectively). Two types of deterioration patterns were exhibited at these locks. They were loss concentrated around the upper pool region and evenly distributed losses around the lower pool area.

The loss around upper pool levels was illustrated well at Lockport Lock and Dam and Point Marion Lock and Dam. This loss pattern can be

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attributed to the fact that the locks are in service year round at times when freeze-thaw and abrasion can occur simultaneously. The loss around lower pool is characterized by Locks and Dams 13 and 15. This pattern is attributable to lack of operation during the winter months. The locks are generally out of service from late December to early March, and their chamber pools are left at lower pool elevations. The goal of these measurements was to get an overall picture of loss in a range of lock chambers to assist with developing a function to closely represent the true loss. This function will be used directly in the model to determine concrete deterioration of lock walls due to freeze-thaw and abrasion.

Lockport Lock - Chicago Ship and Sanitary Canal

Lockport Lock was constructed in 1933 and exhibits severe loss of concrete from the vertical surfaces. The lock hardware was rehabilitated in July 1984, and the lock walls were scheduled for resurfacing in July 1995. The lock wall vertical geometry was measured in 1984 when the lock was completely dewatered. These measurements were made using a plumb line along both the land wall (even monolith numbers) and river wall (odd monolith numbers). Data were taken at 1-ft increments in elevation at centers of selected monoliths and at or near selected joints. Similar measurements were made in January 1993 at the same locations as in 1984 to provide additional loss data and an indication of the time dependence of the concrete loss.

Typically, the deterioration along the land wall is generally worse than that along the river wall. The higher losses on the land wall are due to increased impacts resulting from the location of the floating mooring bits which influence tow operator locking preferences for entry and exit at the lock. Maximum losses were about 10 in. in 1984 and about 11 in. in 1993 in the land wall. Maximum river wall losses were about 4 and 5 in., respectively, in 1984 and 1993. Losses are quite uneven with elevation and between monoliths. The most severe losses in most monoliths occur near upper pool (el 578 ft)[1] in most cases.

All of the data from both sets of measurements are presented in Figures 2 through 9. The losses measured in 1984 at land wall monoliths are plotted versus elevation in Figure 2. Measurements of concrete loss along river wall monoliths in 1984 are shown in Figure 3. Figures 4 and 5 present 1984 loss measurements at joints along the land wall and river wall, respectively. Similar measurements made in 1993 are presented in Figures 6 through 9 for land wall and river wall monoliths and joints.

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[1]   Unless otherwise stated, all elevations (el) are stated in feet as referred to in National Geodetic Vertical Datum (NGVD) of 1929.
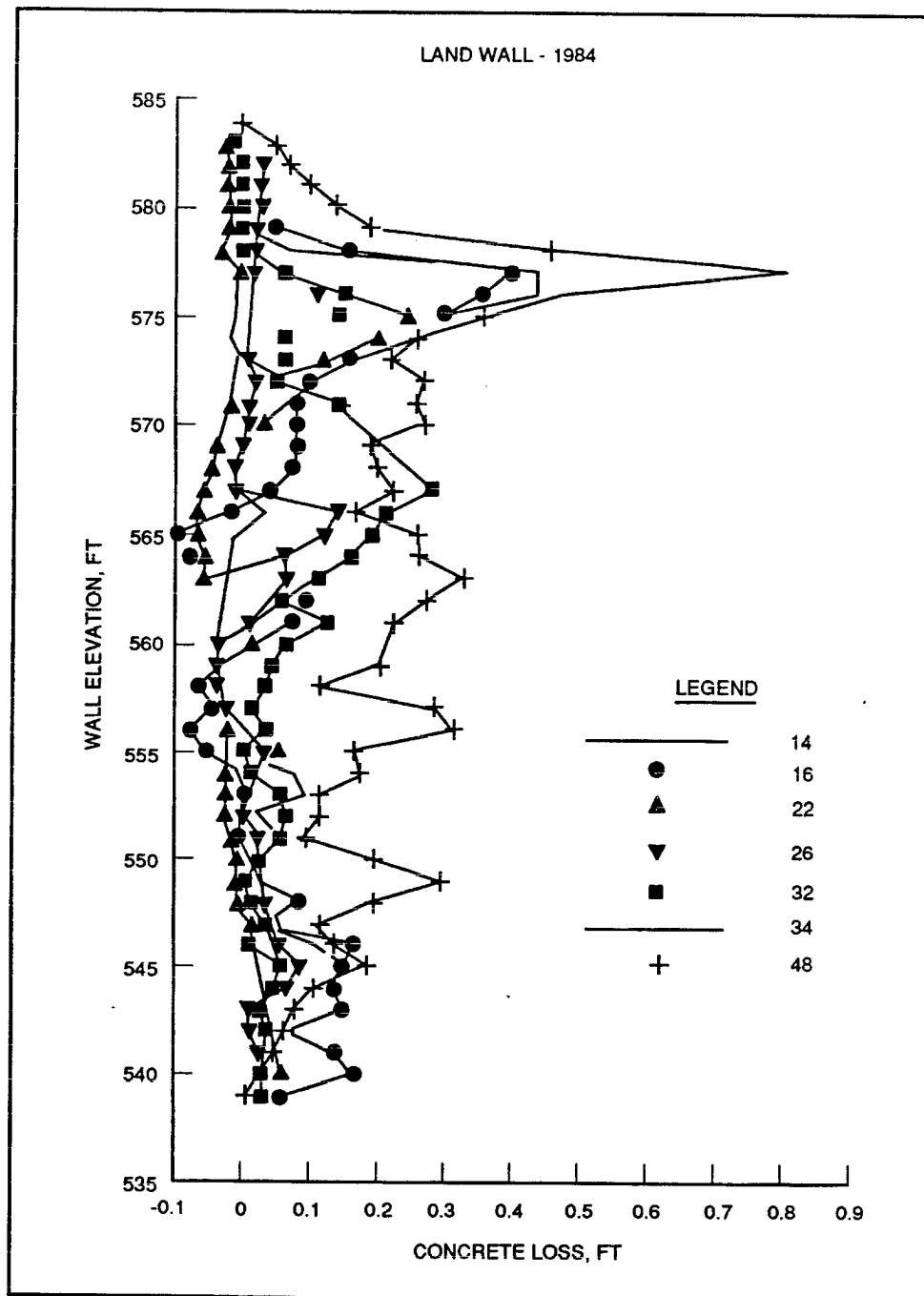
Figure 2. Loss measurements for Lockport land wall monoliths, 1984
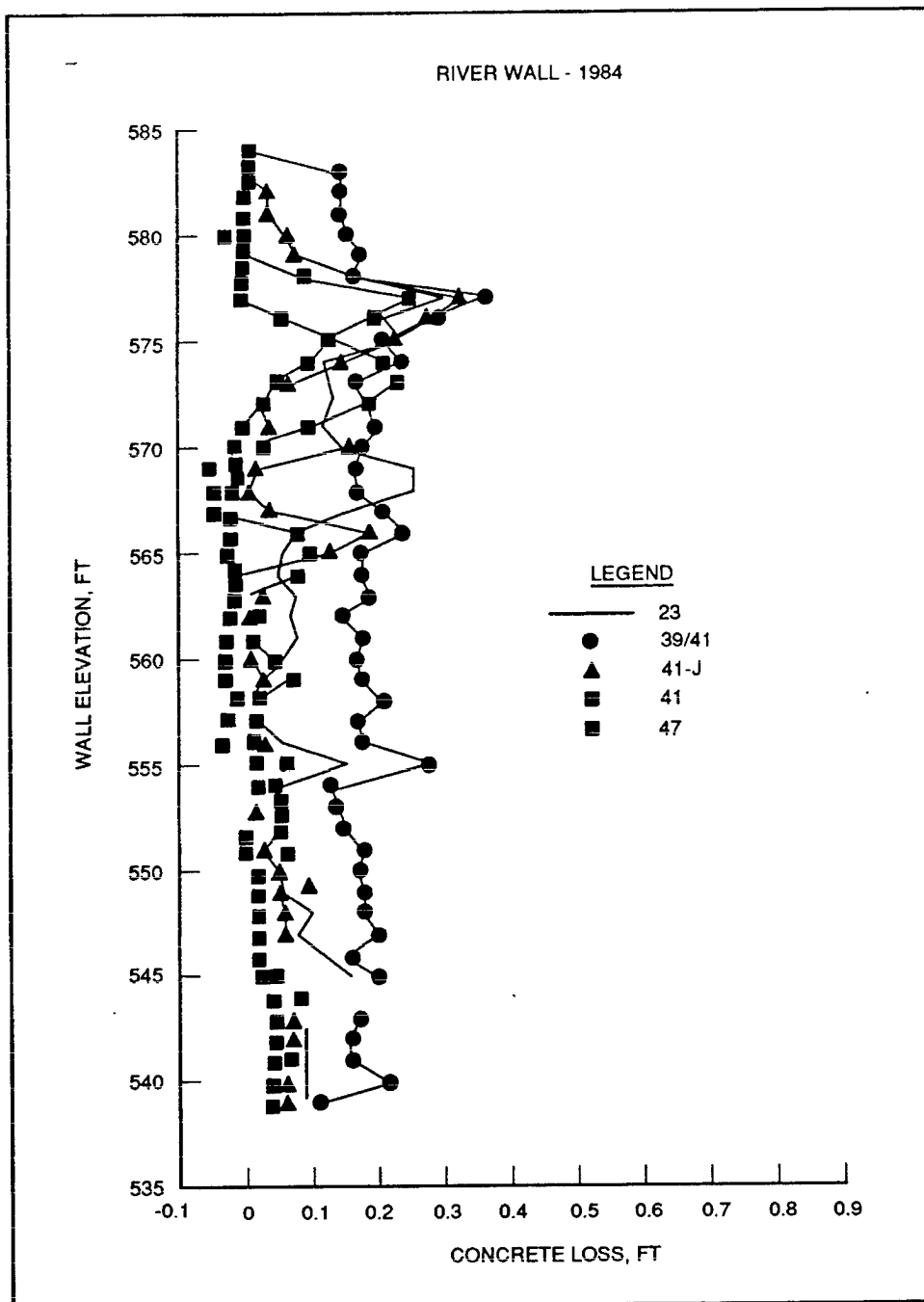
Figure 3. Loss measurements for Lockport river wall monoliths, 1984
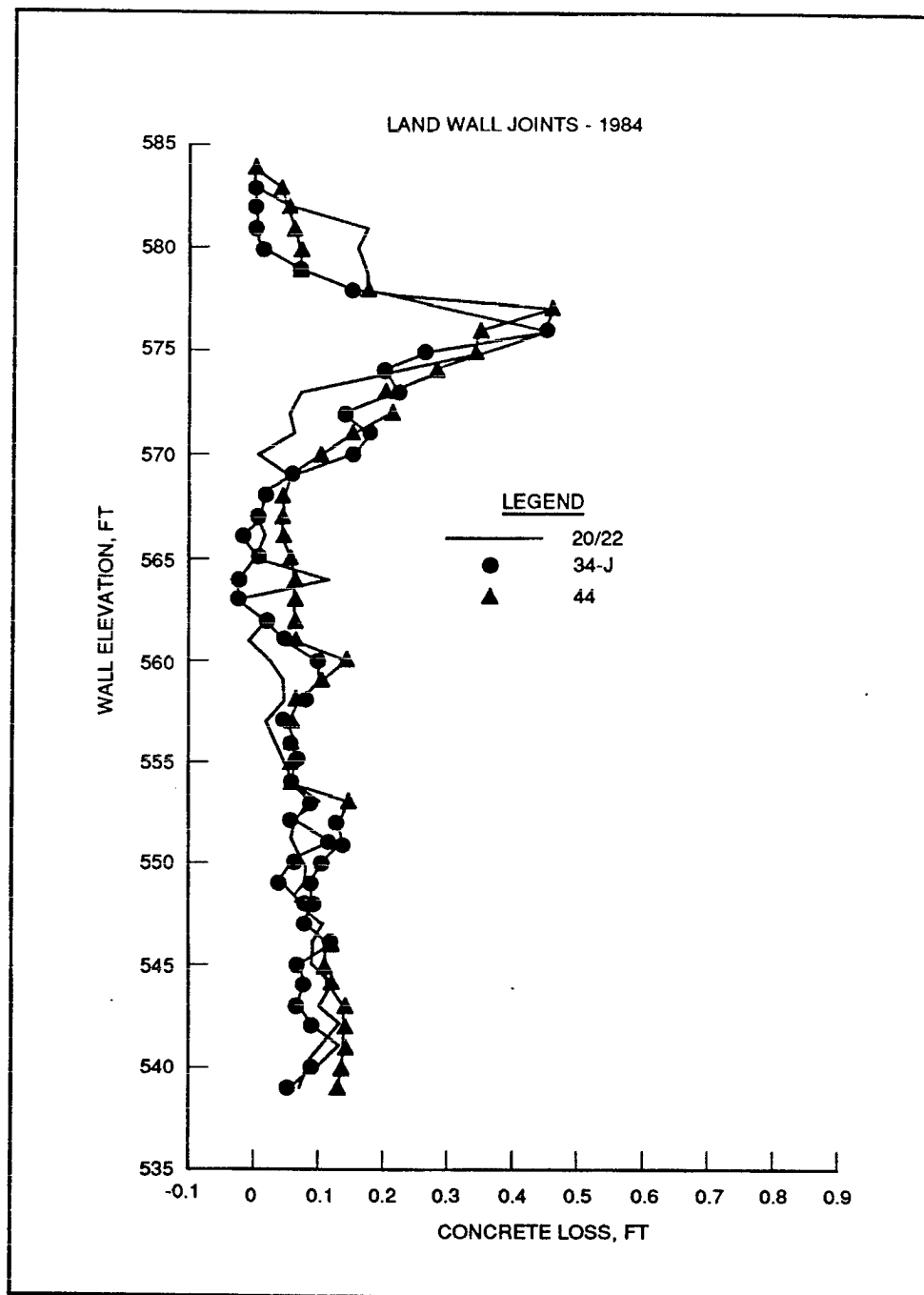
Figure 4. Loss measurements for Lockport land wall joints, 1984
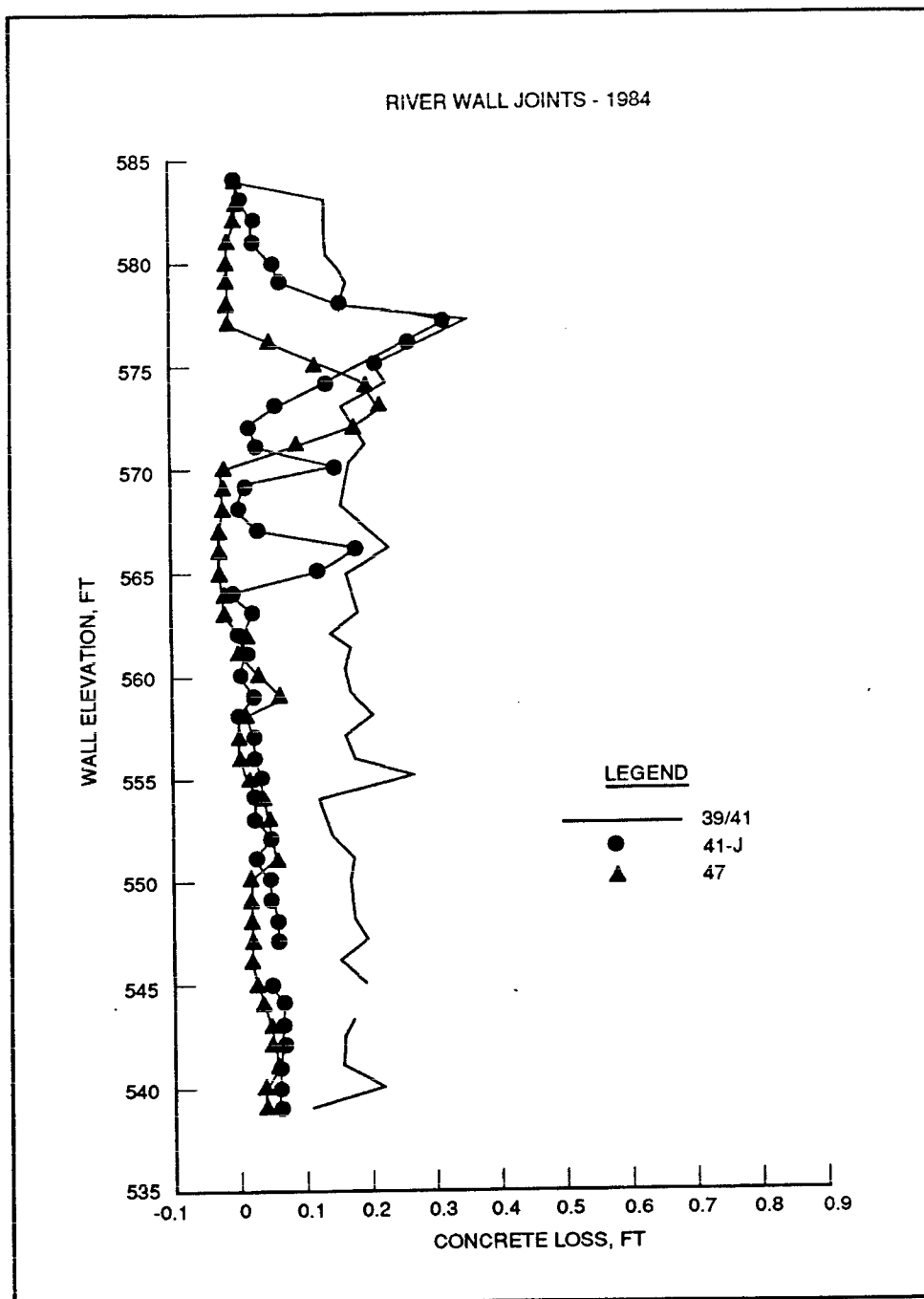
Figure 5. Loss measurements for Lockport river wall joints, 1984
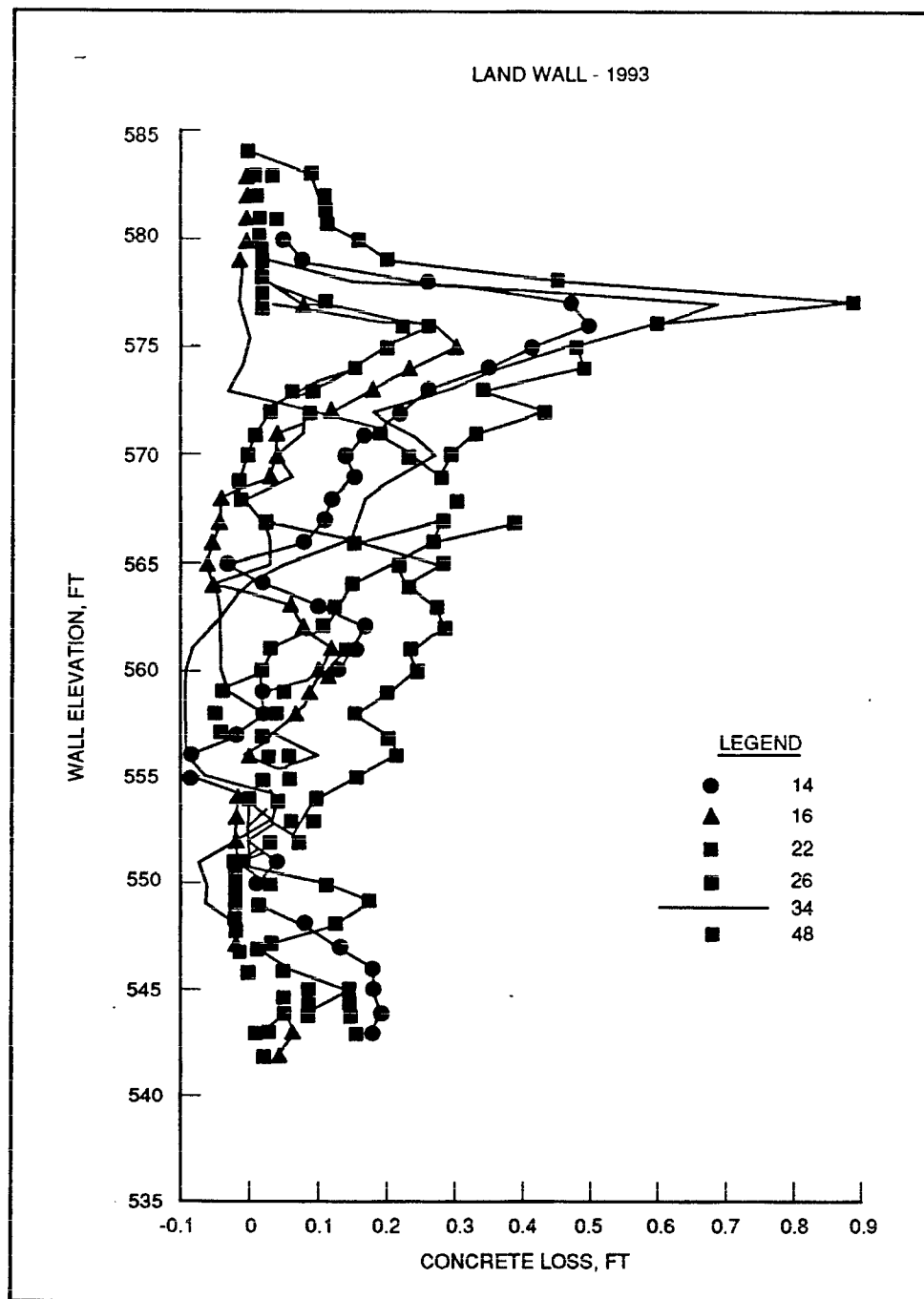
Figure 6. Loss measurements for Lockport land wall monoliths, 1993
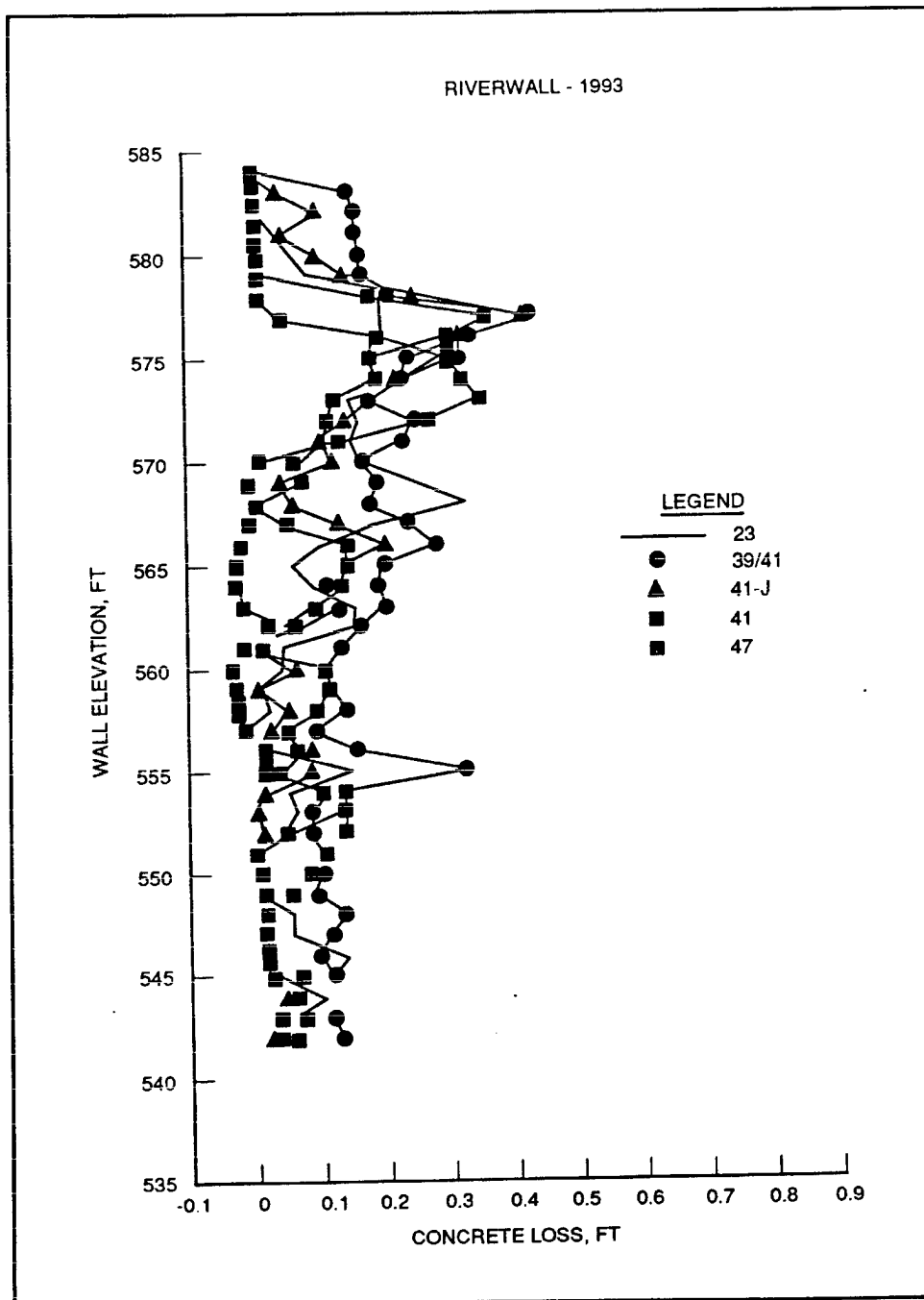
Figure 7. Loss measurements for Lockport river wall monoliths, 1993
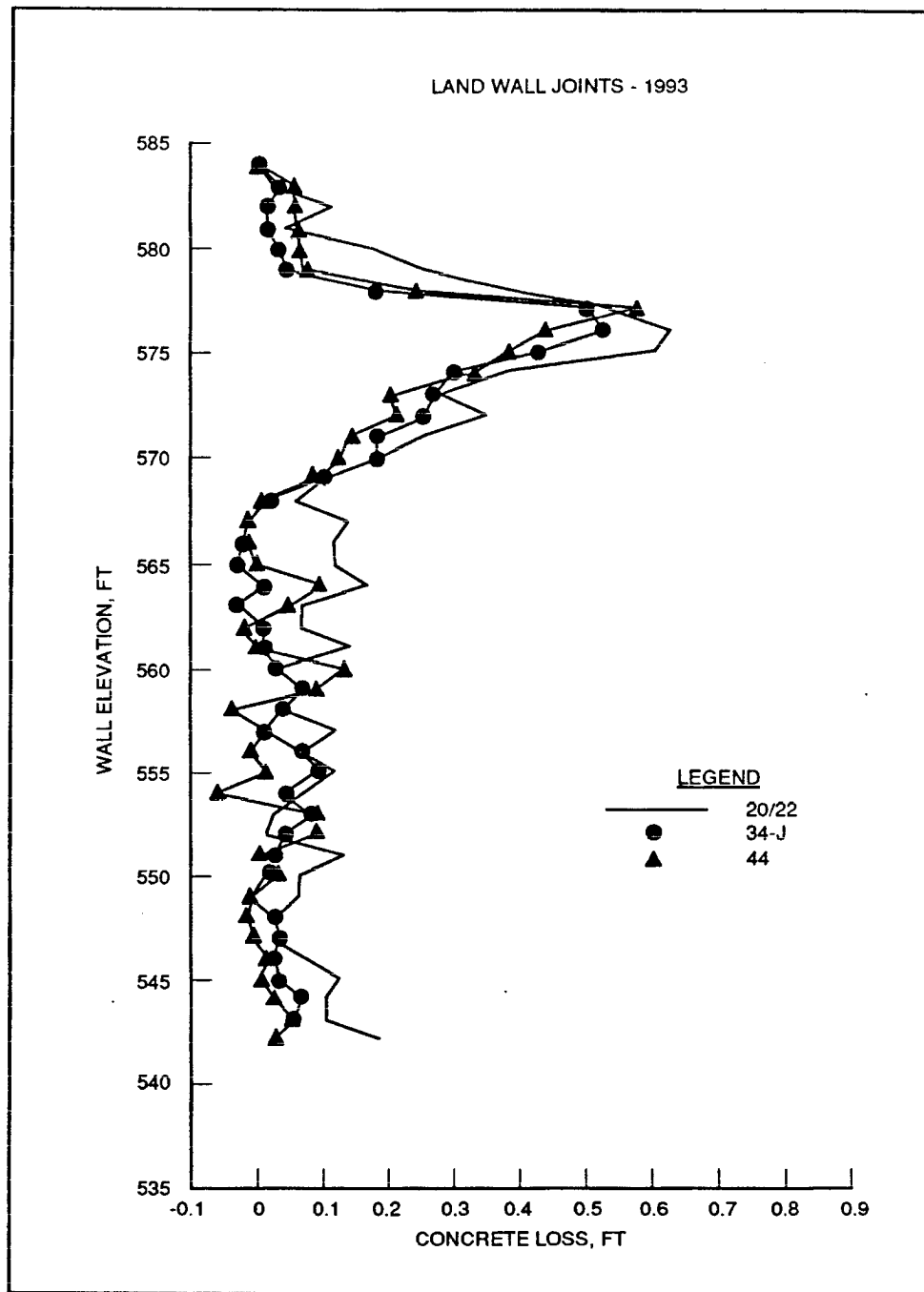
Figure 8. Loss measurements for Lockport land wall joints, 1993
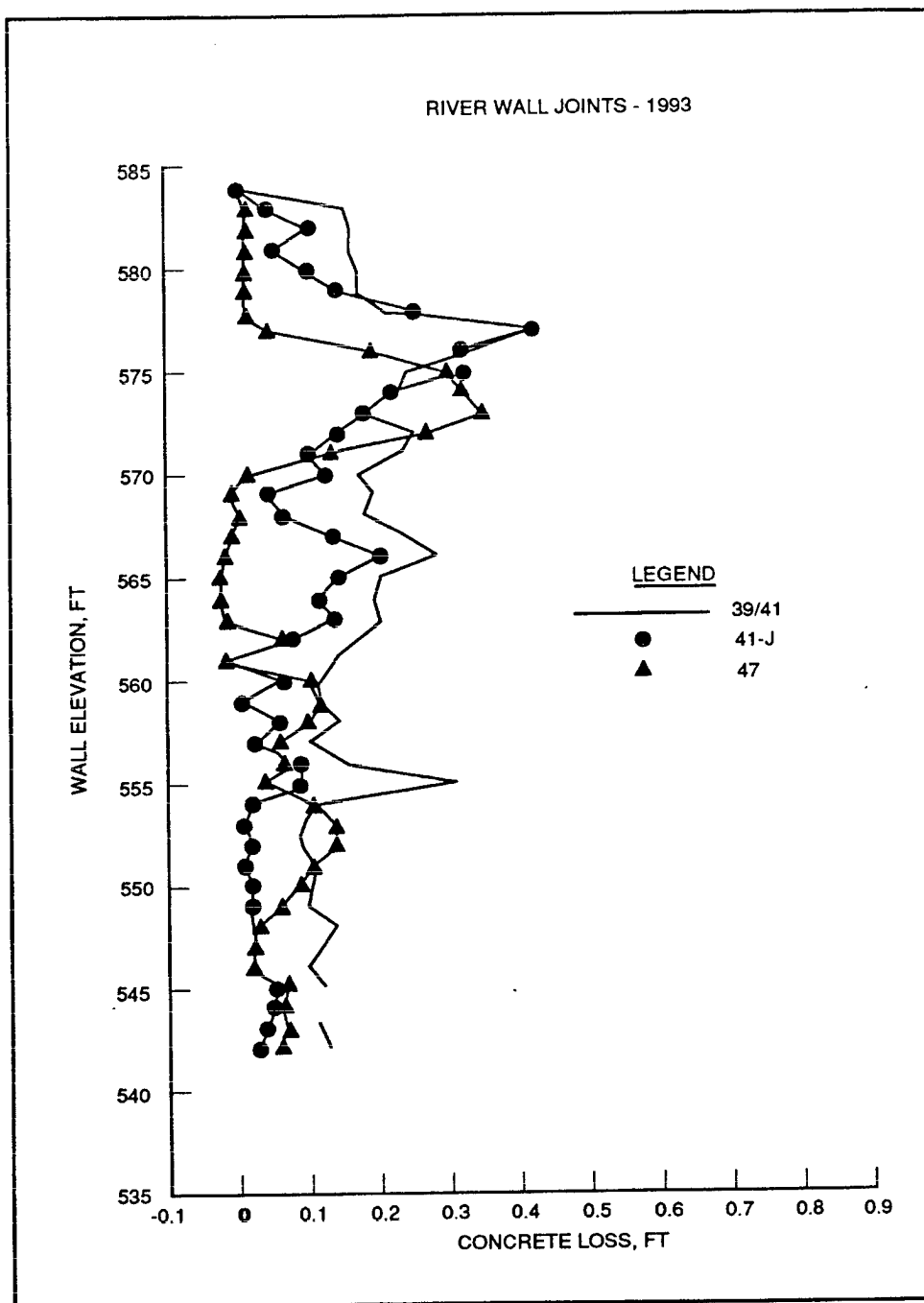
Figure 9. Loss measurements for Lockport river wall joints, 1993

Point Marion Lock and Dam - Monongahela River

Point Marion Lock and Dam was constructed in the 1930's and, like Lockport, has suffered measurable concrete loss from the lock wall vertical surfaces. In fact, a shotcrete rehabilitation of the chamber was conducted in the late 1950's. Measurements made in September 1993 confirmed that much of the 3-in.-thick shotcrete layer had debonded and fallen off the vertical walls. The measurements were made at 1-ft el increments at several locations along individual selected monoliths on both the land and river walls. Losses along the selected monoliths range up to about 12 in., with land wall losses generally higher than those on the river wall. These losses are attributable to the preference of mooring the tows on the land side of the chamber. The losses are generally higher in the upper regions of the walls near upper pool el 793.

The data from these measurements are presented for various monoliths in Figures 10 through 14. Specifically, measurements are depicted for different positions along land wall monoliths 15, 19, and 21 and river wall monoliths 5 and 11 in these figures.

Lock and Dam 13 - Mississippi River

Lock and Dam 13 (Figure 15) was operational in 1939. The lock chamber has suffered sporadic loss of concrete from the lock wall surfaces. Measurements of the lock chamber taken in October 1994 indicated that a majority of the vertical surfaces were in excellent condition except at monolith and construction joints and around the gates. These patterns of deterioration are generally exhibited at most locks because these areas are subjected to an increased number of barge impacts. Lock 13 underwent complete vertical wall replacement during the winter months of 1994.

Measurements were taken at a total of five monoliths on both the intermediate and landside walls. The maximum losses ranged from 1 to 1.5 in. and were concentrated near lower pool. This loss can be attributable to abrasion from a concentration of barge impacts distributed over the lower pool level during most of the year. The lock is not typically subjected to any freeze-thaw except at the lower pool elevations since the lock is not in service from late December to early March, and the lock chamber is left at lower pool elevation. Lock 13 also does not flush ice during winter months because of the submersible gates on the dams which allow ice to flow over the dam.

Lock and Dam 15 - Mississippi River

Lock and Dam 15 (Figure 16), operational since 1934, was selected because it is one of the few locks that exhibits little or no loss of the vertical surfaces. Loss measurements were taken during October 1994 on a total of five land and intermediate monolith walls. All of the vertical surfaces appeared solid and in excellent shape, which may be attributable to admixtures in the concrete during construction. Any substantial losses which
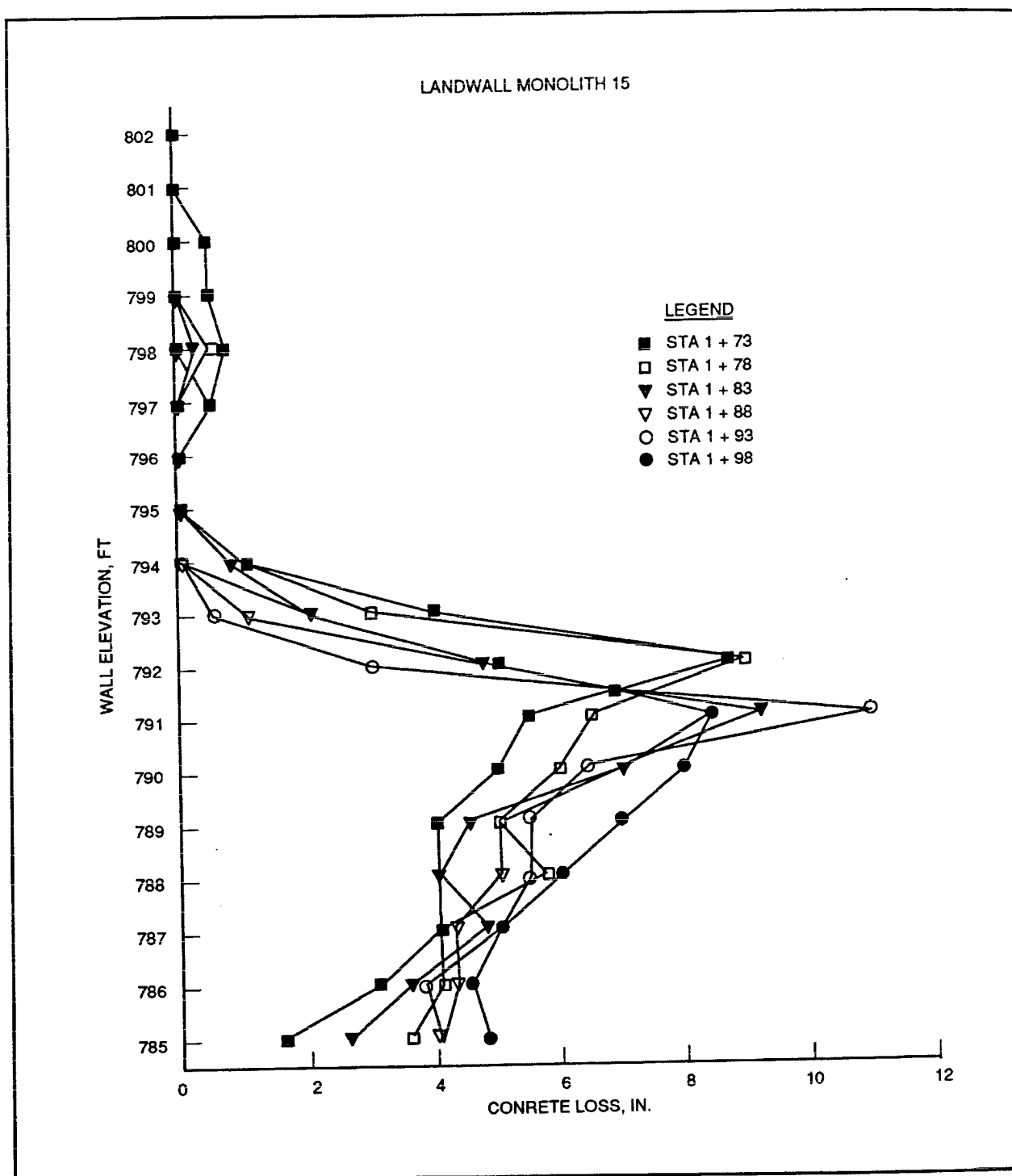
Figure 10. Loss measurements for Point Marion Lock and Dam land wall - Monolith 15
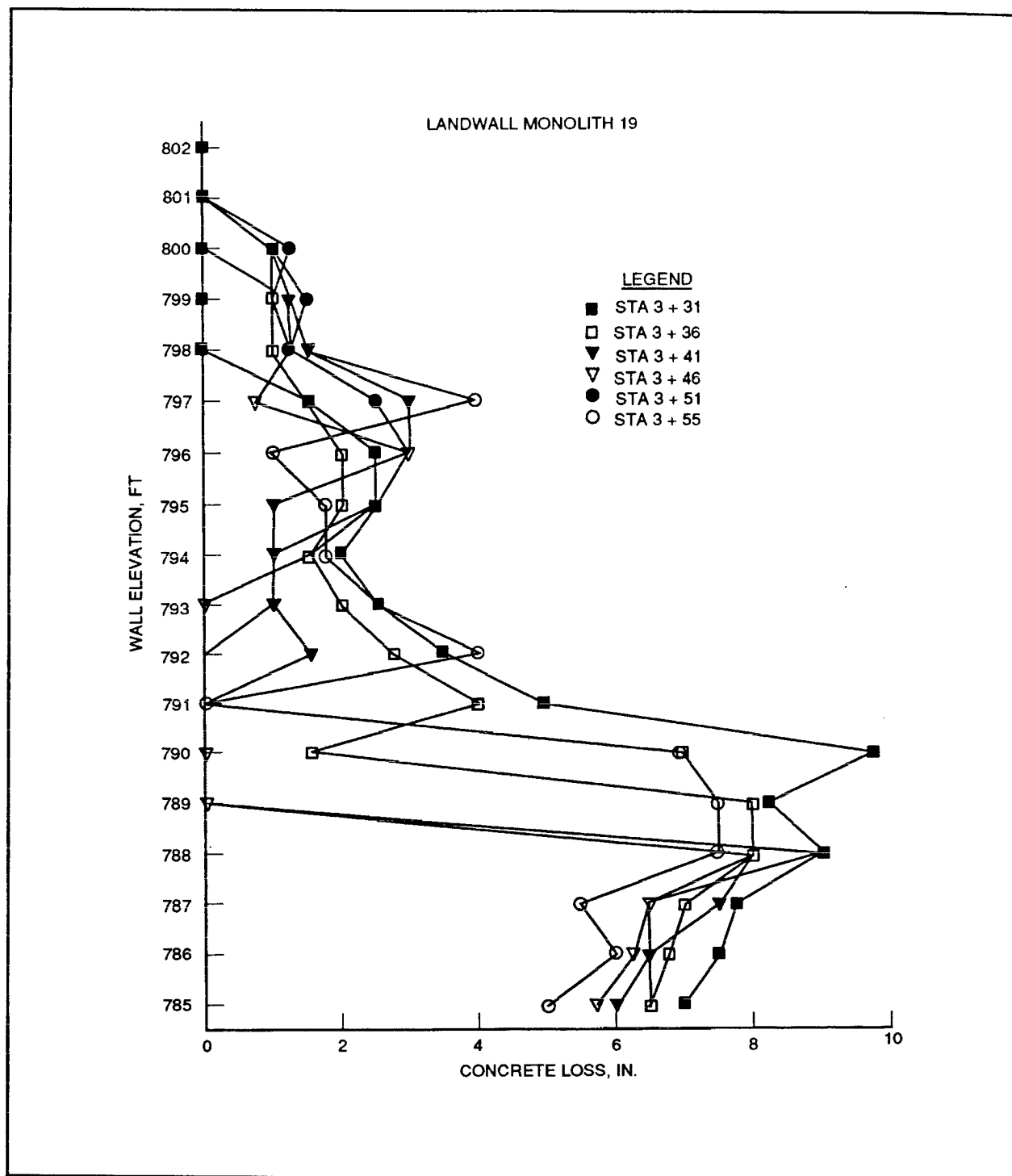
Figure 11. Loss measurements for Point Marion Lock and Dam land wall - Monolith 19
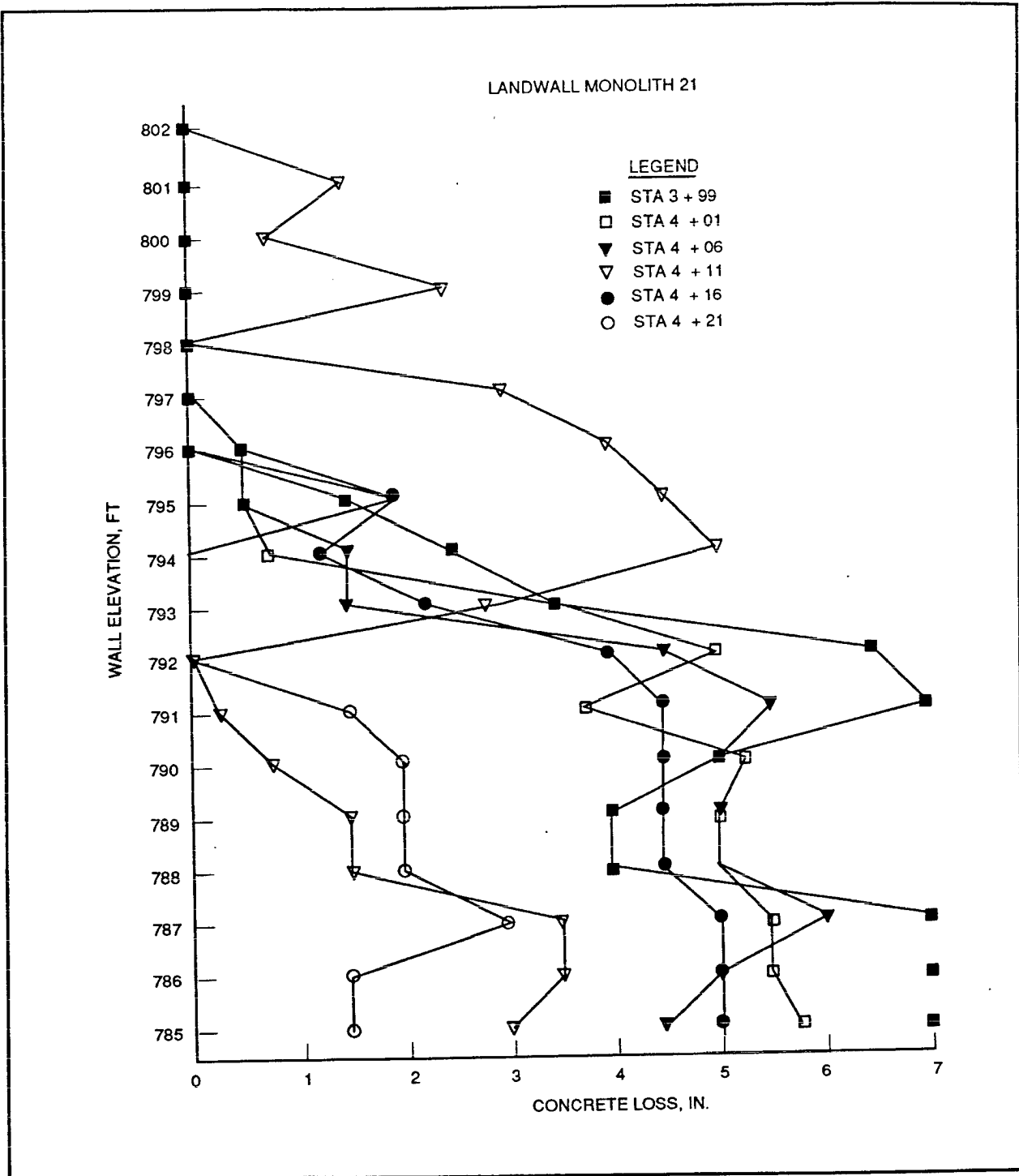
Figure 12. Loss measurements for Point Marion Lock and Dam land wall - Monolith 21
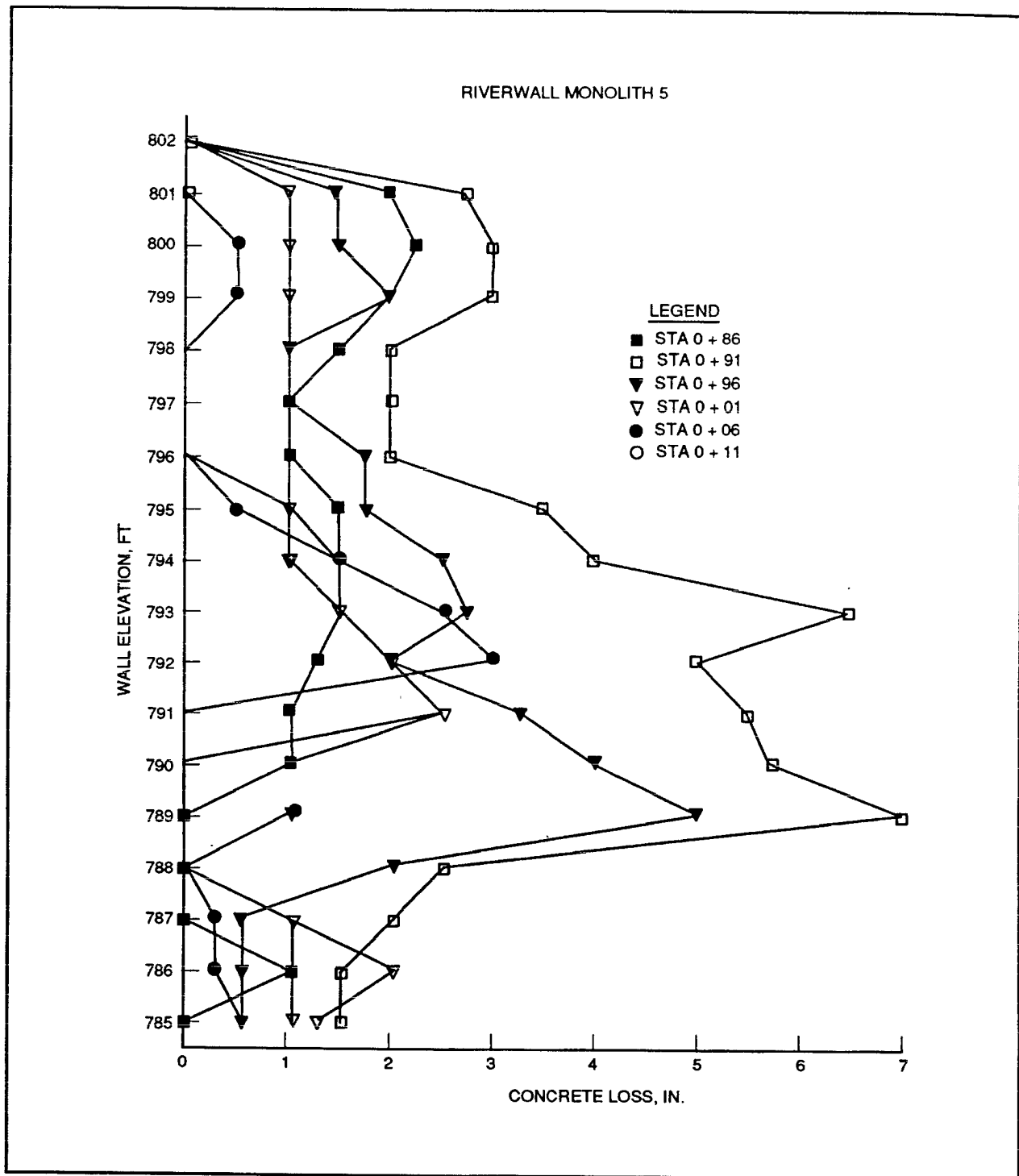
Figure 13. Loss measurements for Point Marion Lock and Dam river wall - Monolith 5
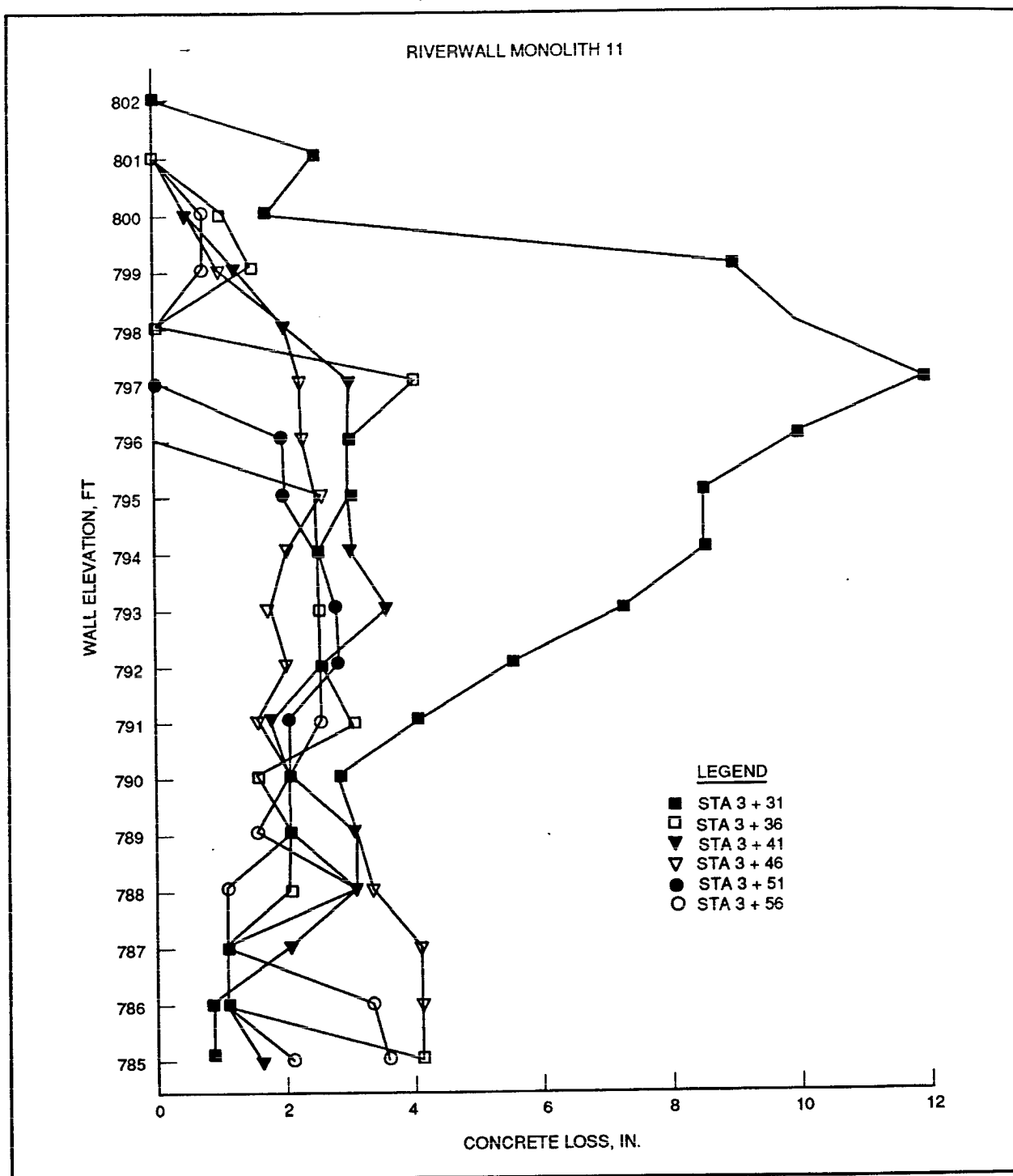
Figure 14. Loss measurements for Point Marion Lock and Dam river wall - Monolith 11

Lock and Dam 13 - Monolith 38
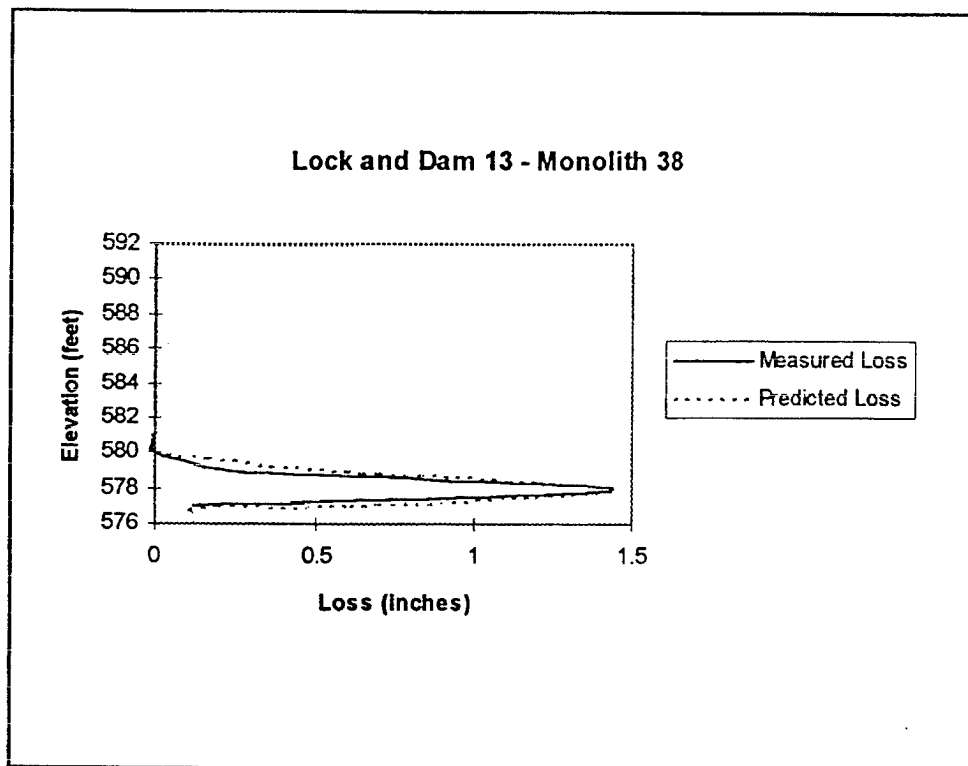
Figure 15. Loss measurements for Lock and Dam 13 - Monolith 38

Lock and Dam 15 - Monolith 13
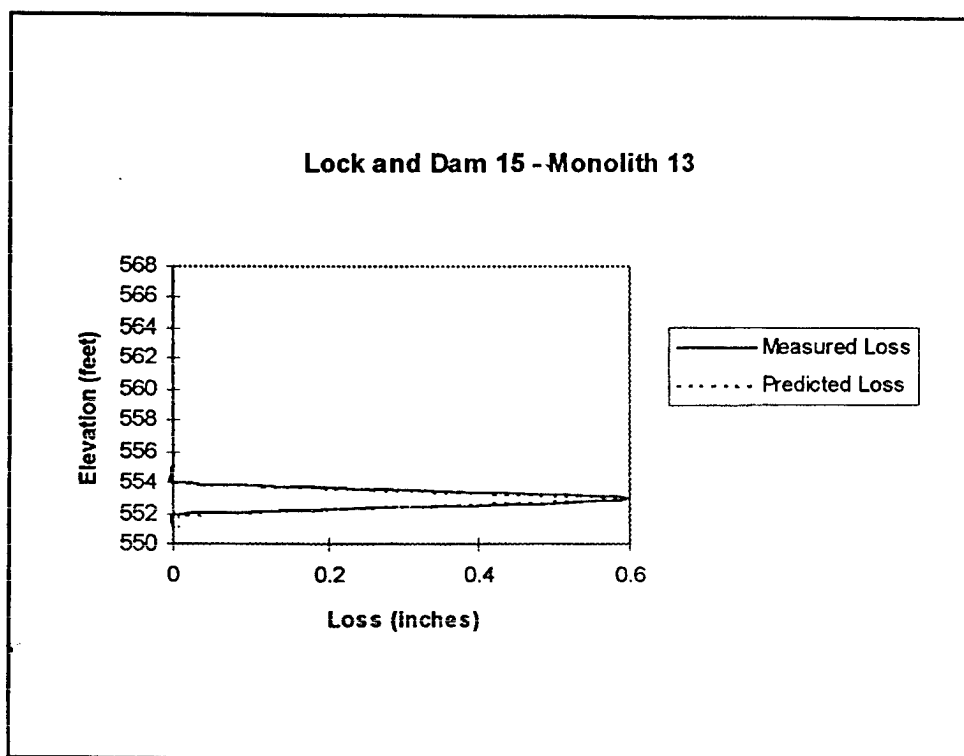
Figure 16. Loss measurements for Lock and Dam 15 - Monolith 13

were concentrated around the gates and construction joints were rehabili-
tated during the winter of 1993.

The losses were measured for the monoliths considered to be in the
worst shape. Losses ranged from of 0.3 to 0.7 in. Similar to Lock 13, the
losses were distributed around a zone at lower pool. This can also be at-
tributed to the fact that the winter operation allows for the shutdown of
the lock to river traffic and the chamber pool is left at lower pool level.

Data Tendencies and Observations

The first look at the data presented in the previous paragraphs leads to
several general conclusions regarding any underlying tendencies of con-
crete loss. First, the observed loss for these lock walls does not follow the
parabolic shape assumed in the prior study. The current data indicate
more localized regions of high loss, generally not centered near midpool.
In fact, where any observable pattern of deterioration exists in a set of
measurements, maximum losses tend to occur near upper pool elevation
with lesser losses at other elevations. There appears to be a general ten-
dency for maximum loss near upper pool, another smaller maxima near
lower pool, with lesser losses between pool levels decreasing to little or
none near the wall top and bottom.

These observations of the patterns of deterioration not only follow
from the data but satisfy plausible explanations of physical phenomena
that may lead to the loss. Specifically, the loss of concrete is attributed to
the combined effects of freeze-thaw deterioration and abrasion from tran-
siting tows. From the abrasion side of this equation, it is obvious that
more abrasion should be expected near the two pool elevations since these
are the levels at which tows enter and exit the lock. Although rubbing of
the walls by the tow is evident during chamber filling and emptying, the
resulting forces and abrasion damage should be significantly less in this re-
gion due to the much smaller barge velocities involved.

Previous studies have shown that freeze-thaw effects and deterioration
should be expected to be higher near upper pool, compared to other eleva-
tions. Above this elevation, the degree of saturation in the concrete is gen-
erally less than the critical value required for freeze-thaw damage since
external water levels remain below this elevation. Below upper pool where
saturation may be critical, the insulating effects of water in the chamber
tend to keep concrete temperature above the critical temperature for dam-
age. Thus, the concrete in the upper pool region has a higher probability
of freeze-thaw damage. Freeze-thaw damage generally decreases with
decreasing elevation below upper pool. In addition, since the upper pool
elevation is maintained relatively constant and the lower pool (tailwater)
varies considerably, barge impacts are concentrated over a smaller height
near upper pool, leading to higher concrete loss.

The combination of higher abrasion near pool levels and higher prob-
ability of freeze-thaw damage near upper pool supports a rationale for the
observed loss at Lockport and Monongahela 8. There is also a likelihood

that losses should be higher between pool levels than above or below these elevations. The data and physical phenomena indicate a loss pattern that increases from some point below the wall top to a maximum near upper pool, decreases for some distance, and generally is less to near midpool. The pattern appears somewhat reflected below midpool but with lesser magnitudes of loss. This general pattern provides the basis for selection of analytical functions to represent concrete loss for the model.

One final observation regarding the data and the mechanics of the vertical surfaces model permits a simplification in the analysis of the data for a representative loss function. The data and physical phenomena indicate that losses are generally higher in the upper regions of the lock wall, particularly near upper pool. Since tows necessarily transverse the full height of the wall between upper and lower pool, and the operational problem is more critical where slopes (losses) are larger, it is really only necessary to consider the vertical surface in the upper region.

Analytical Representation of Loss

The foregoing observations of measured concrete loss at Lockport and Monongahela 8, along with the application of rational notions of the causes of such loss in general, led to some general characteristics of an analytical function that would be representative of these and other structures in this region. These characteristics are summarized as:

    a. Higher loss near upper pool.

    b. Some lesser losses between upper pool and midpool.

    c. Loss near lower pool.

Several analytical functions that could satisfy these general characteristics were evaluated for appropriateness by two measures. First, they should provide a reasonable "fit" to the measured data, as reflected in a linear regression. The criteria are relatively obvious considering the intended purpose of prediction. Second, the functions should be simple enough and require minimal input to describe the vertical surface. The criteria follow from the need for a relatively simple method to predict wall slope given a limited amount of information regarding concrete loss. A number of functions, and combinations of functions, including polynomial expansions, fit to the data with limited success are not presented herein. The functional form that best met the above criteria is discussed in the following text.

A functional form that satisfied the loss characteristics listed previously and met the evaluation criteria quite well was a linear combination of three distinct functions that individually match with the listed characteristics.

This function for loss $Z(y)$ is

$$Z(y) = \sum C_i Y_i(y) \tag{6}$$

where

$Y_0 = $ constant $\qquad\qquad y \leq y_{pml} - w_2 \qquad\qquad\qquad$ (6a)

$Y_1 = \cos^2(\pi(y - y_{pml})/2w_1) \qquad y_{pml} \leq y \leq y_{pml} + w_1 \qquad$ (6b)
$\quad\ = 0 \qquad\qquad\qquad\qquad\qquad$ elsewhere

$Y_2 = \cos^2(\pi(y - y_{pml})/2w_2) \qquad y_{pml} - w_2 \leq y \leq y_{pml} \qquad$ (6c)
$\quad\ = 0 \qquad\qquad\qquad\qquad\qquad$ elsewhere

and

$y_{pml} = $ elevation at upper pool

$w_1 = $ range of $\cos^2()$ function above upper pool

$w_2 = $ range of $\cos^2()$ function below upper pool

and is depicted schematically in Figure 17. The constant term, Y_0, provides the consistent losses below upper pool that may be due to causes other than typical abrasion and freeze-thaw, e.g., during pool filling and emptying. The second term provides for a region of higher losses above upper pool over a range of "w_1" feet (and zero outside this range) that is maximum at upper pool and is continuous in the first derivative. The
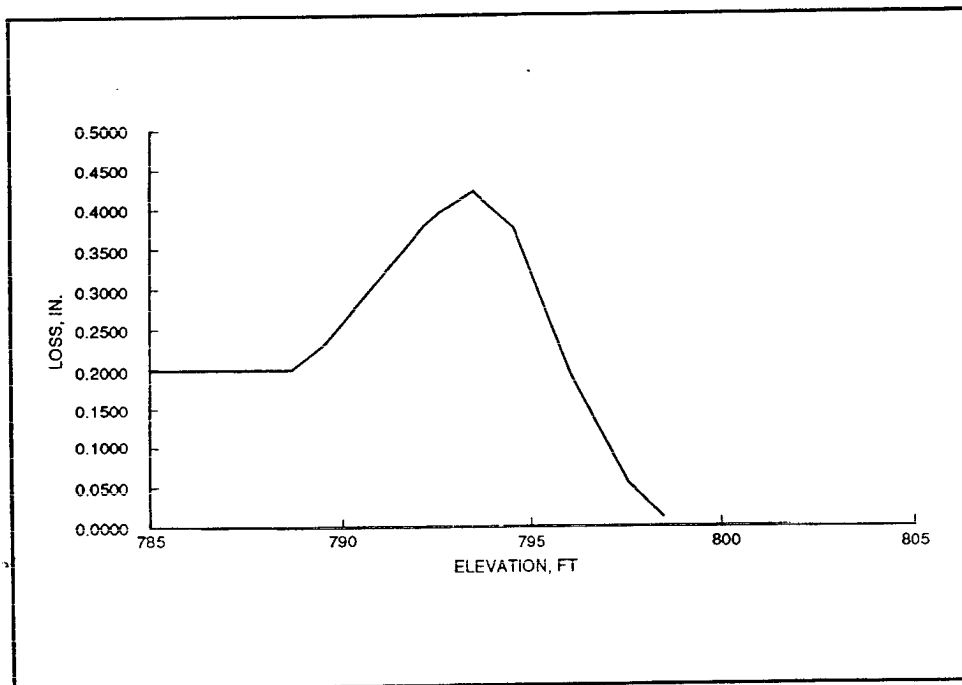
Figure 17. Functional form selected for model (Equation 6)

third term provides for a region of higher losses below upper pool over a range of "w_2" feet (and zero outside this range) that is maximum at upper pool, decreases to the constant value Y_0 at $y_{pml} - w_2$, and is continuous in the first derivative. The second and third terms are associated with the direct abrasion during tow entry and exit of the lock chamber.

Figures 18 through 20 show examples of the loss function (predicted) to the actual loss measurement taken in the chamber. The examples shown are an average representative of the fit of the function. Figure 18 is for Monolith 16 of Lockport Lock and Dam. The values used in the loss function $y_{pml} = 576$ (around upper pool), $w_1 = 2$, $w_2 = 9$, $Y_0 = 0.1$. Figure 19 is for Monolith 38 at Lock and Dam 13. The values used in the loss function were: $y_{pml} = 578$, $w_1 = 1.8$, $w_2 = 1.8$, $Y_0 = 0.27$. Figure 20 is for Monolith 13 at Lock and Dam 15. The values used for the loss function were: $y_{pml} = 553$, $w_1 = 0.95$, $w_2 = 1$, $Y_0 = 0.01$.

This functional form was evaluated for "goodness of fit" via linear regression where (1) Y_i (y) are the independent variables, (2) $Z(y)$ is the linearly dependent variable, and (3) the coefficients C_i were determined using spreadsheet analysis. The linear regression was performed solely on loss data normalized by the maximum value, i.e., the loss function ranged from -1.0 to +1.0 (primarily positive). The linear regressions for selected sets of data from the measurements at Lockport are presented in Figures 21 through 23. The magnitudes of "w_1" in Equation 6b and "w_2" in Equation 6c were selected after a few trials using the available data. The values for w_1 and w_2 for Locks 13 and 15 are shown in Table 1.
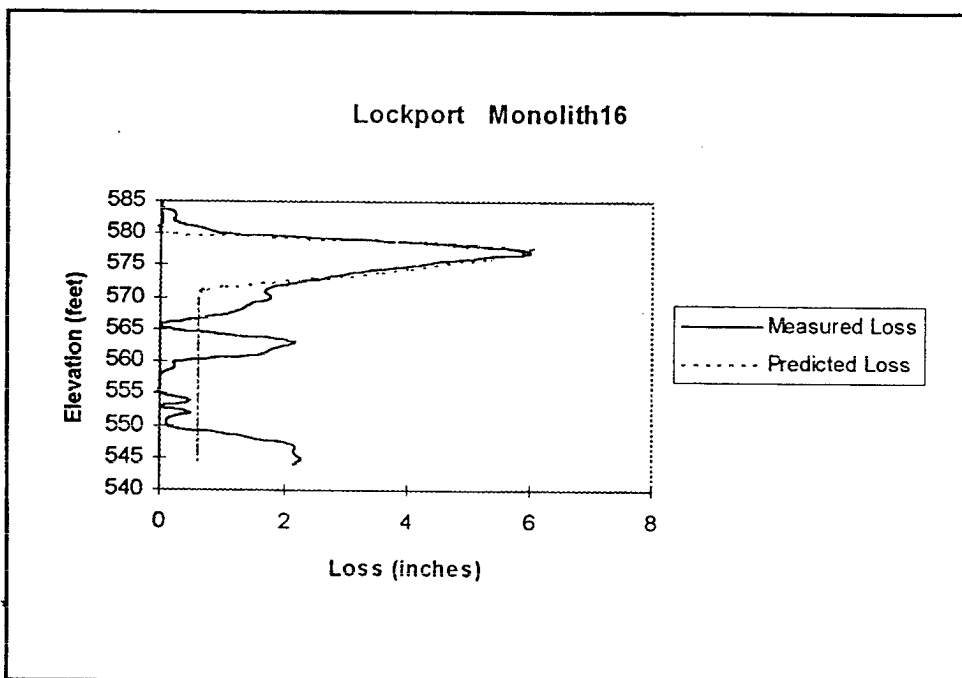
Figure 18. Measured versus predicted losses at Lockport Lock and Dam
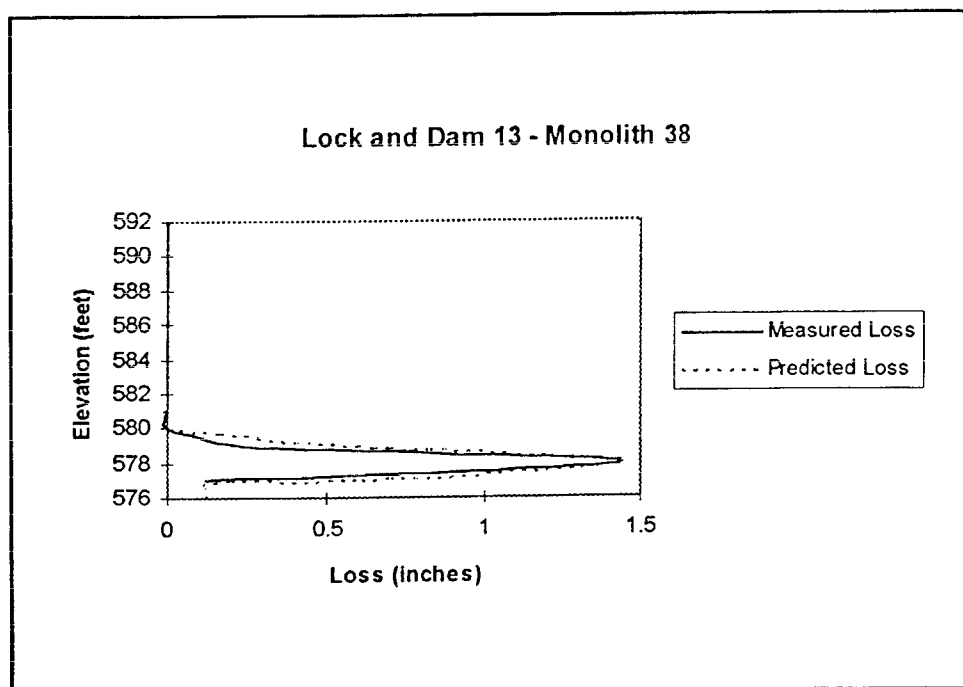
Figure 19. Measured versus predicted losses at Lock and Dam 13
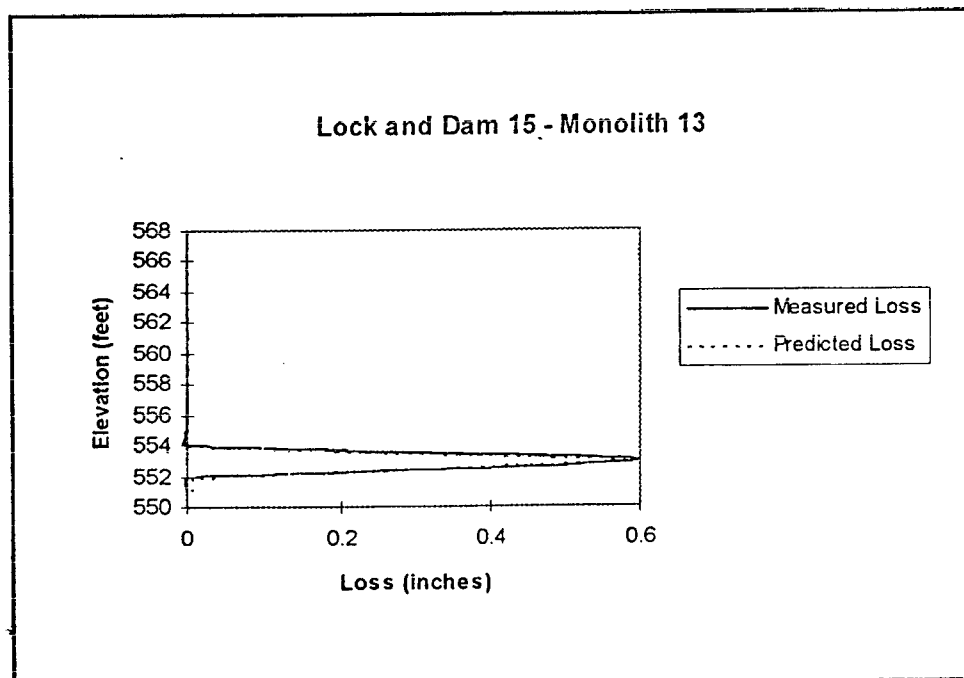
Figure 20. Measured versus predicted losses at Lock and Dam 15
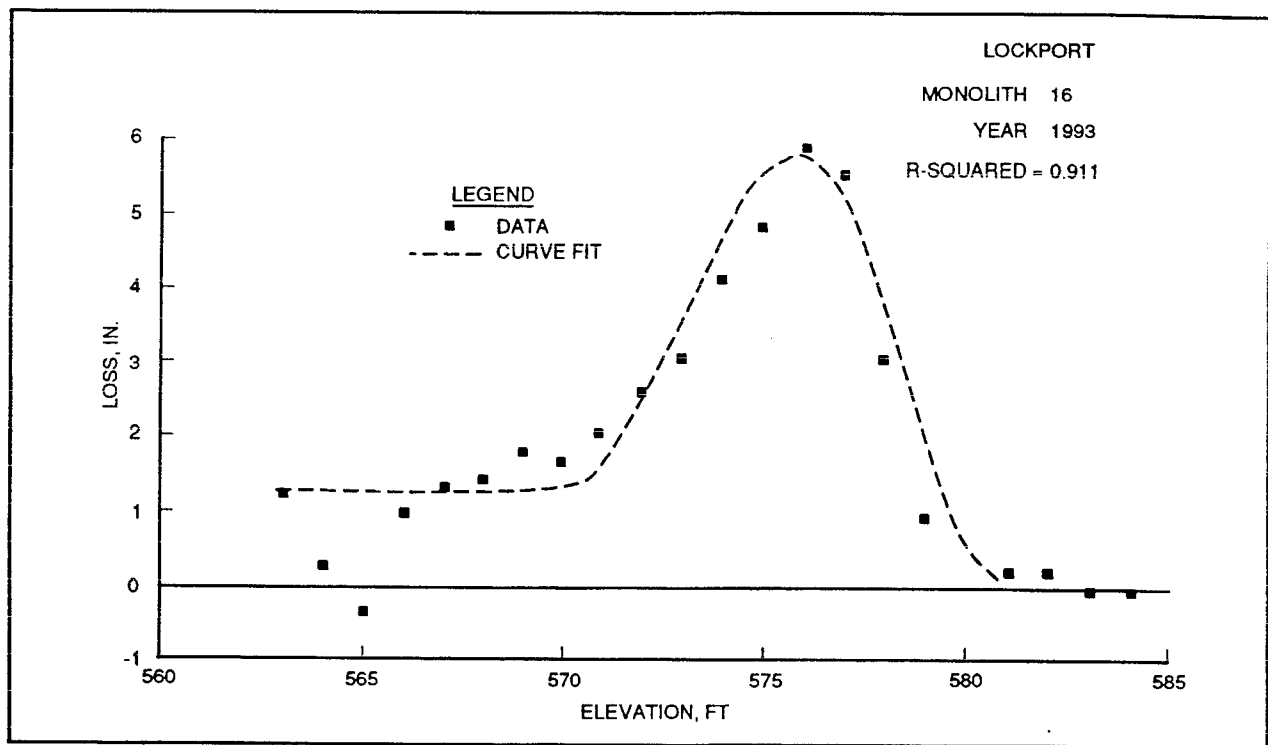
Figure 21. Linear regression for Lockport Monolith 16, 1993
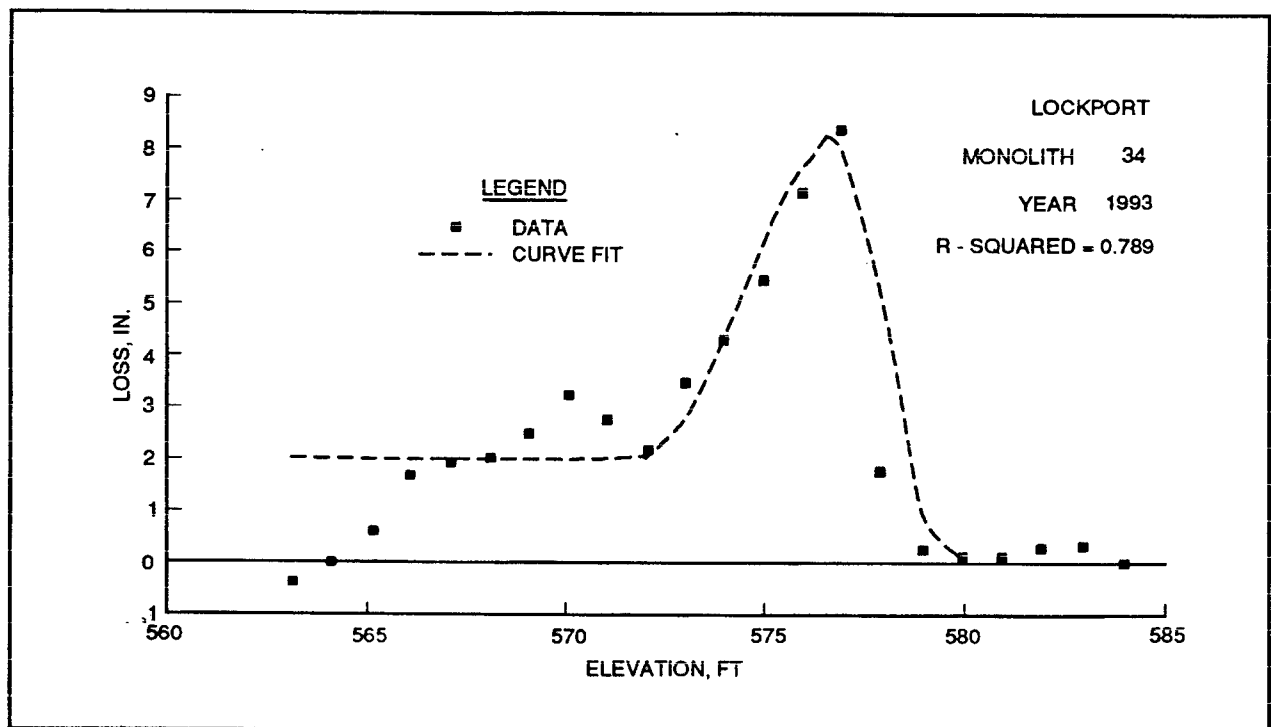
Figure 22. Linear regression for Lockport Monolith 34, 1993

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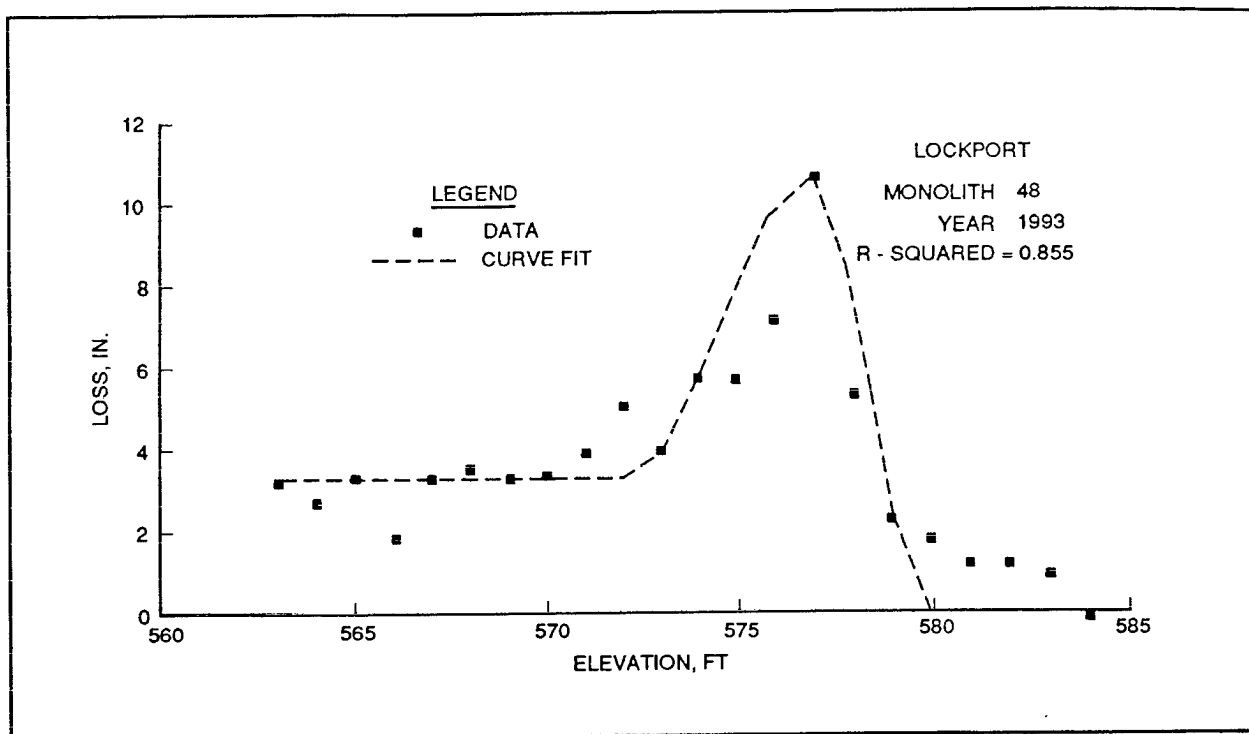
Figure 23. Linear regression for Lockport Monolith joint 48, 1993

Table 1
Measured Lock Parameters for Upper Mississippi Lock Chambers

Lock-Monolith	w_1, ft	w_2, ft	r	Measured Loss, in.	Evaluation of Maximum Loss, ft
Lock 13 - Upper Pool 583 Lower Pool 572					
13-41	2.5	1.8	0.27	0.84	581
13-42	1.47	3	0.1	0.6	587
13-38	1.45	1.5	0.1	1.43	578
13-25	1.73	1.5	0.1	0.83	580
13-16	3.4	2.8	0.05	0.6	579
Lock 15 - Upper Pool 561 Lower Pool 545					
15-25 (a)	1.2	2.2	0	0.141	566.9
15-25 (b)	1.2	2.2	0	0.141	551.9
15-15	1.2	0.89	0	0.89	552
15-13	1.2	0.89	0	0.63	553
15-8	1.2	1.455	0	0.243	554
15-16	1.2	1	0	1.117	558

Chapter 2 Vertical Surface Losses in Lock Chambers

The data and linear regression for Lockport Monolith 16, 1993 measurements, are presented in Figure 21, for the region between top of wall (el 585) and midpool elevation (el 563). The data and the "best fit" curve for the function are plotted. The individual points are the measurements and the dashed line is the curve fit. The goodness of fit is measured quantitatively by the R^2 term, i.e., the closer R^2 is to unity, the "better" the fit. The R^2 value for this case of 0.91 represents a good fit to the data using this functional form. This quantitative assessment is reinforced by the graphical comparison of the data and the regression line.

A similar result for the data from Monolith 34 in 1993 is presented in Figure 22. In this case the regression is reasonably good ($R^2 = 0.79$). The curve fit captures the essential features of the concrete loss required to determine the governing slope for the lock wall limit state previously described. The data and curve fit for Monolith 48 (1993) are shown in Figure 23. Again, the regression is good ($R^2 = 0.86$), and the curve fit captures the essential features of the concrete loss.

Relative Concrete Loss at Midpool and Upper Pool

The vertical surfaces model requires, in addition to definition of specific elevations and loss widths (w_1 and w_2), the prediction of loss at upper pool and nearer midpool (constant function). The prediction of maximum concrete loss due to freeze-thaw degradation and barge impact abrasion at upper pool is described by Patev et al.[1] A similar analytical model is not available for predicting the lesser losses near midpool, particularly since the transiting barge impact parameters are not significant nor easily defined. Due to this lack of an analytical procedure for predicting this lesser loss magnitude, the existing loss data were examined to determine any relationship between upper pool loss and midpool loss. Specifically, the ratio of average midpool loss to upper pool loss was determined for each set of measurements at Lockport Lock, Point Marion Lock and Dam, and Locks and Dams 13 and 15 (Table 1), i.e.,

$$r = \frac{average\ midpool\ loss}{upper\ pool\ loss}$$

This ratio is utilized to predict midpool loss in the vertical surfaces model. Specifically, the upper pool loss is determined from the concrete loss model described by Patev et al.,[1] and the midpool loss is computed directly using the above ratio.

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[1] R. C. Patev, Reed L. Mosher, Mary Ann Leggett, Paul F. Mlakar, and Larry M. Bryant. "Reliability analysis of lock walls subjected to concrete deterioration due to freeze-thaw and abrasion" (Technical report in preparation), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Refined Model

The vertical surfaces model for the limit state of the barge "hanging up" on uneven slopes of the lock wall is based on the refined prediction of the loss function along the wall. This refined model is depicted schematically in Figure 24. The basics of the friction model are the same as the previous model, with the slope of the wall being determined from the refined prediction of concrete loss along the wall described in the previous section.
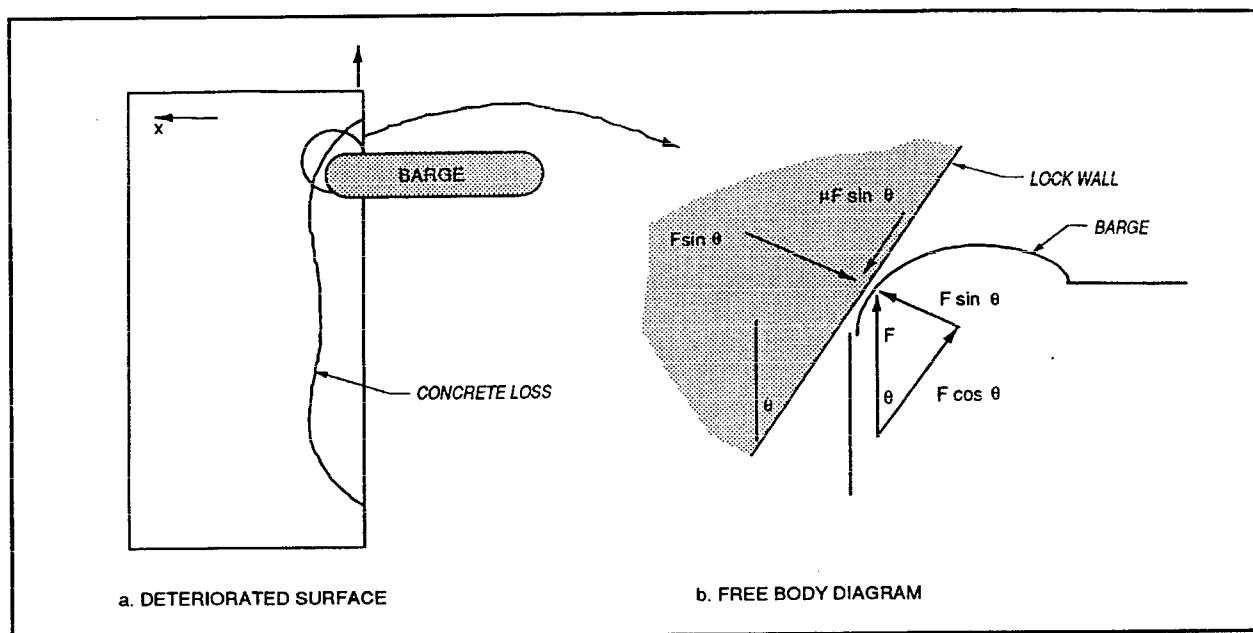
Figure 24. Refined vertical surfaces model

In the previous model, there was no question as to the location of the maximum slope of the wall that could impinge barge motion. In that case, the maximum slope was at the top of the deteriorated surface and could be calculated directly. In the refined model it is more difficult to determine the location and magnitude of the maximum *admissible* slope, i.e., where a barge could actually encounter the wall. Specifically, the point of contact along the surface above upper pool may be limited by the minimum loss value below upper pool if the barge draft is large compared to the combined widths of the upper pool loss ($w_1 + w_2$). If the combined widths of loss are large compared to the barge draft, the barge could translate and move between the slopes below and above upper pool, leading to a different contact point and different slope.

Thus, the maximum admissible slope must be determined from both the concrete loss function and the barge minimum draft. The calculation for maximum admissible slope in the current model numerically considers 10 evenly spaced potential points of contact in the region of highest slope. If any point is admissible from considerations of geometry, the slope is then likewise admissible. The largest of these admissible slopes is then used in the limit state.

3 Data Collection Using Time-Lapse Videotape

Introduction

Reliability assessment models focus on limit states which inherently use random variables. Proper estimates of these variables are crucial to the successful development and implementation of reliability models. The collection of physical data for reliability purposes is often a very expensive and tedious work effort. However, use of time-lapse videotape monitoring is an inexpensive, accurate, and economical way to obtain and permanently catalog field data.

The collection of physical data from lock chambers was required to properly develop the models for concrete deterioration and loading cycles for the fatigue assessment of hydraulic steel structures used for the U.S. Army Corps of Engineers (USACE) UMR-IWW Navigation Study. The UMR-IWW Navigation Study is currently being used to prioritize navigation investment decisions to the year 2050 for the 37 locks and dams in the UMR-IWW navigation area using reliability-based assessment methods.

The objectives of the work were to investigate and document unknown or estimated variables for reliability assessment models. Statistical data needed for these models were collected from the time-lapse videotape monitoring of three lock chambers in the UMR-IWW navigation area. Each item was crucial in developing the proper constraints to be used in the reliability assessment models.

Since the field collection of physical data is often a time-consuming task, time-lapse monitoring was implemented to assist with physically cataloging over 12,000 hours of field data at a minimal cost. The collected data characterized the values for the number of impacts on lock walls that occur during a lockage, the velocity of a barge in three different locations in a lock chamber, the fluctuation of chamber pools with time, and the number of unrecorded lockages for ice. These data were used as a basis in the successful implementation of the reliability models, since the constraints of these models were based directly on input of variables or constants in the probabilistic models.

Time-Lapse Video Technology

The technology of time-lapse video has been applied to many different fields of engineering. The application to collection of physical data for reliability assessment models has just entered its infancy. This technology provides the ability to collect data when it would be difficult or impossible to be physically present. Many different extensions to the current technology are being developed by the USACE. Technological advances such as infrared cameras for night use, onscreen imaging of onsite data collection equipment, and solar power units enhance video technology.

The basic equipment required for time-lapse videotaping is rather simplistic. Only a time-lapse video recorder and camera are required. Video cameras can have either a wide angle or telephoto lenses. The cameras and recorders can be enclosed in weatherproof cases that are small enough to be mounted anywhere. Heaters and cooling fans can be installed in the cases to control temperature extremes. Solar power panels can also be utilized in remote locations that do not have a source of power. The USACE has mounted cameras in locations such as near the tops of electrical transmission towers to remote navigation locations that have no access via roads.

The time-lapse recorder can record times from 2 to 480 hr on a single VHS cassette. A recording time of 120 hr allows a single frame to be taken every 2 sec. The time-lapse rates recommended by USACE based on recording 15 hr a day are shown in Table 2 below. Costs for the equipment are minimal when compared to possible real-time field collection costs of manpower time onsite including associated living expenditures. On average, the time-lapse video equipment costs range from $3,000.00 to $10,000.00 per set of recorder, camera, and weatherproof cases. Generally, the only maintenance after proper setup is removal of videotapes at the end of taping period. Very little onsite maintenance has been required by the USACE in using time-lapse video equipment.

Table 2 Recommended Time-Lapse Video Rates			
	Time-Lapse Rate, Hours	Duration, Days	Seconds Per Frame
Accessible sites	120	7	2
Remote sites	240	14	4

The monitoring of two lock chambers in the UMR-IWW navigation area was performed to assist with determining various variables for the concrete deterioration model. This monitoring refined previously unknown or estimated values for the number of impacts that occur during a lockage at upper pool, the velocities of a barge in different locations in a lock chamber, and the fluctuation of chamber pools with time. All of

these parameters are directly input as variables or constants in the probabilistic model that is discussed by Patev et al.[1]

Two individual time-lapse video cameras and recorders were used to record lockages at each site. This capability allowed the cameras to capture each lockage in both the upstream and downstream directions. The cameras were installed and mounted on light standards approximately 20 to 22 ft above the ground surface. This was to ensure that they were out of the way from any possible operational interference with tows. The video cameras were also extended a few feet over the edge of the lock wall to permit a full view of the entire lock chamber.

The time-lapse video recorder was set up to tape for a time period from 5:00 a.m. (0500 hr) to 8:00 p.m. (2000 hr), 7 days a week. The video recorder was also programmed to imprint continuously the date and time on the video output. This greatly assisted with the logging of each lockage and with determining the barge velocities based on actual time in the field.

The lock monitoring was performed on Lockport Lock and Dam on the Illinois Waterway (Chicago Sanitary and Ship Canal), and Lock and Dam 22 on the Mississippi River. Lockport Lock and Dam was monitored from the period starting on December 16, 1993, and ending on March 31, 1994. This time frame represented approximately 15 total weeks of lockages. Both video cameras were installed and operational for a period of 10 weeks even under the worst effects from the weather in the Chicago area. However, the downstream camera did fail after a power surge during a snow storm and was not functional for the last 5 weeks of taping.

Lockport Lock and Dam - Chicago Ship and Sanitary Canal

Lockport was selected because it is one of the few locks in the UMR-IWW navigation area that is fully operational during the winter months. The selection of Lockport provided a significant number of lockages that could be analyzed for the data required for this study.

The tapes from Lockport were analyzed for the following information:

 a. Number of bumps at upper pool and around the upper gate.

 b. Barge velocities at upper and lower gates and at the midpoint of the lock chamber.

 c. Average time periods of pool fluctuations.

The general location of the camera setup for Lockport is shown in Figure 25.

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[1] Ibid.
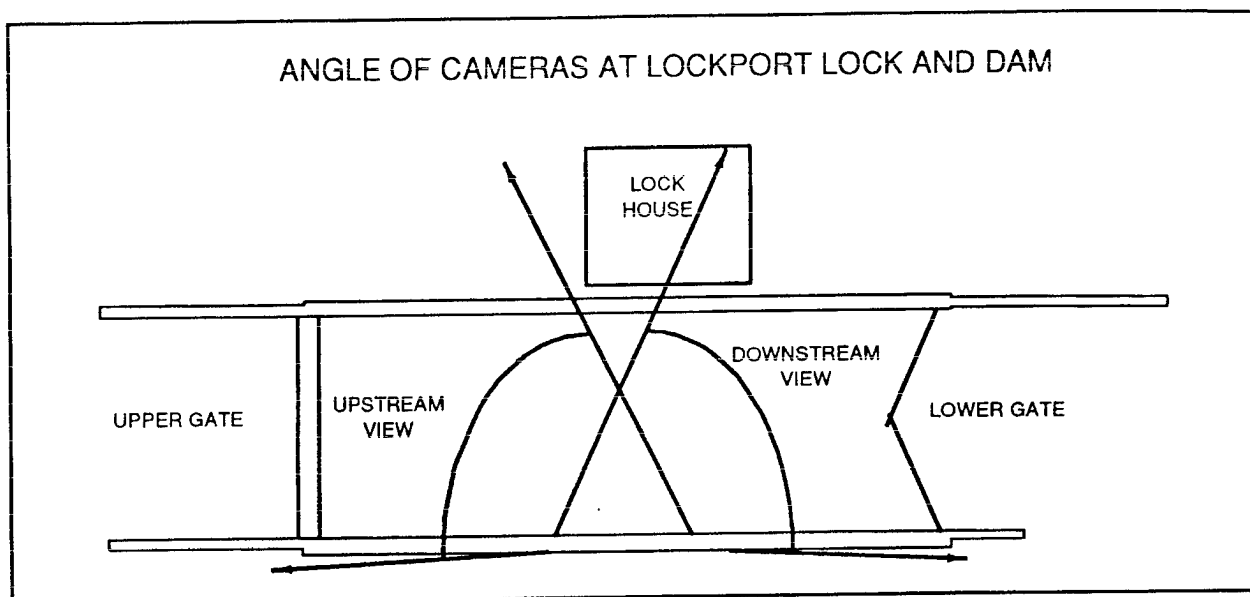
Figure 25. Lock monitoring at Lockport Lock and Dam

Lock and Dam 22 - Mississippi River

Lock and Dam 22 on the Mississippi River was monitored beginning on December 14, 1993, and ending on March 31, 1994. Lock and Dam 22 was selected because of the amount of barge traffic that could be expected from the grain elevators upstream in Quincy, IL. However, due to a railroad bridge span that was being replaced, the section of the Mississippi River above Lock and Dam 22 was closed to river traffic for a period from approximately December 17 to 27, 1994. Anticipating this, most of the expected barge traffic had avoided this delay and moved a majority of the grain south a few weeks before the monitoring could be set up.

With a limited amount of traffic to be expected, the tapes from Lock and Dam 22 could only be utilized to establish the fluctuations of the chamber pools in a nonoperational lock during the winter months. This gave great insight in determining a basis as to what occurs during the winter months when river traffic is at a minimum. This though will be typical of most of the locks and dams in the UMR-IWW navigation area.

The general location of the camera setup for Lock and Dam 22 is shown in Figure 26.

Results

Barge impacts

The impact of barges on chamber walls was determined for various locations in a lock chamber. These locations were located at upper pool,

33
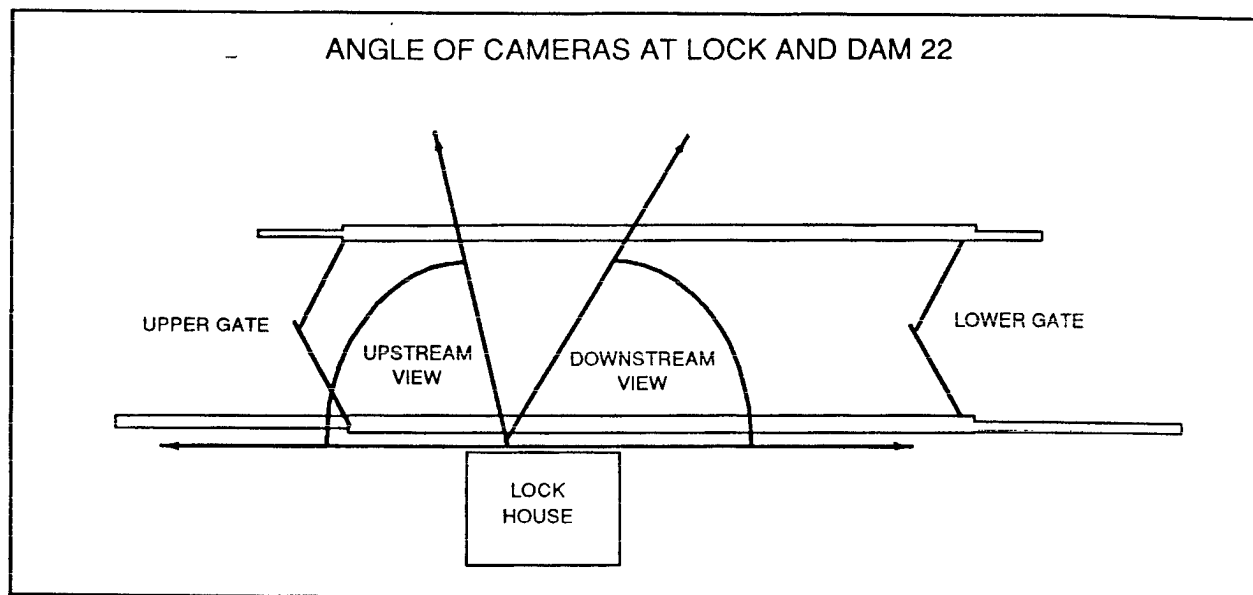
Figure 26. Lock monitoring at Lock and Dam 22

around the gates (both lower and upper and limited to two monoliths into lock chamber), lock walls during emptying and filling of the lock, and at lower pool. However, only the impacts at upper pool and around the upper gate will be presented at this time for use in the probabilistic model by Patev et al.[1]

The determination if a barge impacted the lock wall was based either on a continuous rub along the lock wall by a barge or a single "bump" of the barge against the lock wall. Barge impacts were counted during each lockage for each camera view (upstream and downstream). This counting process allowed for a total number of impacts to represent the total number of impacts in the entire lock chamber at upper pool. The total number of impacts was then averaged over the total number of lockages that occurred during the specified period. In probabilistic model,[1] the number of impacts per lockage is then divided in half to account for the distance of one wall which is 600 ft in length.

The mean value determined from the monitoring for the number of impacts per lockage was 2.52 impacts per lockage or 1.26 impacts per wall. This statistic was based on a total number of 281 lockages and a total of 709 impacts on the lock chamber over a 7-week period. The standard deviation for the number of impacts was very high, since the distribution of the lockages showed that many lockages had no impacts while some had many. This fact is clearly shown by the frequency distribution and histogram of the number of impacts per lockage. These are shown in Figures 27 and 28, respectively.

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[1] Ibid.

Bin	Frequency	Cumulative %
0	88	31.32
1	40	45.55
2	50	63.35
3	29	73.67
4	15	79.00
5	22	86.83
6	9	90.04
7	9	93.24
8	4	94.66
9	4	96.09
10	5	97.86
11	3	98.93
12	0	98.93
13	1	99.29
14	1	99.64
15	1	100.00

Figure 27. Frequency distribution and cumulative percent frequency for number of impacts at Lockport Lock and Dam
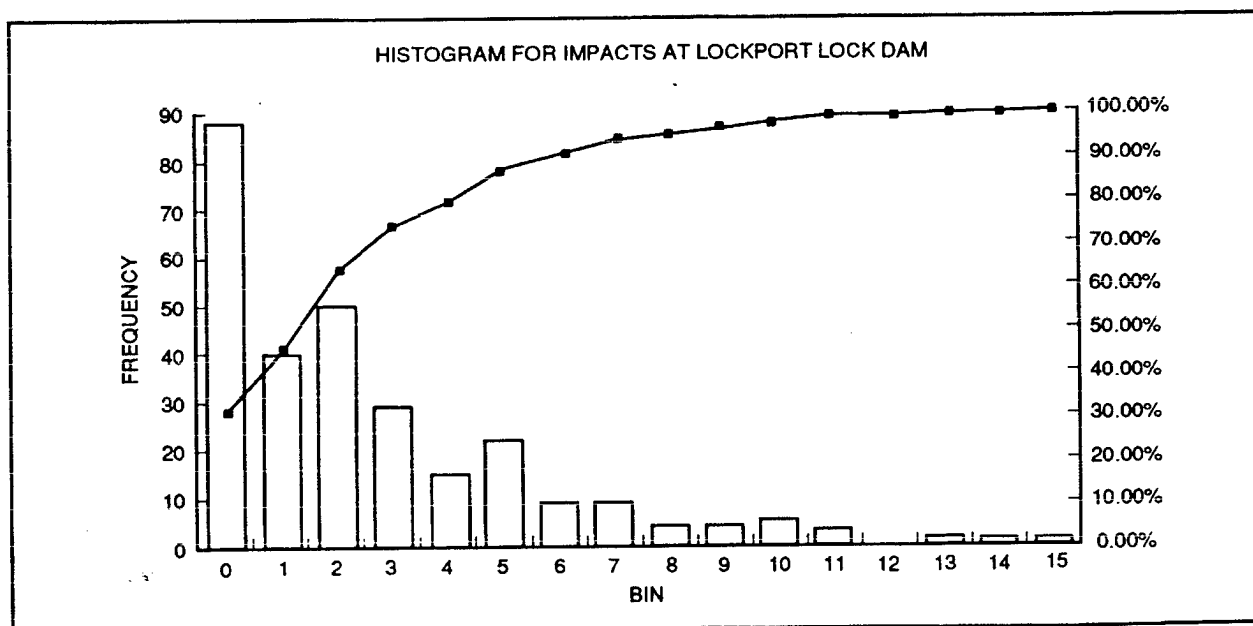
Figure 28. Histogram for number of impacts at Lockport Lock and Dam

Tow velocities

Velocities of tows were investigated at different points in the lock chamber to look at different speeds that could occur in a lock during an impact. The areas highlighted were points that were inside the upper and lower gates (both at time of entry and at time of mooring) and at a point approximately at midchamber. The velocities are also broken into upstream and downstream lockages because the velocities are different due to the effects of the current. These locations are shown in Figure 29.
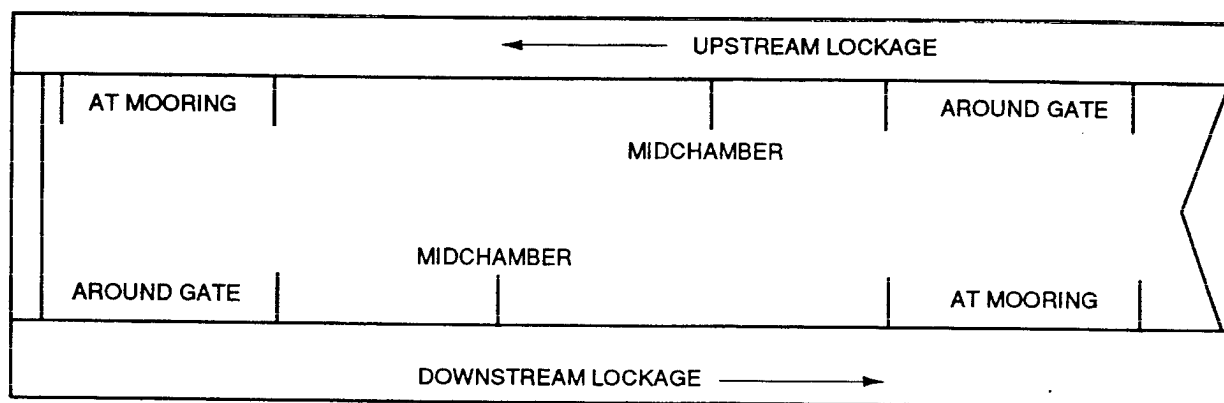
Figure 29. Locations of velocity measurements

The velocities of the tows were determined by using known distances between monoliths or marking on the lock walls and measuring the actual amount of time it took to travel that distance by the time on the tape. The average velocity over that distance was the velocity value that was obtained. The tow velocities were taken from a 4-week period from December 16, 1993, to January 14, 1994, over a total number of 135 lockages.

The average tow velocities and representative coefficients of variation COV) for lockages downstream and upstream are shown in the Table 3.

Table 3 Tow Velocities at Lockport Lock and Dam			
	Mean		
Downstream Lockage	mph	ft/s	COV
Around gate	1.88	2.75	0.42
Midchamber	1.79	2.63	0.44
At mooring	0.71	1.04	0.38
Upstream Lockage			
Around gate	1.56	2.29	0.49
Midchamber	1.31	1.91	0.45
At mooring	0.55	0.82	0.49

36

Fluctuation in pool times

The fluctuations in pool times were determined from the monitoring by analyzing the amount of time that a pool stayed at a continuous level, i.e., upper or lower pool. The times were measured directly from the videotapes from the time when the pool level was reached to the time it started to rise or drop. The pool times determined at the start and end of each videotape, i.e., 5:00 a.m. and 8:00 p.m., were not utilized since it was not known how long the pools were at these levels. This dwell time is crucial to determining the depth that saturation can penetrate the concrete at upper pool. The determination of this value for dwell time will be directly input into the probabilistic model discussed by Patev et al.[1]

The pool times were determined both for Lockport Lock and Dam and Lock and Dam 22 based on actual monitored field times. The actual field times for Lockport are applicable to a lock that is generally operational during the winter months. The actual field times for Lock and Dam 22 are applicable to a nonoperational lock that is at a slowdown down for the winter months. Each location tends to have a different distribution of times at upper pool. This again determines the actual dwell time that the concrete can saturate.

There are other factors that could assist in determining the dwell time. These may be known operational procedures that occur at a lock with the pools. For example, at Lockport the operational procedure during the winter in a slowdown period is to cycle the pools every 2 hours to keep the oil from freezing. A factor like this could be used as a reasonable basis for the value of the dwell time.

The pool time for Lockport was based on 216 upper pool observations and 219 lower pool observations. The pool times for Lock and Dam 22 were based on 142 upper pool observations and 181 lower pool observations. The values for the mean pool times for each lock are shown in Table 4.

Table 4 Pool Times at Lockport Lock and Dam and Lock and Dam 22		
Lockport	Min	Hr
Upper pool	93.04	1.62
Lower pool	71.76	1.19
Lock and Dam 22		
Upper pool	71.71	1.19
Lower pool	245.6	4.09

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[1] Ibid.

The standard deviations for the pool times are very large compared to the mean values. This is attributable to the distribution of the observations of the pool times. The frequency distributions and histograms for both locks and dams are shown in Figures 30 through 35.

Histogram Data for Lower Pool Times at Lockport

Bin	Frequency	Cumulative %
20	23	10.65
40	61	38.89
60	48	61.11
80	24	72.22
100	11	77.31
120	13	83.33
140	9	87.50
160	4	89.35
180	2	90.28
200	13	96.30
300	7	99.54
400	1	100.00
500	0	100.00
600	0	100.00

Histogram Data for Upper Pool Times at Lockport

Bin	Frequency	Cumulative %
20	44	20.37
40	53	44.91
60	41	63.89
80	20	73.15
100	13	79.17
120	7	82.41
140	7	85.65
160	6	88.43
180	2	89.35
200	10	93.98
300	7	97.22
400	3	98.61
500	3	100.00
600	0	100.00

Figure 30. Frequency distributions for upper and lower pool times at Lockport Lock and Dam
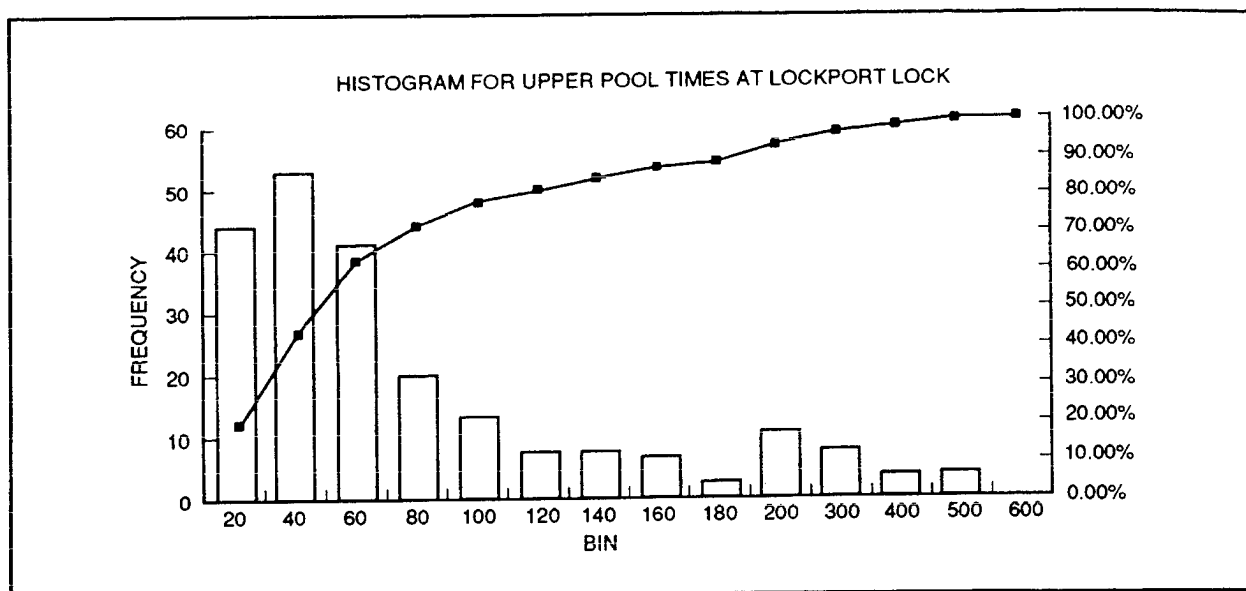
Figure 31. Histogram of upper pool times at Lockport Lock and Dam
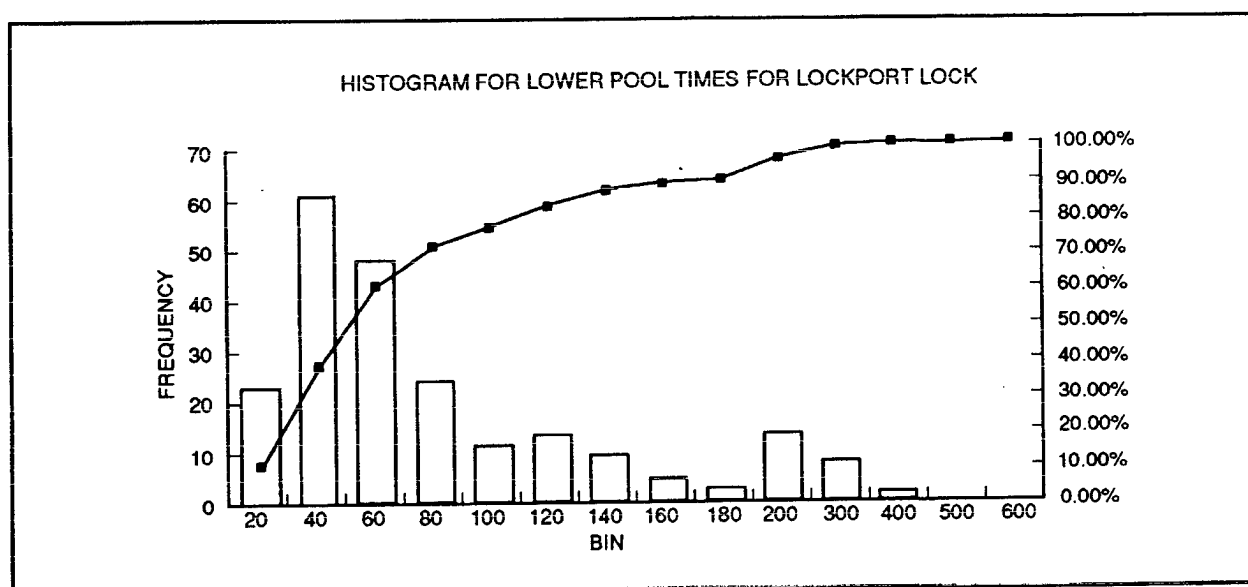
Figure 32. Histogram of lower pool times at Lockport Lock and Dam

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Histogram Data for Lower Pool Times
at Lock and Dam 22

Bin	Frequency	Cumulative %
20	23	14.02
40	10	20.12
60	6	23.78
80	9	29.27
100	28	46.34
200	32	65.85
300	20	78.05
400	11	84.76
500	6	88.41
600	9	93.90
700	2	95.12
800	4	97.56
900	4	100.00

Histogram Data for Upper Pool Times
at Lock and Dam 22

Bin	Frequency	Cumulative %
20	45	44.12
40	16	59.80
60	10	69.61
80	5	74.51
100	15	89.22
200	3	92.16
300	2	94.12
400	3	97.06
500	2	99.02
600	0	99.02
700	0	99.02
800	1	100.00
900	0	100.00

Figure 33. Frequency distributions for upper and lower pool times at Lock and Dam 22
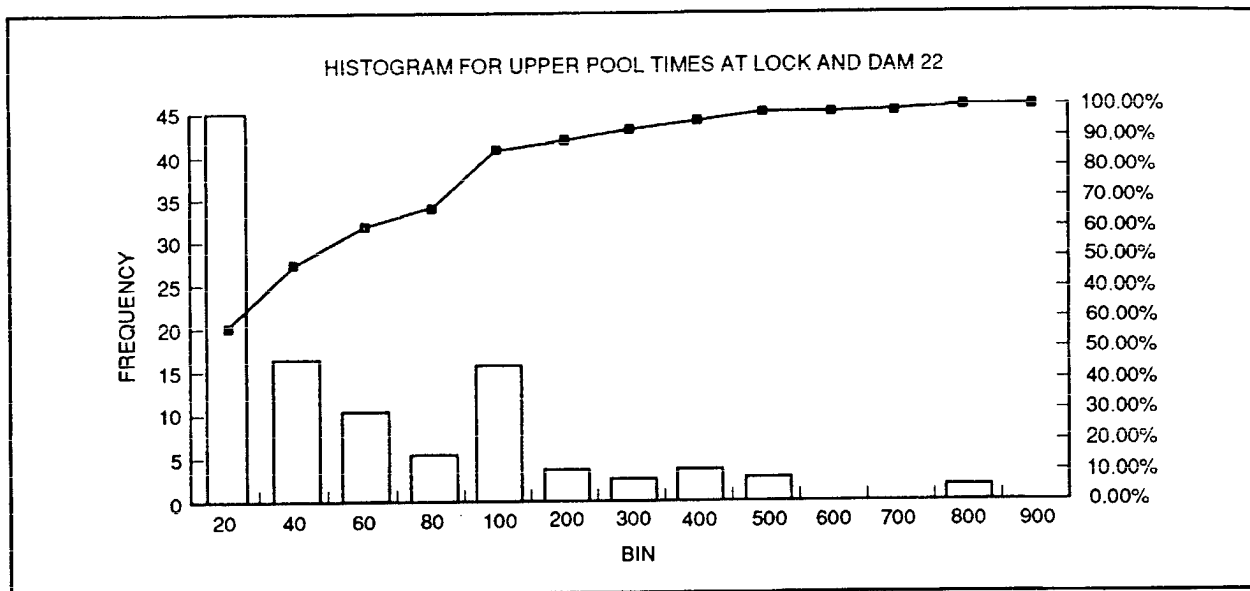
Figure 34. Histogram of upper pool times at Lock and Dam 22
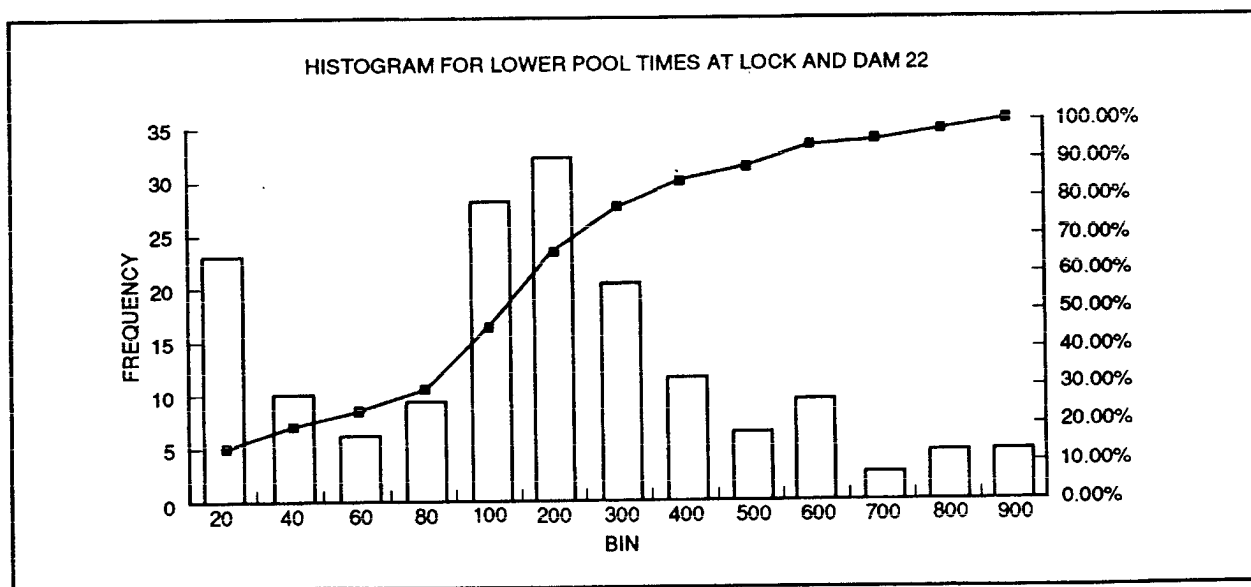
Figure 35. Histogram of lower pool times at Lock and Dam 22

Chapter 3 Data Collection Using Time-Lapse Videotape

Lockages for ice

Winter weather directly affects the number of loading cycles for fatigue assessment of miter gates because some locks are completely closed to river traffic during the winter months because of ice buildup on the river, and no loading cycles occur during the winter. Other locks are operated year-round and experience buildup of ice in the upper approach regions of locks. Sometimes, miter gates are operated for the purpose of passing ice flows to reduce ice buildup in the upper approach and to relieve any pressure on the gates. The loading cycles for managing the ice flow are usually not recorded in operational logs.

The daily hardware cycles can be computed and adjusted for ice hardware cycles (Ayyub et al.).[1] A hardware cycle is a mechanical emptying or filling of a lock chamber. The adjustment for the ice lockages was based on time-lapsed videotapes in the winter months of 1993-1994 for Lock and Dam 22 and Lock and Dam 25. The time-lapse videotapes showed 63 and 75 ice lockages, respectively, over periods of 77 and 65 days, respectively. Therefore, an average of one ice lockage per day can be added to the computed lockage cuts, and similarly, two ice hardware cycles per day were added to the computed hardware cycles. However, this is true only for the months of January and February of each year, since this is when the river is frozen over and ice jams need to be flushed through the lock's chamber. These unrecorded loading cycles can contribute up to as many as 6,000 additional hardware cycles over the lifetime of a miter gate, i.e., 50 years. These unrecorded lockages were not previously accounted for in the fatigue reliability assessment of the miter gates.

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[1] B. M. Ayyub, M. P. Kaminsky, R. C. Patev, and M. A. Leggett. "Loading cycles for the fatigue reliability analysis of miter gates," Technical Report ITL-95-12, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

4 Conclusions and Recommendations

The data collected as part of this study were crucial in developing the proper constraints for the UMR-IWW concrete deterioration model. Without the collection of data from this study, the model may have predicted a single value for the depth of concrete loss without recognizing the pattern of loss that occurs in the field. Since the UMR-IWW deterioration model was a first iteration in the development process, results from this study can help to refine the direction of future work as more data are collected.

This study also greatly enhanced our knowledge of collecting physical field data. Typically, the collection of physical field data is an expensive and tedious work effort. This study resulted in a substantial reduction in cost and manpower levels required to collect the variety of physical field data that were cataloged. These videotapes have also been used to investigate other physical field data such as locking of ice and debris and hydraulic flow conditions of lock approaches.

Appendix A
Field Logs for Lockport Loss
Measurements

LOCKPORT LOCKWALL CONCRETE DETERIORATION

Lockport - Land Wall
Top of lockwall Elev. = 585.0

15 JAN 1993

U.P. EL. 578.0

L.P. EL. 548.0

MONOLITH 14
Centerline

MONOLITH 16
Centerline

DEPTH OF LOSS, FEET

DISTANCE BELOW TOP OF LOCKWALL, FEET

LOCKPORT LOCKWALL CONCRETE DETERIORATION

15 JAN 1993

LOCKPORT LOCKWALL CONCRETE DETERIORATION

Lockport - Land Wall
Top of lockwall Elev. = 585.0

Lockport – Land Wall
Top of lockwall Elev. = 585.0

LOCKPORT LOCKWALL CONCRETE DETERIORATION

11 JAN 1993

Appendix A Field Logs for Lockport Loss Measurements

LOCKPORT LOCKWALL CONCRETE DETERIORATION

Lockport - River Wall
Top of lockwall Elev. = 585.0

15 JAN 1993

⊙ 8 JAN 1993
△ 31 JUL 1984

MONOLITH 23
Centerline

MONOLITH 39/41
Joint

DEPTH OF LOSS, FEET

DISTANCE BELOW TOP OF LOCKWALL, FEET

LOCKPORT LOCKWALL CONCRETE DETERIORATION

15 JAN 1993

Lockport - River Wall
Top of lockwall Elev. = 585.0

Appendix A Field Logs for Lockport Loss Measurements

```
***********************************************************
       LOCKPORT CONCRETE LOSS SURVEYS IN JUL 84 AND JAN 93
***********************************************************
LAND WALL                          LAND WALL
MONOLITH  14,   CENTERLINE         MONOLITH  16,   CENTERLINE
============================        ============================
   ELEV   LOSS 84   LOSS 93           ELEV   LOSS 84   LOSS 93
          (FT)      (FT)                     (FT)      (FT)
   584    0.000     0.000             584    0.000     0.000
   583   -0.010     0.000             583    0.010     0.000
   582    0.000     0.010             582    0.010     0.020
   581    0.000     0.000             581    0.010     0.020
   580   -0.010     0.000             580    0.000     0.050
   579   -0.010    -0.010             579    0.050     0.080
   578   -0.010    -0.010             578    0.160     0.260
   577   -0.010    -0.010             577    0.400     0.470
   576   -0.010     0.000             576    0.360     0.500
   575   -0.010     0.000             575    0.300     0.410
   574   -0.020    -0.010             574    0.270     0.350
   573    0.000    -0.030             573    0.160     0.260
   572    0.060     0.080             572    0.100     0.220
   571    0.060     0.080             571    0.080     0.170
   570    0.030     0.040             570    0.080     0.140
   569    0.000     0.060             569    0.080     0.150
   568   -0.010     0.000             568    0.070     0.120
   567   -0.010     0.020             567    0.040     0.110
   566    0.030     0.030             566   -0.020     0.080
   565   -0.010     0.030             565   -0.100    -0.030
   564   -0.030    -0.050             564   -0.080     0.020
   563   -0.030    -0.040             563    0.100     0.100
   562   -0.030    -0.040             562    0.090     0.170
   561   -0.020    -0.040             561    0.070     0.150
   560   -0.020    -0.040             560    0.010     0.130
   559   -0.010    -0.030             559   -0.040     0.020
   558   -0.010     0.020             558   -0.070     0.020
   557    0.030     0.040             557   -0.050    -0.020
   556    0.000     0.100             556   -0.080    -0.080
   555    0.020     0.010             555   -0.060    -0.080
   554    0.020    -0.010             554    0.000     0.000
   553    0.010     0.030             553    0.000     0.040
   552    0.020    -0.020             552   -0.030     0.000
   551    0.050    -0.010             551   -0.010     0.040
   550    0.030    -0.020             550    0.000     0.010
   549    0.020    -0.010             549    0.020     0.010
   548    0.020    -0.010             548    0.080     0.080
   547    0.040     0.000             547    0.030     0.130
   546    0.030    -0.010             546    0.160     0.180
   545    0.050     0.000             545    0.140     0.180
   544    0.050     0.000             544    0.130     0.190
   543    0.050                       543    0.140     0.180
   542    0.050                       542    0.060
   541    0.040                       541    0.130
   540    0.040                       540    0.160
   539    0.030                       539    0.050
          =====     =====                    =====     =====
AVERAGE   0.011     0.004                    0.065     0.115
MAX       0.060     0.100                    0.400     0.500
```

```
***************************************************
      LOCKPORT CONCRETE LOSS SURVEYS IN JUL 84 AND JAN 93
***************************************************
LAND WALL                        LAND WALL
MONOLITHS 20/22 JOINT            MONOLITH  22,  CENTERLINE
============================     ==========================
   ELEV   LOSS 84   LOSS 93        ELEV   LOSS 84   LOSS 93
           (FT)      (FT)                  (FT)      (FT)
    584    0.000     0.000         584     0.000     0.000
    583    0.000     0.020         583    -0.020     0.000
    582    0.060     0.110         582    -0.020     0.000
    581    0.170     0.040         581    -0.020     0.000
    580    0.160     0.180         580    -0.020     0.000
    579    0.170     0.250         579    -0.020    -0.010
    578    0.180     0.380         578    -0.030     0.020
    577    0.310     0.540         577     0.000     0.080
    576    0.460     0.630         576     0.130     0.270
    575    0.360     0.610         575     0.240     0.300
    574    0.240     0.380         574     0.200     0.230
    573    0.070     0.280         573     0.120     0.180
    572    0.050     0.350         572     0.020     0.120
    571    0.060     0.250         571    -0.020     0.040
    570    0.000     0.180         570     0.030     0.040
    569    0.050     0.100         569    -0.040     0.030
    568    0.000     0.050         568    -0.050    -0.040
    567    0.000     0.130         567    -0.060    -0.040
    566    0.010     0.110         566    -0.070    -0.050
    565   -0.010     0.110         565    -0.070    -0.060
    564    0.110     0.160         564    -0.060    -0.050
    563   -0.030     0.060         563    -0.060     0.060
    562    0.010     0.060         562     0.040     0.080
    561   -0.010     0.130         561     0.020     0.120
    560    0.020     0.030         560     0.010     0.100
    559    0.040     0.040         559    -0.030     0.090
    558    0.040     0.030         558    -0.040     0.070
    557    0.010     0.110         557    -0.030     0.030
    556    0.030     0.050         556    -0.030     0.000
    555    0.040     0.110         555     0.050     0.050
    554    0.050     0.060         554    -0.030    -0.020
    553    0.100     0.010         553    -0.030    -0.020
    552    0.050     0.000         552    -0.030    -0.020
    551    0.050     0.120         551    -0.020    -0.020
    550    0.070     0.050         550    -0.010    -0.010
    549    0.070     0.050         549    -0.010    -0.010
    548    0.050     0.010         548     0.000     0.000
    547    0.100     0.000         547     0.010     0.000
    546    0.080     0.060         546     0.030     0.010
    545    0.080     0.110         545     0.050     0.080
    544    0.110     0.090         544     0.060     0.050
    543    0.090     0.090         543     0.060     0.060
    542    0.120     0.170         542     0.060     0.040
    541    0.090                   541     0.050
    540    0.070                   540     0.050
    539    0.060                   539     0.030
           =====     =====                 =====     =====
AVERAGE    0.083     0.147                 0.010     0.042
MAX        0.460     0.630                 0.240     0.300
```

Appendix A Field Logs for Lockport Loss Measurements

```
****************************************************************
     LOCKPORT CONCRETE LOSS SURVEYS IN JUL 84 AND JAN 93
****************************************************************
LAND WALL                        LAND WALL
MONOLITH  26,  CENTERLINE        MONOLITH  32,  CENTERLINE
============================      ============================
  ELEV   LOSS 84   LOSS 93         ELEV   LOSS 84   LOSS 93
          (FT)      (FT)                   (FT)      (FT)
   584    0.000     0.000           584    0.000     0.000
   583    0.040     0.030           583   -0.010     0.010
   582    0.030     0.020           582    0.000     0.010
   581    0.030     0.030           581    0.000     0.010
   580    0.030     0.020           580    0.000     0.010
   579    0.020     0.020           579    0.000     0.010
   578    0.020     0.020           578    0.000     0.020
   577    0.020     0.020           577    0.060     0.110
   576    0.110     0.220           576    0.150     0.260
   575    0.150     0.200           575    0.140     0.200
   574    0.080     0.150           574    0.060     0.160
   573    0.010     0.060           573    0.060     0.090
   572    0.020     0.030           572    0.050     0.090
   571    0.010     0.010           571    0.140     0.190
   570    0.010     0.000           570    0.260     0.230
   569    0.000    -0.010           569    0.180     0.280
   568   -0.010    -0.010           568    0.220     0.300
   567   -0.010     0.020           567    0.280     0.380
   566    0.140     0.150           566    0.210     0.270
   565    0.120     0.220           565    0.190     0.210
   564    0.060     0.150           564    0.160     0.140
   563    0.060     0.120           563    0.110     0.130
   562    0.050     0.100           562    0.060     0.110
   561    0.010     0.030           561    0.120     0.140
   560   -0.040     0.020           560    0.060     0.110
   559   -0.040    -0.040           559    0.040     0.050
   558   -0.040    -0.050           558    0.030     0.040
   557   -0.030    -0.040           557    0.010     0.020
   556    0.030     0.050           556    0.030     0.030
   555    0.030     0.050           555    0.000     0.020
   554    0.020     0.040           554    0.010     0.000
   553    0.060     0.060           553    0.050     0.040
   552    0.000     0.030           552    0.060     0.060
   551    0.020    -0.010           551    0.050    -0.010
   550    0.010     0.030           550    0.020    -0.020
   549    0.010     0.010           549    0.000    -0.020
   548    0.030    -0.010           548    0.010    -0.020
   547    0.030     0.000           547    0.030    -0.010
   546    0.050     0.040           546    0.010     0.000
   545    0.080     0.080           545    0.050     0.050
   544    0.060     0.080           544    0.040     0.050
   543    0.010     0.010           543    0.020     0.020
   542    0.010     0.020           542    0.030     0.020
   541    0.020                     541    0.040
   540    0.010                     540    0.020
   539    0.000                     539    0.020
          =====     =====                  =====     =====
AVERAGE   0.029     0.048                  0.067     0.088
MAX       0.150     0.220                  0.280     0.380
```

```
*********************************************************
       LOCKPORT CONCRETE LOSS SURVEYS IN JUL 84 AND JAN 93
*********************************************************
LAND WALL                          LAND WALL
MONOLITH 34, 1' DS OF US JT        MONOLITH  34,  CENTERLINE
==========================         ==========================
   ELEV  LOSS 84   LOSS 93            ELEV  LOSS 84   LOSS 93
         (FT)      (FT)                     (FT)      (FT)
   584   0.000     0.000              584   0.000     0.000
   583   0.000     0.030              583   0.000     0.030
   582   0.000     0.010              582   0.000     0.020
   581   0.000     0.010              581   0.000     0.010
   580   0.010     0.030              580   0.000     0.010
   579   0.070     0.040              579   0.000     0.020
   578   0.150     0.180              578   0.070     0.150
   577   0.460     0.510              577   0.440     0.700
   576   0.450     0.530              576   0.440     0.600
   575   0.260     0.430              575   0.290     0.460
   574   0.200     0.300              574   0.260     0.360
   573   0.220     0.270              573   0.210     0.290
   572   0.140     0.250              572   0.150     0.180
   571   0.180     0.180              571   0.220     0.230
   570   0.150     0.180              570   0.170     0.270
   569   0.060     0.100              569   0.140     0.210
   568   0.010     0.010              568   0.120     0.170
   567   0.000    -0.020              567   0.140     0.160
   566  -0.020    -0.030              566   0.080     0.140
   565   0.000    -0.040              565   0.000     0.050
   564  -0.030     0.000              564  -0.030     0.000
   563  -0.030    -0.040              563  -0.030    -0.030
   562   0.010     0.000              562  -0.050    -0.050
   561   0.040     0.000              561  -0.060    -0.080
   560   0.090     0.020              560  -0.040    -0.090
   559   0.100     0.060              559  -0.050    -0.090
   558   0.070     0.030              558  -0.040    -0.090
   557   0.040     0.000              557  -0.040    -0.090
   556   0.050     0.060              556  -0.020    -0.090
   555   0.060     0.080              555  -0.020    -0.060
   554   0.050     0.030              554   0.070     0.050
   553   0.080     0.070              553   0.090     0.010
   552   0.050     0.030              552   0.000    -0.020
   551   0.110     0.010              551   0.020    -0.070
   550   0.050     0.000              550   0.020    -0.060
   549   0.030    -0.020              549   0.020    -0.060
   548   0.070     0.010              548   0.030    -0.020
   547   0.070     0.020              547   0.030    -0.030
   546   0.110     0.010              546   0.100     0.060
   545   0.060     0.020              545   0.150     0.150
   544   0.070     0.050              544   0.120     0.090
   543   0.060     0.040              543   0.060     0.000
   542   0.080     0.010              542   0.070     0.010
   541   0.120                        541   0.040
   539   0.040                        539   0.010
         =====     =====                    =====     =====
AVERAGE  0.083     0.080                    0.069     0.081
MAX      0.460     0.530                    0.440     0.700
```

Appendix A Field Logs for Lockport Loss Measurements

```
**************************************************************
       LOCKPORT CONCRETE LOSS SURVEYS IN JUL 84 AND JAN 93
**************************************************************
LAND WALL                          LAND WALL
MONOLITH 44, 4' US OF DS JT        MONOLITH  48,  CENTERLINE
============================       ============================
  ELEV  LOSS 84  LOSS 93             ELEV  LOSS 84  LOSS 93
        (FT)     (FT)                      (FT)     (FT)
  584   0.000    0.000               584   0.000    0.000
  583   0.040    0.050               583   0.050    0.090
  582   0.050    0.050               582   0.070    0.110
  581   0.060    0.060               581   0.100    0.110
  580   0.070    0.060               580   0.140    0.160
  579   0.070    0.070               579   0.190    0.200
  578   0.170    0.240               578   0.460    0.450
  577   0.460    0.580               577   0.800    0.890
  576   0.350    0.440               576   0.500    0.600
  575   0.340    0.380               575   0.360    0.480
  574   0.280    0.330               574   0.260    0.490
  573   0.200    0.200               573   0.220    0.340
  572   0.210    0.210               572   0.270    0.430
  571   0.150    0.140               571   0.260    0.330
  570   0.100    0.120               570   0.270    0.290
  569   0.050    0.080               569   0.190    0.280
  568   0.040    0.000               568   0.200    0.300
  567   0.040   -0.020               567   0.220    0.280
  566   0.040   -0.020               566   0.170    0.160
  565   0.050   -0.010               565   0.260    0.280
  564   0.060    0.090               564   0.260    0.230
  563   0.060    0.040               563   0.330    0.270
  562   0.060   -0.030               562   0.270    0.280
  561   0.060   -0.010               561   0.220    0.230
  560   0.140    0.120               560   0.210    0.240
  559   0.100    0.080               559   0.200    0.200
  558   0.060   -0.050               558   0.110    0.150
  557   0.050    0.000               557   0.280    0.200
  556   0.050   -0.020               556   0.310    0.210
  555   0.050    0.000               555   0.160    0.150
  554   0.050   -0.070               554   0.170    0.100
  553   0.140    0.080               553   0.110    0.090
  552   0.120    0.080               552   0.110    0.070
  551   0.130   -0.010               551   0.090   -0.020
  550   0.100    0.020               550   0.190    0.110
  549   0.080   -0.020               549   0.290    0.170
  548   0.080   -0.030               548   0.190    0.120
  547   0.070   -0.020               547   0.110    0.020
  546   0.110    0.000               546   0.130    0.050
  545   0.100   -0.010               545   0.180    0.140
  544   0.110    0.010               544   0.100    0.140
  543   0.130    0.040               543   0.070    0.150
  541   0.130                        541   0.040
  540   0.130                        540   0.000
  539   0.120                        539   0.000
        =====    =====                     =====    =====
AVERAGE 0.113    0.077                     0.200    0.227
MAX     0.460    0.580                     0.800    0.890
```

```
*****************************************************************
          LOCKPORT CONCRETE LOSS SURVEYS IN JUL 84 AND JAN 93
*****************************************************************
RIVER WALL                      RIVER WALL
MONOLITH  23,   CENTERLINE      MONOLITH   39/41   JOINT
===============================  ===========================
  ELEV   LOSS 84   LOSS 93        ELEV   LOSS 84   LOSS 93
          (FT)      (FT)                   (FT)      (FT)
   584    0.000     0.000          584    0.000     0.000
   583    0.020     0.030          583    0.140     0.150
   582    0.020     0.020          582    0.140     0.160
   581    0.030     0.030          581    0.140     0.160
   580    0.040     0.060          580    0.150     0.170
   579    0.080     0.090          579    0.170     0.170
   578    0.160     0.260          578    0.160     0.210
   577    0.300     0.400          577    0.360     0.430
   576    0.210     0.320          576    0.290     0.340
   575    0.230     0.290          575    0.200     0.240
   574    0.110     0.230          574    0.230     0.230
   573    0.120     0.150          573    0.160     0.180
   572    0.130     0.160          572    0.180     0.250
   571    0.110     0.150          571    0.190     0.230
   570    0.140     0.160          570    0.170     0.170
   569    0.250     0.250          569    0.160     0.190
   568    0.250     0.330          568    0.160     0.180
   567    0.150     0.190          567    0.200     0.240
   566    0.070     0.100          566    0.230     0.280
   565    0.050     0.060          565    0.170     0.200
   564    0.040     0.090          564    0.170     0.190
   563    0.070     0.150          563    0.180     0.200
   562    0.060     0.150          562    0.140     0.160
   561    0.070     0.040          561    0.170     0.130
   560    0.050     0.040          560    0.160     0.110
   559    0.020     0.010          559    0.170     0.110
   558    0.030     0.020          558    0.200     0.140
   557    0.010    -0.020          557    0.160     0.090
   556    0.050     0.030          556    0.170     0.150
   555    0.150     0.150          555    0.270     0.320
   554    0.040     0.050          554    0.120     0.100
   553    0.060     0.060          553    0.130     0.080
   552    0.050     0.040          552    0.140     0.080
   551    0.050     0.000          551    0.170     0.100
   550    0.040     0.000          550    0.160     0.100
   549    0.050     0.010          549    0.170     0.090
   548    0.090     0.050          548    0.170     0.130
   547    0.070     0.050          547    0.190     0.110
   546    0.110     0.130          546    0.150     0.090
   545    0.150     0.110          545    0.190     0.110

   543    0.080     0.020          543    0.160     0.110
   542    0.080     0.020          542    0.150     0.120
   541    0.080                    541    0.150
   540    0.080                    540    0.210
   539    0.080                    539    0.100
          =====     =====                 =====     =====
AVERAGE   0.092     0.105                 0.172     0.166
MAX       0.300     0.400                 0.360     0.430
```

```
************************************************************
      LOCKPORT CONCRETE LOSS SURVEYS IN JUL 84 AND JAN 93
************************************************************
RIVER WALL                        RIVER WALL
MONOLITH 41 1' DS OF US JT        MONOLITH  41,  CENTERLINE
=========================        ==========================
 ELEV   LOSS 84   LOSS 93          ELEV   LOSS 84   LOSS 93
         (FT)      (FT)                    (FT)      (FT)
  584    0.000     0.000            584    0.000     0.000
  583    0.010     0.040            583   -0.010     0.000
  582    0.030     0.100            582   -0.010     0.000
  581    0.030     0.050            581   -0.010     0.000
  580    0.060     0.100            580   -0.030     0.000
  579    0.070     0.140            579   -0.020     0.010
  578    0.160     0.250            578    0.080     0.180
  577    0.320     0.420            577    0.240     0.360
  576    0.270     0.320            576    0.190     0.300
  575    0.220     0.320            575    0.110     0.180
  574    0.140     0.220            574    0.090     0.190
  573    0.060     0.180            573    0.040     0.120
  572    0.020     0.140            572    0.020     0.110
  571    0.030     0.100            571   -0.010     0.110
  570    0.150     0.120            570    0.020     0.060
  569    0.010     0.040            569   -0.060    ·0.070
  568    0.000     0.060            568   -0.050     0.000
  567    0.030     0.130            567   -0.050     0.050
  566    0.180     0.200            566    0.070     0.140
  565    0.120     0.140            565    0.090     0.140
  564   -0.010     0.110            564    0.070     0.130
  563    0.020     0.130            563   -0.010     0.090
  562    0.000     0.070            562   -0.030     0.020
  561    0.010    -0.020            561   -0.040     0.010
  560    0.000     0.060            560   -0.040    -0.040
  559    0.020     0.000            559   -0.040    -0.030.
  558    0.000     0.050            558   -0.020    -0.030
  557    0.020     0.020            557   -0.030    -0.020
  556    0.020     0.080            556   -0.040     0.010
  555    0.030     0.080            555    0.050     0.010
  554    0.020     0.010            554    0.010     0.130
  553    0.020     0.000            553    0.000     0.120
  552    0.040     0.010            552   -0.010     0.040
  551    0.020     0.000            551   -0.010    -0.010
  550    0.040     0.010            550    0.000     0.000
  549    0.040     0.010            549    0.000     0.010
  548    0.050     0.010            548    0.000     0.010
  547    0.050     0.010            547    0.010     0.010

  545    0.040     0.040            545    0.030     0.020
  544    0.060     0.040            544    0.070     0.100
  543    0.060     0.030            543    0.030     0.030
  542    0.060     0.020            542    0.030     0.030

  541    0.050                      541    0.020
  540    0.050                      540    0.020
  539    0.050                      539    0.020
         =====     =====                   =====     =====
AVERAGE  0.059     0.089                   0.017     0.062
MAX      0.320     0.420                   0.240     0.360
```

```
*************************************************
        LOCKPORT CONCRETE LOSS SURVEYS IN JUL 84 AND JAN 93
*************************************************
RIVER WALL
MONOLITH 47 1' DS OF US JT
===========================
  ELEV    LOSS 84   LOSS 93
           (FT)      (FT)
   584    0.000     0.000
   583    0.000     0.010
   582    0.000     0.010
   581   -0.010     0.010
   580   -0.010     0.010
   579   -0.010     0.010
   578   -0.010     0.010
   577   -0.010     0.040
   576    0.050     0.190
   575    0.120     0.300
   574    0.200     0.320
   573    0.220     0.350
   572    0.180     0.270
   571    0.090     0.130
   570   -0.020     0.010
   569   -0.020    -0.010
   568   -0.020     0.000
   567   -0.030    -0.010
   566   -0.030    -0.020
   565   -0.030    -0.030
   564   -0.020    -0.030
   563   -0.020    -0.020
   562    0.010     0.060
   561    0.000    -0.020
   560    0.030     0.100
   559    0.060     0.110
   558    0.010     0.090
   557    0.000     0.050
   556    0.000     0.060
   555    0.010     0.030
   554    0.030     0.100
   553    0.040     0.130
   552    0.040     0.130
   551    0.050     0.100
   550    0.010     0.080
   549    0.010     0.050
   548    0.010     0.020
   547    0.010     0.010
   546    0.010     0.010
   545    0.020     0.060
   544    0.030     0.050
   543    0.040     0.060
   542    0.040     0.050
   541    0.050
   540    0.030
   539    0.030
          =====     =====
AVERAGE   0.026     0.067
MAX       0.220     0.350
```

Appendix A Field Logs for Lockport Loss Measurements

```
*********************************************************
    LOCKPORT CONCRETE LOSS SURVEYS IN JUL 84 AND JAN 93
*********************************************************
LAND WALL - BETWEEN POOLS          LAND WALL - BETWEEN POOLS
MONOLITH  14,   CENTERLINE         MONOLITH  16,   CENTERLINE
==============================     ==============================
   ELEV   LOSS 84   LOSS 93           ELEV   LOSS 84   LOSS 93
           (FT)      (FT)                     (FT)      (FT)
   578    -0.010    -0.010            578     0.160     0.260
   577    -0.010    -0.010            577     0.400     0.470
   576    -0.010     0.000            576     0.360     0.500
   575    -0.010     0.000            575     0.300     0.410
   574    -0.020    -0.010            574     0.270     0.350
   573     0.000    -0.030            573     0.160     0.260
   572     0.060     0.080            572     0.100     0.220
   571     0.060     0.080            571     0.080     0.170
   570     0.030     0.040            570     0.080     0.140
   569     0.000     0.060            569     0.080     0.150
   568    -0.010     0.000            568     0.070     0.120
   567    -0.010     0.020            567     0.040     0.110
   566     0.030     0.030            566    -0.020     0.080
   565    -0.010     0.030            565    -0.100    -0.030
   564    -0.030    -0.050            564    -0.080     0.020
   563    -0.030    -0.040            563     0.100     0.100
   562    -0.030    -0.040            562     0.090     0.170
   561    -0.020    -0.040            561     0.070     0.150
   560    -0.020    -0.040            560     0.010     0.130
   559    -0.010    -0.030            559    -0.040     0.020
   558    -0.010     0.020            558    -0.070     0.020
   557     0.030     0.040            557    -0.050    -0.020
   556     0.000     0.100            556    -0.080    -0.080
   555     0.020     0.010            555    -0.060    -0.080
   554     0.020    -0.010            554     0.000     0.000
   553     0.010     0.030            553     0.000     0.040
   552     0.020    -0.020            552    -0.030     0.000
   551     0.050    -0.010            551    -0.010     0.040
   550     0.030    -0.020            550     0.000     0.010
   549     0.020    -0.010            549     0.020     0.010
   548     0.020    -0.010            548     0.080     0.080
           =====     =====                    =====     =====
AVERAGE    0.005     0.005                    0.062     0.123
MAX        0.060     0.080                    0.400     0.500
```

Appendix A Field Logs for Lockport Loss Measurements

```
*****************************************************************
        LOCKPORT CONCRETE LOSS SURVEYS IN JUL 84 AND JAN 93
*****************************************************************
LAND WALL - BETWEEN POOLS          LAND WALL - BETWEEN POOLS
MONOLITHS 20/22 JOINT              MONOLITH  22,   CENTERLINE
===========================        ===========================
   ELEV  LOSS 84  LOSS 93             ELEV  LOSS 84   LOSS 93
         (FT)     (FT)                       (FT)      (FT)
    578  0.180    0.380              578  -0.030     0.020
    577  0.310    0.540              577   0.000     0.080
    576  0.460    0.630              576   0.130     0.270
    575  0.360    0.610              575   0.240     0.300
    574  0.240    0.380              574   0.200     0.230
    573  0.070    0.280              573   0.120     0.180
    572  0.050    0.350              572   0.020     0.120
    571  0.060    0.250              571  -0.020     0.040
    570  0.000    0.180              570   0.030     0.040
    569  0.050    0.100              569  -0.040     0.030
    568  0.000    0.050              568  -0.050    -0.040
    567  0.000    0.130              567  -0.060    -0.040
    566  0.010    0.110              566  -0.070    -0.050
    565 -0.010    0.110              565  -0.070    -0.060
    564  0.110    0.160              564  -0.060    -0.050
    563 -0.030    0.060              563  -0.060     0.060
    562  0.010    0.060              562   0.040     0.080
    561 -0.010    0.130              561   0.020     0.120
    560  0.020    0.030              560   0.010     0.100
    559  0.040    0.040              559  -0.030     0.090
    558  0.040    0.030              558  -0.040     0.070
    557  0.010    0.110              557  -0.030     0.030
    556  0.030    0.050              556  -0.030     0.000
    555  0.040    0.110              555   0.050     0.050
    554  0.050    0.060              554  -0.030    -0.020
    553  0.100    0.010              553  -0.030    -0.020
    552  0.050    0.000              552  -0.030    -0.020
    551  0.050    0.120              551  -0.020    -0.020
    550  0.070    0.050              550  -0.010    -0.010
    549  0.070    0.050              549  -0.010    -0.010
    548  0.050    0.010              548   0.000     0.000
         =====    =====                   =====     =====
AVERAGE  0.080    0.167                   0.005     0.051
MAX      0.460    0.630                   0.240     0.300
```

Appendix A Field Logs for Lockport Loss Measurements

```
*************************************************************
          LOCKPORT CONCRETE LOSS SURVEYS IN JUL 84 AND JAN 93
*************************************************************
LAND WALL - BETWEEN POOLS          LAND WALL - BETWEEN POOLS
MONOLITH  26,   CENTERLINE         MONOLITH  32,   CENTERLINE
=============================      =============================
   ELEV   LOSS 84   LOSS 93           ELEV   LOSS 84   LOSS 93
          (FT)      (FT)                     (FT)      (FT)
    578   0.020     0.020            578     0.000     0.020
    577   0.020     0.020            577     0.060     0.110
    576   0.110     0.220            576     0.150     0.260
    575   0.150     0.200            575     0.140     0.200
    574   0.080     0.150            574     0.060     0.160
    573   0.010     0.060            573     0.060     0.090
    572   0.020     0.030            572     0.050     0.090
    571   0.010     0.010            571     0.140     0.190
    570   0.010     0.000            570     0.260     0.230
    569   0.000    -0.010            569     0.180     0.280
    568  -0.010    -0.010            568     0.220     0.300
    567  -0.010     0.020            567     0.280     0.380
    566   0.140     0.150            566     0.210     0.270
    565   0.120     0.220            565     0.190     0.210
    564   0.060     0.150            564     0.160     0.140
    563   0.060     0.120            563     0.110     0.130
    562   0.050     0.100            562     0.060     0.110
    561   0.010     0.030            561     0.120     0.140
    560  -0.040     0.020            560     0.060     0.110
    559  -0.040    -0.040            559     0.040     0.050
    558  -0.040    -0.050            558     0.030     0.040
    557  -0.030    -0.040            557     0.010     0.020
    556   0.030     0.050            556     0.030     0.030
    555   0.030     0.050            555     0.000     0.020
    554   0.020     0.040            554     0.010     0.000
    553   0.060     0.060            553     0.050     0.040
    552   0.000     0.030            552     0.060     0.060
    551   0.020    -0.010            551     0.050    -0.010
    550   0.010     0.030            550     0.020    -0.020
    549   0.010     0.010            549     0.000    -0.020
    548   0.030    -0.010            548     0.010    -0.020
          =====     =====                    =====     =====
AVERAGE   0.029     0.052                    0.091     0.116
MAX       0.150     0.220                    0.280     0.380
```

```
*********************************************************
       LOCKPORT CONCRETE LOSS SURVEYS IN JUL 84 AND JAN 93
*********************************************************
LAND WALL - BETWEEN POOLS          LAND WALL - BETWEEN POOLS
MONOLITH 34, 1' DS OF US JT        MONOLITH  34,  CENTERLINE
=============================      ============================
  ELEV   LOSS 84   LOSS 93           ELEV   LOSS 84   LOSS 93
          (FT)      (FT)                     (FT)      (FT)
   578    0.150     0.180             578    0.070     0.150
   577    0.460     0.510             577    0.440     0.700
   576    0.450     0.530             576    0.440     0.600
   575    0.260     0.430             575    0.290     0.460
   574    0.200     0.300             574    0.260     0.360
   573    0.220     0.270             573    0.210     0.290
   572    0.140     0.250             572    0.150     0.180
   571    0.180     0.180             571    0.220     0.230
   570    0.150     0.180             570    0.170     0.270
   569    0.060     0.100             569    0.140     0.210
   568    0.010     0.010             568    0.120     0.170
   567    0.000    -0.020             567    0.140     0.160
   566   -0.020    -0.030             566    0.080     0.140
   565    0.000    -0.040             565    0.000     0.050
   564   -0.030     0.000             564   -0.030     0.000
   563   -0.030    -0.040             563   -0.030    -0.030
   562    0.010     0.000             562   -0.050    -0.050
   561    0.040     0.000             561   -0.060    -0.080
   560    0.090     0.020             560   -0.040    -0.090
   559    0.100     0.060             559   -0.050    -0.090
   558    0.070     0.030             558   -0.040    -0.090
   557    0.040     0.000             557   -0.040    -0.090
   556    0.050     0.060             556   -0.020    -0.090
   555    0.060     0.080             555   -0.020    -0.060
   554    0.050     0.030             554    0.070     0.050
   553    0.080     0.070             553    0.090     0.010
   552    0.050     0.030             552    0.000    -0.020
   551    0.110     0.010             551    0.020    -0.070
   550    0.050     0.000             550    0.020    -0.060
   549    0.030    -0.020             549    0.020    -0.060
   548    0.070     0.010             548    0.030    -0.020
          =====     =====                    =====     =====
AVERAGE   0.100     0.103                    0.084     0.101
MAX       0.460     0.530                    0.440     0.700
```

Appendix A Field Logs for Lockport Loss Measurements

```
************************************************************
      LOCKPORT CONCRETE LOSS SURVEYS IN JUL 84 AND JAN 93
************************************************************
LAND WALL - BETWEEN POOLS          LAND WALL - BETWEEN POOLS
MONOLITH 44, 4' US OF DS JT         MONOLITH  48,  CENTERLINE
==========================          ==========================
  ELEV   LOSS 84   LOSS 93            ELEV   LOSS 84   LOSS 93
          (FT)      (FT)                      (FT)      (FT)
   578    0.170     0.240              578    0.460     0.450
   577    0.460     0.580              577    0.800     0.890
   576    0.350     0.440              576    0.500     0.600
   575    0.340     0.380              575    0.360     0.480
   574    0.280     0.330              574    0.260     0.490
   573    0.200     0.200              573    0.220     0.340
   572    0.210     0.210              572    0.270     0.430
   571    0.150     0.140              571    0.260     0.330
   570    0.100     0.120              570    0.270     0.290
   569    0.050     0.080              569    0.190     0.280
   568    0.040     0.000              568    0.200     0.300
   567    0.040    -0.020              567    0.220     0.280
   566    0.040    -0.020              566    0.170     0.160
   565    0.050    -0.010              565    0.260     0.280
   564    0.060     0.090              564    0.260     0.230
   563    0.060     0.040              563    0.330     0.270
   562    0.060    -0.030              562    0.270     0.280
   561    0.060    -0.010              561    0.220     0.230
   560    0.140     0.120              560    0.210     0.240
   559    0.100     0.080              559    0.200     0.200
   558    0.060    -0.050              558    0.110     0.150
   557    0.050     0.000              557    0.280     0.200
   556    0.050    -0.020              556    0.310     0.210
   555    0.050     0.000              555    0.160     0.150
   554    0.050    -0.070              554    0.170     0.100
   553    0.140     0.080              553    0.110     0.090
   552    0.120     0.080              552    0.110     0.070
   551    0.130    -0.010              551    0.090    -0.020
   550    0.100     0.020              550    0.190     0.110
   549    0.080    -0.020              549    0.290     0.170
   548    0.080    -0.030              548    0.190     0.120
          =====     =====                     =====     =====
AVERAGE   0.125     0.095                     0.256     0.271
MAX       0.460     0.580                     0.800     0.890
```

```
************************************************************
        LOCKPORT CONCRETE LOSS SURVEYS IN JUL 84 AND JAN 93
************************************************************
RIVER WALL - BETWEEN POOLS          RIVER WALL - BETWEEN POOLS
MONOLITH  23,   CENTERLINE          MONOLITH    39/41   JOINT
=========================           ==========================
   ELEV  LOSS 84   LOSS 93             ELEV  LOSS 84   LOSS 93
         (FT)      (FT)                      (FT)      (FT)
   578   0.160     0.260               578   0.160     0.210
   577   0.300     0.400               577   0.360     0.430
   576   0.210     0.320               576   0.290     0.340
   575   0.230     0.290               575   0.200     0.240
   574   0.110     0.230               574   0.230     0.230
   573   0.120     0.150               573   0.160     0.180
   572   0.130     0.160               572   0.180     0.250
   571   0.110     0.150               571   0.190     0.230
   570   0.140     0.160               570   0.170     0.170
   569   0.250     0.250               569   0.160     0.190
   568   0.250     0.330               568   0.160     0.180
   567   0.150     0.190               567   0.200     0.240
   566   0.070     0.100               566   0.230     0.280
   565   0.050     0.060               565   0.170     0.200
   564   0.040     0.090               564   0.170     0.190
   563   0.070     0.150               563   0.180     0.200
   562   0.060     0.150               562   0.140     0.160
   561   0.070     0.040               561   0.170     0.130
   560   0.050     0.040               560   0.160     0.110
   559   0.020     0.010               559   0.170     0.110
   558   0.030     0.020               558   0.200     0.140
   557   0.010    -0.020               557   0.160     0.090
   556   0.050     0.030               556   0.170     0.150
   555   0.150     0.150               555   0.270     0.320
   554   0.040     0.050               554   0.120     0.100
   553   0.060     0.060               553   0.130     0.080
   552   0.050     0.040               552   0.140     0.080
   551   0.050     0.000               551   0.170     0.100
   550   0.040     0.000               550   0.160     0.100
   549   0.050     0.010               549   0.170     0.090
   548   0.090     0.050               548   0.170     0.130
         =====     =====                     =====     =====
AVERAGE  0.104     0.126                     0.184     0.182
MAX      0.300     0.400                     0.360     0.430
```

Appendix A Field Logs for Lockport Loss Measurements

```
************************************************************
        LOCKPORT CONCRETE LOSS SURVEYS IN JUL 84 AND JAN 93
************************************************************
RIVER WALL - BETWEEN POOLS          RIVER WALL - BETWEEN POOLS
MONOLITH 41 1' DS OF US JT          MONOLITH  41,   CENTERLINE
=========================          =========================
  ELEV   LOSS 84   LOSS 93            ELEV   LOSS 84   LOSS 93
          (FT)      (FT)                      (FT)      (FT)
   578    0.160     0.250             578    0.080     0.180
   577    0.320     0.420             577    0.240     0.360
   576    0.270     0.320             576    0.190     0.300
   575    0.220     0.320             575    0.110     0.180
   574    0.140     0.220             574    0.090     0.190
   573    0.060     0.180             573    0.040     0.120
   572    0.020     0.140             572    0.020     0.110
   571    0.030     0.100             571   -0.010     0.110
   570    0.150     0.120             570    0.020     0.060
   569    0.010     0.040             569   -0.060     0.070
   568    0.000     0.060             568   -0.050     0.000
   567    0.030     0.130             567   -0.050     0.050
   566    0.180     0.200             566    0.070     0.140
   565    0.120     0.140             565    0.090     0.140
   564   -0.010     0.110             564    0.070     0.130
   563    0.020     0.130             563   -0.010     0.090
   562    0.000     0.070             562   -0.030     0.020
   561    0.010    -0.020             561   -0.040     0.010
   560    0.000     0.060             560   -0.040    -0.040
   559    0.020     0.000             559   -0.040    -0.030
   558    0.000     0.050             558   -0.020    -0.030
   557    0.020     0.020             557   -0.030    -0.020
   556    0.020     0.080             556   -0.040     0.010
   555    0.030     0.080             555    0.050     0.010
   554    0.020     0.010             554    0.010     0.130
   553    0.020     0.000             553    0.000     0.120
   552    0.040     0.010             552   -0.010     0.040
   551    0.020     0.000             551   -0.010    -0.010
   550    0.040     0.010             550    0.000     0.000
   549    0.040     0.010             549    0.000     0.010
   548    0.050     0.010             548    0.000     0.010
          =====     =====                    =====     =====
AVERAGE   0.066     0.105                    0.021     0.079
MAX       0.320     0.420                    0.240     0.360
```

```
************************************************************
          LOCKPORT CONCRETE LOSS SURVEYS IN JUL 84 AND JAN 93
************************************************************
RIVER WALL - BETWEEN POOLS
MONOLITH 47 1' DS OF US JT
============================
    ELEV    LOSS 84    LOSS 93
             (FT)       (FT)
     578    -0.010      0.010
     577    -0.010      0.040
     576     0.050      0.190
     575     0.120      0.300
     574     0.200      0.320
     573     0.220      0.350
     572     0.180      0.270
     571     0.090      0.130
     570    -0.020      0.010
     569    -0.020     -0.010
     568    -0.020      0.000
     567    -0.030     -0.010
     566    -0.030     -0.020
     565    -0.030     -0.030
     564    -0.020     -0.030
     563    -0.020     -0.020
     562     0.010      0.060
     561     0.000     -0.020
     560     0.030      0.100
     559     0.060      0.110
     558     0.010      0.090
     557     0.000      0.050
     556     0.000      0.060
     555     0.010      0.030
     554     0.030      0.100
     553     0.040      0.130
     552     0.040      0.130
     551     0.050      0.100
     550     0.010      0.080
     549     0.010      0.050
     548     0.010      0.020
             =====      =====
AVERAGE      0.033      0.030
MAX          0.220      0.350
```

Appendix A Field Logs for Lockport Loss Measurements

Appendix B
Field Logs for Point Marion Loss Measurements

Lock 8 Monongahela River
Land Wall Monolith-15 Station 1+63.11
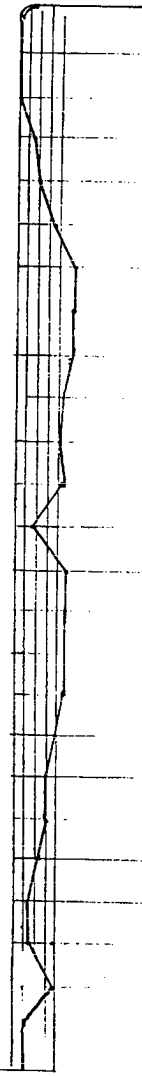
Temp 64°
Upper Pool 793.2

MJ-14¢15

Top of Wall 803.0

0	1'
0	2'
5"	3'
6"	4'
10"	5'
15¼	6'
15"	7'
15"	8'
13"	9'
12"	10'
12½"	11
5"	12'
14½"	13'
14"	14'
14"	15'
14"	16'
12"	17'
9"	18'
9"	19'
7"	20'
4"	21'
4½"	22
11"	23
3"	24
3"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Lock 8 Monongahela River
Land Wall Monolith-_15_ Station _1+68_ B

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

½"	1'
½"	2'
1"	3'
1"	4'
1"	5'
1"	6'
1"	7'
2"	8'
3"	9'
3"	10'
7½"	11
6"	12'
4½"	13'
4"	14'
3"	15'
4"	16'
3"	17'
2"	18'
2¾"	19'
2¼"	20'
2¼"	21'
2¼"	22
2"	23
1½"	24
2"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/27/93
3/8"=1'-0"

Lock 8 Monongahela River
Land Wall Monolith-15 Station 1+73 B
Temp 64°
Upper Pool 793.2

Top of Wall 803.0

Measurement	Depth
0	1'
0	2'
1/2"	3'
1/2"	4'
3/4"	5'
1/2"	6'
0	7'
0	8'
1"	9'
4"	10'
8 3/4"	11
5 1/2"	12'
5"	13'
4"	14'
4"	15'
4"	16'
3"	17'
1 1/2"	18'
2"	19'
2 1/2"	20'
1 1/4"	21'
1"	22
1 1/2"	23
2"	24
3"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Lock 8 Monongahela River
Land Wall Monolith-15 Station 1+78 B

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

0	1'
0	2'
0	3'
0	4'
½"	5'
0	6'
0	7'
0	8'
1"	9'
3"	10'
9"	11
6½"	12'
6"	13'
5"	14'
5¾"	15'
4"	16'
4"	17'
3½"	18'
3¼"	19'
3"	20'
1½"	21'
1¼"	22
1"	23
3"	24
3"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8=1'-0"

Lock 8 Monongahela River

Land Wall Monolith-15 Station 1+83 B

Temp 64°

Upper Pool 793.2

Top of Wall 803.0

0	1'
0	2'
0	3'
0	4'
1/4"	5'
0	6'
0	7'
0	8'
3/4"	9'
2"	10'
5"	11
9 1/4"	12'
7"	13'
4 1/2"	14'
4"	15'
4 3/4"	16'
3 1/2"	17'
2 1/2"	18'
3 3/4"	19'
4 1/2"	20'
6"	21'
5 1/2"	22
5"	23
5"	24
5"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8"=1'=0"

B6

Lock 8 Monongahela River
Land Wall Monolith-15 Station 1+88 B

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

0	1'
0	2'
0	3'
0	4'
0	5'
0	6'
0	7'
0	8'
0	9'
1"	10'
4 3/4"	11
8 1/2	12'
7"	13'
5"	14'
5"	15'
4 1/4"	16'
4 1/4"	17'
4"	18'
3 1/2"	19'
4"	20'
5"	21'
5 3/4"	22
6 1/4"	23
4 1/2"	24
4 1/2"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Lock 8 Monongahela River
Land Wall Monolith-15 Station 1+93 B

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

Measurement	Depth
0	1'
0	2'
0	3'
0	4'
0	5'
1/2"	6'
0	7'
0	8'
0	9'
1/2"	10'
3"	11
11"	12'
6 1/2"	13'
5 1/2"	14'
5 1/2"	15'
5"	16'
3 3/4"	17'
4"	18'
4 1/2	19'
6"	20'
6 1/4	21'
6"	22
6 1/4"	23
6"	24
6"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8=1'=0"

Lock 8 Monongahela River
Land Wall Monolith- _15_ Station _1+98 B_

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

Measurement	Depth
0	1'
0	2'
0	3'
0	4'
0	5'
0	6'
0	7'
0	8'
0	9'
2"	10'
5"	11
8½	12'
8"	13'
7"	14'
6"	15'
5"	16'
4½"	17'
4¾"	18'
4"	19'
7"	20'
7"	21'
6½"	22
5½"	23
4½"	24
4½"	25

Upper Pool EL 793.0

Lower Pool EL 778.0

9/21/93
3/8 = 1'-0"

Lock 8 Monongahela River
Land Wall Monolith-15 Station 2+03 B

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

Measurement	Depth
0	1'
1 3/4"	2'
2"	3'
1 1/2"	4'
1 1/4"	5'
0	6'
0	7'
0	8'
1 1/2"	9'
3"	10'
6 1/4"	11
9 1/2"	12'
8"	13'
8 1/2"	14'
7"	15'
5 1/2"	16'
4 1/2"	17'
4"	18'
4"	19'
7"	20'
7"	21'
5 1/2"	22
5 3/4"	23
5 1/2"	24
5 1/2"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8"=1'-0"

Lock 8 Monongahela River
Land Wall Monolith- 15/16 Station 2+07

Temp 64°
Upper Pool 793.2
MJ 15-16   Top of Wall 803.0

                    2"   1'
                    6"   2'
                    5"   3'
                    4 1/2"   4'
                    5 1/2"   5'
                    5"   6'
                    5 1/2"   7'
                    5 1/2"   8'
Upper Pool   5 1/2"   9'
EL 793.0   7"   10'
                    10"   11
                    10 1/2"   12'
                    8"   13'
                    8"   14'
                    8"   15'
                    7"   16'
                    6"   17'
                    5"   18'
                    6"   19'
                    8 1/2"   20'
                    10 1/4"   21'
                    10"   22
                    8"   23
Lower Pool   6 3/4"   24
EL 778.0   6 3/4"   25

                    9/21/93
                    3/8 = 1'-0"

Lock 8 - Monongahela River
Land Wall Monolith-_19_ Station _3+26_ B

Temp 64°
Upper Pool 793.2
MJ 18 & 19

Top of Wall 803.0

1 ½"	1'
2 ½"	2'
3 ½"	3'
9	4'
4 ½"	5'
5 "	6'
5 ½"	7'
5 ½"	8'
4 ¾"	9'
5 ¾"	10'
5 ½"	11
9 ½"	12'
14 ¼"	13'
14 "	14'
13 "	15'
9 "	16'
10 ½"	17'
11 "	18'
11 "	19'
11 "	20'
14 ½"	21'
16 "	22
14 "	23
9 ½"	24
9 "	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Lock 8 Monongahela River
Land Wall Monolith-19 Station 3+31 E

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

Measurement	Station
0	1'
0	2'
0	3'
0	4'
0	5'
1 1/2"	6'
2 1/2"	7'
2 1/2"	8'
2"	9'
2 1/2"	10'
3 1/2"	11
5"	12'
9 3/4"	13'
8 1/4"	14'
9"	15'
7 3/4"	16'
7 1/2"	17'
7"	18'
7"	19'
7 3/4"	20'
8"	21'
7 1/2"	22
6 3/4"	23
6 3/4"	24
6 3/4"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Lock 8 Monongahela River
Land Wall Monolith-19 Station 3+36

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

Upper Pool
EL 793.0

Lower Pool
EL 778.0

Measurement	Station
0	1'
0	2'
1"	3'
1"	4'
1"	5'
1 1/2"	6'
2"	7'
2"	8'
1 1/2"	9'
2"	10'
2 3/4"	11
4"	12'
1 1/2"	13'
8"	14'
8"	15'
7"	16'
6 3/4"	17'
6 1/2"	18'
6 1/2"	19'
7"	20'
8"	21'
7"	22
5 1/4"	23
5 1/4"	24
5 1/4"	25

9/21/93
3/8=1'-0"

Lock 8 Monongahela River
Land Wall Monolith-19 Station 3+41 B

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

0	1'
0	2'
1"	3'
1'¼"	4'
1'½"	5'
3"	6'
3"	7'
1	8'
1	9'
1	10'
1 ½	11
0	12'
0	13'
0	14'
8	15'
7'½"	16'
6'½"	17'
6"	18'
6"	19'
6"	20'
7"	21'
7"	22
6'½"	23
6'½	24
7"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Lock 8 Monongahela River
Land Wall Monolith-_19_ Station 3+46 ±

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

0	1'
0	2'
0	3'
1 1/4"	4'
1 1/4"	5'
3/4"	6'
3"	7'
2 1/2"	8'
1"	9'
1"	10'
0	11
0	12'
0	13'
0	14'
9"	15'
6 1/2"	16'
6 1/4"	17'
5 3/4"	18'
6"	19'
6"	20'
7"	21'
6 1/2"	22
6 1/2"	23
6 1/2"	24
6 1/2"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Lock 8 Monongahela River
Land Wall Monolith-19 Station 3+51

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

0	1'
0	2'
1 1/4"	3'
1"	4'
1 1/4"	5'
2 1/2"	6'
3"	7'
2 1/2"	8'
1 1/2"	9'
0	10'
0	11
0	12'
0	13'
0	14'
8"	15'
6 1/2"	16'
6 1/2"	17'
6 1/2"	18'
6"	19'
7 1/2"	20'
7"	21'
6 3/4"	22
6"	23
6"	24
6"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Appendix B Field Logs for Point Marion Loss Measurements

Lock 8 Monongahela River
Land Wall Monolith-19 Station 3+55]

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

0	1'
0	2'
1"	3'
1 1/2"	4'
1 1/4"	5'
4"	6'
1"	7'
1 3/4"	8'
1 3/4"	9'
2 1/2"	10'
4"	11
0	12'
7"	13'
7 1/2"	14'
7 1/2"	15'
5 1/2"	16'
6"	17'
5"	18'
5"	19'
6 1/4"	20'
7"	21'
7"	22
6 1/4"	23
6"	24
5 1/2"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

B18

Appendix B Field Logs for Point Marion Loss Measurements

Lock 8 Monongahela River
Land Wall Monolith-19 Station 3+61 B

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

Measurement	Depth
0	1'
0	2'
0	3'
3/4"	4'
1 3/4"	5'
4"	6'
3 1/2"	7'
3"	8'
4 1/2"	9'
6"	10'
1"	11
1"	12'
2"	13'
5"	14'
8"	15'
7"	16'
8 1/2"	17'
6 1/2"	18'
6 1/4"	19'
7 1/2"	20'
7"	21'
6 1/4"	22
5 1/2"	23
5"	24
5 1/2"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/27/93
3/8 = 1'-0"

Lock 8 Monongahela River
Land Wall Monolith-19&20 Station 3+62 B

Temp 64°
Upper Pool 793.2

MJ 19&20

Top of Wall 803.0

0	1'
3"	2'
0	3'
5"	4'
7"	5'
0	6'
11"	7'
12"	8'
12"	9'
14"	10'
11"	11
6"	12'
5"	13'
4 1/2"	14'
3"	15'
3"	16'
7"	17'
9"	18'
7"	19'
8"	20'
11"	21'
14"	22
15"	23
14"	24
15	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/27/93
3/8 = 1'-0"

Lock 8 Monongahela River
Land Wall Monolith-20/21 Station 3+94B

Temp 64°
Upper Pool 793.2

MJ 20&21   Top of Wall 803.0

Measurement	Depth
1 ½"	1'
3 ¾"	2'
0	3'
6 ½"	4'
7 ¾	5'
11"	6'
10 ¼"	7'
10"	8'
12 ½"	9'
15"	10'
13 ½"	11
15"	12'
16"	13'
16"	14'
17"	15'
16"	16'
16"	17'
15"	18'
13 ½"	19'
12 ½"	20'
12 ½"	21'
13"	22
9"	23
7"	24
7"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/27/93
3/8 = 1'-0"

Lock 8 Monongahela River
Land Wall Monolith-21 Station 3+99

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

0	1'
0	2'
0	3'
0	4'
0	5'
0	6'
0	7'
1 1/2"	8'
2 1/2"	9'
3 1/2"	10'
6 1/2"	11
7"	12'
5"	13'
4"	14'
4"	15'
7"	16'
7"	17'
7"	18'
7"	19'
7"	20'
7"	21'
7"	22
5"	23
5"	24
5"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8" = 1'-0"

Lock 8 Monongahela River
Land Wall Monolith-21 Station 4+01

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

Measurement	Depth
0	1'
0	2'
0	3'
0	4'
0	5'
0	6'
1/2"	7'
1/2"	8'
3/4"	9'
3 1/2"	10'
5"	11
6 3/4"	12'
5 1/4"	13'
5"	14'
5"	15'
5 1/2"	16'
5 1/2"	17'
5 3/4"	18'
5"	19'
5"	20'
5"	21'
5"	22
5"	23
5"	24
5"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8" = 1'-0"

Lock 8 Monongahela River
Land Wall Monolith-21 Station 4+06

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

0	1'
0	2'
0	3'
0	4'
0	5'
0	6'
1/2"	7'
1/2"	8'
1 1/2"	9'
1 1/2"	10'
4 1/2"	11
5 1/2"	12'
5"	13'
5"	14'
5"	15'
6"	16'
5"	17'
4 1/2"	18'
4 1/2"	19'
5"	20'
5"	21'
4 1/2"	22
4 1/2"	23
4 1/2"	24
4 1/2"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Lock 8 Monongahela River
Land Wall Monolith-21 Station 4+11
Temp 64°
Upper Pool 793.2

Top of Wall 803.0

0	1'
1 1/2"	2'
3/4"	3'
2 1/2"	4'
0	5'
3"	6'
4"	7'
4 1/2"	8'
5"	9'
3"	10'
0	11
1/4"	12'
3/4"	13'
1 1/2"	14'
1 1/2"	15'
3 1/2"	16'
3 1/2"	17'
3"	18'
3 1/2"	19'
3 1/2"	20'
3"	21'
3 3/4"	22
4"	23
7"	24
6"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Appendix B Field Logs for Point Marion Loss Measurements

Lock 8 Monongahela River
Land Wall Monolith-21 Station 4+16

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

Measurement	Depth
0	1'
0	2'
0	3'
0	4'
0	5'
0	6'
1/2"	7'
2"	8'
0	9'
0	10'
0	11
1 1/2"	12'
2"	13'
2"	14'
2"	15'
3"	16'
1 1/2"	17'
1 1/2"	18'
1 1/4"	19'
1 1/4"	20'
2"	21'
2 1/4"	22
2 1/2"	23
3"	24
3 1/2"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8=1'-0"

Lock 8 Monongahela River
Land Wall Monolith-21 Station 4+21 B
Temp 64°
Upper Pool 793.2

Top of Wall 803.0

0	1'
0	2'
0	3'
0	4'
0	5'
0	6'
0	7'
2"	8'
1 1/4"	9'
2 1/4"	10'
4"	11
4 1/2"	12'
4 1/2"	13'
4 1/2"	14'
4 1/2"	15'
5"	16'
5"	17'
5"	18'
5"	19'
4"	20'
5"	21'
4 1/2"	22
3 3/4"	23
3 1/2"	24
3 1/2"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Lock 8 Monongahela River
River Wall Monolith-4/5 Station 0+818

Temp 64°
Upper Pool 793.2

MJ 4&5   Top of Wall 803.0

0	1'
3/4"	2'
1"	3'
1"	4'
0"	5'
2"	6'
2"	7'
2"	8'
1"	9'
1"	10'
1 1/2	11
1 1/4"	12'
1 1/2"	13'
2"	14'
2"	15'
0	16'
0	17'
0	18'
0	19'
0	20'
0	21'
0	22
2"	23
0	24
0	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/27/93
3/8 = 1'-0"

Lock 8 Monongahela River
River Wall Monolith-5 Station 0+86 B

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

0	1'
2"	2'
2 1/4"	3'
2"	4'
1 1/2"	5'
1"	6'
1"	7'
1 1/2"	8'
1 1/2"	9'
1 1/2"	10'
1 1/4"	11
1"	12'
1"	13'
0	14'
0	15'
0	16'
1"	17'
0	18'
0	19'
0	20'
0	21'
0	22
0	23
1"	24
0	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8=1'-0"

Lock 8 Monongahela River
River Wall Monolith-5 Station D+91B

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

Measurement	Depth
0	1'
2 ¾"	2'
3 "	3'
3 "	4'
2 "	5'
2 "	6'
2 "	7'
3 ½"	8'
4 "	9'
6 ½"	10'
5 "	11
5 ½"	12'
5 ¾"	13'
7 "	14'
2 ½"	15'
2 "	16'
1 ½"	17'
1 ½"	18'
0	19'
0	20'
1 ½"	21'
0	22
1	23
0	24
0	25

*Upper Pool
EL 793.0*

*Lower Pool
EL 778.0*

9/27/93
3/8 = 1'-0"

Lock 8 Monongahela River
River Wall Monolith-5 Station 0+96

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

Measurement	Depth
0	1'
1 1/2"	2'
1 1/2"	3'
2"	4'
1"	5'
1"	6'
1 3/4"	7'
1 3/4	8'
2 1/2"	9'
2 3/4"	10'
2"	11
3 1/4"	12'
4"	13'
5"	14'
2"	15'
1/2"	16'
1/2"	17'
1/2"	18'
0	19'
1/2"	20'
0	21'
1	22
0	23
0	24
0	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Lock 8 Monongahela River
River Wall Monolith-5 Station 1+01

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

0	1'
1"	2'
1"	3'
1"	4'
1"	5'
1"	6'
1"	7'
1"	8'
1"	9'
1½"	10'
2"	11
2½"	12
1"	13'
1"	14'
0	15'
1"	16
2"	17'
1¼"	18'
1"	19'
1"	20'
1"	21'
1"	22
1"	23
0	24
0	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Lock 8 Monongahela River
River Wall Monolith-5 Station 1+06

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

Measurement	Depth
0	1'
0	2'
1/2"	3'
1/2"	4'
0	5'
0	6'
0	7'
1"	8'
1 1/2"	9'
1 1/2"	10'
2"	11
2 1/2"	12'
0	13'
0	14'
0	15'
1/4"	16'
1/4"	17'
1/2"	18'
1"	19'
3/4"	20'
1/2"	21'
1/2"	22
2 1/4"	23
0	24
0	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Appendix B Field Logs for Point Marion Loss Measurements

Lock 8 Monongahela River
River Wall Monolith-5 Station 1+11 B

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

Measurement	Station
0	1'
0	2'
1/2"	3'
1/2"	4'
0	5'
0	6'
0	7'
1/2"	8'
1 1/2"	9'
2 1/2"	10'
3"	11
0	12'
0	13'
0	14'
0	15'
1"	16'
1"	17'
1"	18'
1"	19'
1"	20'
1"	21'
1"	22
3/4"	23
0	24
3"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/27/93
3/8 = 1'-0"

B34

Lock 8 Monongahela River
River Wall Monolith-5 Station 1+16

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

Measurement	Depth
0	1'
1/2"	2'
3/4"	3'
1 1/2"	4'
1"	5'
1"	6'
1 1/2"	7'
2"	8'
3 1/2"	9'
3 1/2"	10'
4"	11
1"	12
1"	13'
1"	14'
1"	15'
2"	16'
1"	17'
1"	18'
0	19'
0	20'
0	21'
0	22
1/2"	23
4"	24
3"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Appendix B Field Logs for Point Marion Loss Measurements

Lock 8 Monongahela River
River Wall Monolith-5/6 Station 1+19.11 B

Temp 64°
Upper Pool 793.2

MJ 5&6

Top of Wall 803.0

3/4"	1'
3"	2'
0	3'
7"	4'
9"	5'
9"	6'
17"	7'
19"	8'
20"	9'
16"	10'
5"	11
7"	12'
5"	13'
6"	14'
6"	15'
5"	16'
5"	17'
5"	18'
5"	19'
3"	20'
3"	21'
4"	22
4"	23
9"	24
9"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Lock 8 Monongahela River
River Wall Monolith-11/12 Station 3+26 B

Temp 64°
Upper Pool 793.2

MJ 11 & 12

Top of Wall 803.0

Upper Pool
EL 793.0
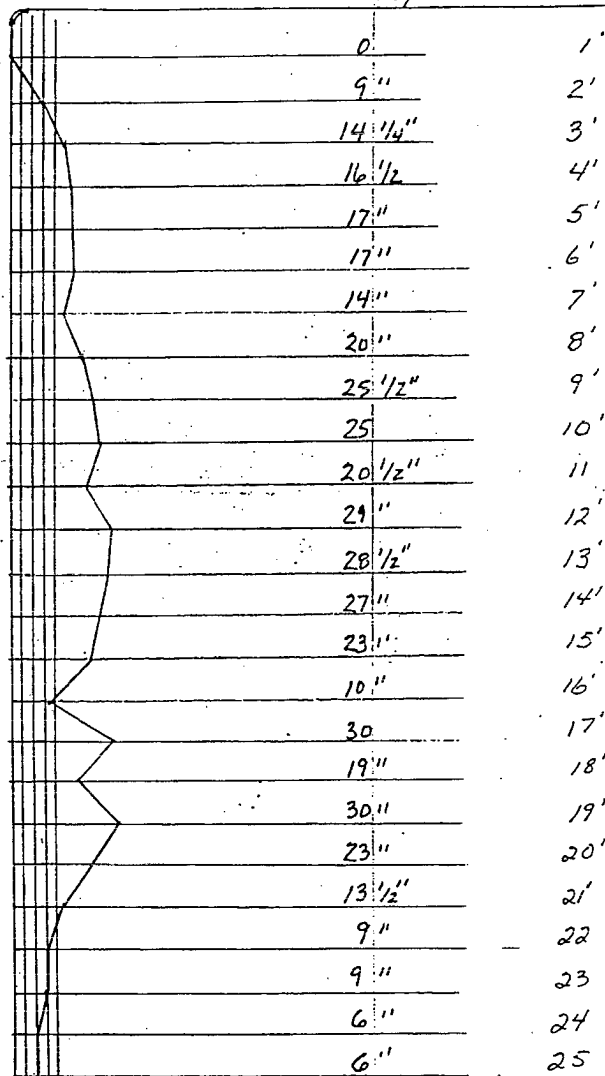
Lower Pool
EL 778.0

Measurement	Depth
0'	1'
9"	2'
14 1/4"	3'
16 1/2	4'
17"	5'
17"	6'
14"	7'
20"	8'
25 1/2"	9'
25	10'
20 1/2"	11
24"	12'
28 1/2"	13'
27"	14'
23"	15'
10"	16'
30	17'
19"	18'
30"	19'
23"	20'
13 1/2"	21'
9"	22
9"	23
6"	24
6"	25

9/21/93
3/8 = 1'-0"

Lock 8 Monongahela River
River Wall Monolith-11 Station 3+31 B

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

Measurement	Depth
0	1'
2 1/2"	2'
1 3/4"	3'
9"	4'
10"	5'
12"	6'
10"	7'
8 1/2"	8'
8 1/2"	9'
7 1/4	10'
5 1/2"	11
4"	12'
2 3/4"	13'
3"	14'
3"	15'
2"	16'
3/4"	17'
3/4"	18'
1"	19'
3/4"	20'
3/4"	21'
3/4"	22
1/2'	23
3/4"	24
2"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/27/93
3/2=1'-0"

Lock 8 Monongahela River
River Wall Monolith-11 Station 3+36

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

measurement	station
0	1'
0	2'
1"	3'
1½"	4'
0	5'
4"	6'
3"	7'
3"	8'
2½'	9'
2½"	10'
2½"	11
3	12'
1½"	13'
2"	14'
2"	15'
1"	16'
1"	17'
4"	18'
3¾"	19'
3½"	20'
1"	21'
¾"	22
1	23
2½	24
3½	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Lock 8 Monongahela River
River Wall Monolith-11 Station 3+41B

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

Reading	Depth
0	1'
0	2'
½"	3'
1 ¼"	4'
2"	5'
3"	6'
3"	7'
3"	8'
3"	9'
3 ½"	10'
2 ½"	11
1 ¾"	12'
2"	13'
2"	14'
3"	15'
1"	16'
1"	17'
1 ½"	18'
3 ½"	19'
3"	20'
1 ½"	21'
1 ½"	22
1"	23
2 ½	24
3"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Lock 8 Monongahela River
River Wall Monolith-11 Station 3+46 B

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

Measurement	Depth
0	1'
0	2'
1/2"	3'
1"	4'
2"	5'
2 1/4"	6'
2 1/4"	7'
2 1/2"	8'
2"	9'
1 3/4"	10'
2"	11
1 1/2"	12'
2"	13'
3"	14'
3 1/4"	15'
4"	16'
4"	17'
4"	18'
4 1/4"	19'
4 1/2"	20'
1 1/2"	21'
1 1/4"	22
1 1/2"	23
3"	24
3"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Lock 8 Monongahela River
River Wall Monolith-11   Station 3+51

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

Measurement	Depth
0	1'
0	2'
0	3'
0	4'
0	5'
0	6'
0	7'
2 1/2"	8'
2 1/2"	9'
2 3/4"	10'
2 3/4"	11
2"	12'
2"	13'
1 1/2"	14'
3"	15'
1"	16'
1"	17'
2"	18'
3"	19'
3 1/2"	20'
1 1/2"	21'
1 1/4"	22
1 1/2"	23
2 1/2"	24
3"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8=1'-0"

Lock 8 Monongahela River
River Wall Monolith-11 Station 3+56 B

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

measurement	ft
0	1'
0	2'
3/4"	3'
3/4"	4'
0	5'
0	6'
2"	7'
2"	8'
2 1/2"	9'
2 1/2"	10'
2 1/2"	11
2 1/2"	12'
2"	13'
2"	14'
1"	15'
1"	16'
3 1/4"	17'
3 1/2"	18'
3 3/4"	19'
3"	20'
1 1/2"	21'
1 3/4"	22
1 1/2	23
5"	24
3"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/27/93
3/8 = 1'-0"

B43

Lock 8 Monongahela River
River Wall Monolith-11 Station 3+61B

Temp 64°
Upper Pool 793.2

Top of Wall 803.0

Measurement	Foot
0	1'
0	2'
3/4"	3'
1/4"	4'
0	5'
0	6'
0	7'
2"	8'
3"	9'
3 1/2"	10'
4 1/2"	11
4 1/2	12'
5"	13'
3"	14'
3"	15'
1 1/2"	16
1 1/2"	17'
3"	18'
4"	19'
2"	20'
2"	21'
2 1/4"	22
2"	23
6"	24
3"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93
3/8 = 1'-0"

Lock 8 Monongahela River
River Wall Monolith-11/12 Station 3+62B

Temp 64°

Upper Pool 793.2

Top of Wall 803.0

0	1'
3"	2'
1 1/2"	3'
2 1/2"	4'
0	5'
0	6'
0	7'
0	8'
5"	9'
1/2"	10'
1"	11
1"	12'
5"	13'
7"	14'
7"	15'
6."	16'
6."	17'
7"	18'
5."	19'
5"	20'
5"	21'
7"	22
2"	23
0"	24
5"	25

Upper Pool
EL 793.0

Lower Pool
EL 778.0

9/21/93

3/8 = 1'-0"

Appendix C
Field Logs for Lock and Dam 13
Loss Measurements

Lock 13

Land wall
Monolith 41 - 1 ft from U/S joint

Top of lock wall elevation	592.0
Upper pool	583.0
Lower pool	572.0
Gage zero	568.7
Stage upper pool	14.46
Stage lower pool	6.75

Depth (feet)	Loss (feet)
1	0.03
2	0.06
3	0.02
4	0.01
5	0
6	0.02
7	0.01
8	0.01
9	0.03
10	0.02
11	0.04
12	0.07
13	0.03
14	0.02
15	0.06
16	0.11

Lock 13

Land wall
Monolith 42 - 8.5 ft from D/S joint

Top of lock wall elevation	592.0
Upper pool	583.0
Lower pool	572.0
Gage zero	568.7
Stage upper pool	14.46
Stage lower pool	6.75

Depth (feet)	Loss (feet)
1	0.01
2	0.02
3	0.02
4	0.01
5	0
6	0.01
7	0.05
8	0.04
9	0.01
10	0
11	0.02
12	0.01
13	0.02
14	0
15	0.01
16	0

Lock 13

Land wall
Monolith 38 - 7 ft from U/S joint

Top of lock wall elevation	592.0
Upper pool	583.0
Lower pool	572.0
Gage zero	568.7
Stage upper pool	14.46
Stage lower pool	6.75

Depth (feet)	Loss (feet)
1	0
2	0.02
3	0.02
4	0.02
5	0.02
6	0.02
7	0.03
8	0.03
9	0.04
10	0.04
11	0.03
12	0.03
13	0
14	0.02
15	0.12 (construction joint)
16	0.01

Lock 13

Intermediate wall
Monolith 25 - 6.5 ft from U/S joint

Top of lock wall elevation   592.0

Upper pool   583.0
Lower pool   572.0
Gage zero   568.7

Stage upper pool   14.46
Stage lower pool   6.75

Depth (feet)	Loss (feet)
1	0.01
2	0
3	0.01
4	0.01
5	0.01
6	0.02
7	0.01
8	0.02
9	0.02
10	0.02
11	0
12	0.03
13	0.07
14	0.07
15	0.09
16	0.12

Lock 13

Intermediate wall
Monolith 16 - 13 ft from U/S joint

Top of lock wall elevation   592.0

Upper pool	583.0
Lower pool	572.0
Gage zero	568.7

Stage upper pool	14.46
Stage lower pool	6.75

Depth (feet)	Loss (feet)
1	0.01
2	0
3	0.01
4	0.02
5	0.02
6	0.02
7	0.02
8	0.02
9	0.02
10	0.01
11	0
12	0.02
13	0.04
14	0.05
15	0.04
16	0

Appendix D
Field Logs for Lock and Dam 15
Loss Measurements

Lock 15

Land wall
Monolith 25 - 14 ft from U/S joint

Top of lock wall elevation	568.25
Upper pool	561.0
Lower pool	545.0
Gage zero	542.2
Stage upper pool	18.66
Stage lower pool	6.66

Depth (feet)	**Loss** (feet)
1	0
2	0.01
3	0.01
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	0
12	0
13	0
14	0
15	0
16	0
17	0.01
18	0.01
19	0

Lock 15

Land wall
Monolith 15 - 15 ft from D/S joint

Top of lock wall elevation	568.25
Upper pool	561.0
Lower pool	545.0
Gage zero	542.2
Stage upper pool	18.66
Stage lower pool	6.66

Depth (feet)	**Loss** (feet)
1	0
2	0
3	0
4	0
5	0.01
6	0.02
7	0.01
8	0.02
9	0.02
10	0.03
11	0.02
12	0.04
13	0.04
14	0.03
15	0.03
16	0.01
17	0.07
18	0.01

Lock 15

Land wall
Monolith 13 - 4.8 ft from D/S joint

Top of lock wall elevation	568.25
Upper pool	561.0
Lower pool	545.0
Gage zero	542.2
Stage upper pool	18.66
Stage lower pool	6.66

Depth (feet)	Loss (feet)
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0.03
11	0.01
12	0.01
13	0.01
14	0.01
15	0.02
16	0.05
17	0
18	0

Lock 15

Intermediate wall
Monolith 8 - 3 ft from D/S joint

Top of lock wall elevation	568.25
Upper pool	561.0
Lower pool	545.0
Gage zero	542.2
Stage upper pool	18.66
Stage lower pool	6.66

Depth (feet)	Loss (feet)
1	0.01
2	0.02
3	0.03
4	0
5	0.01
6	0.01
7	0
8	0
9	0
10	0.01
11	0
12	0.01
13	0.01
14	0.01
15	0.02
16	0.01
17	0
18	0

Lock 15

Intermediate wall
Monolith 16 - 10.5 ft from D/S joint

Top of lock wall elevation   568.25

Upper pool   561.0
Lower pool   545.0
Gage zero   542.2

Stage upper pool   18.66
Stage lower pool   6.66

Depth (feet)	Loss (feet)
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0.09 (construction joint)
11	0.01
12	0.01
13	0.02
14	0.01
15	0.01
16	0
17	0
18	0

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13. ABSTRACT *(Maximum 200 words)*

A multifaceted study was performed as part of the Upper Mississippi River - Illinois Waterways Navigation Study (UMR-IWW) to gather unknown or previously estimated data to assist with studying the deterioration and loss of concrete from lock walls. This effort revolved around physically monitoring barge traffic in lock chambers with time-lapse video equipment as well as measuring the actual losses from lock wall surfaces to determine the critical parameters needed for the model. Time-lapse videotape equipment was installed at three lock chambers in the UMR-IWW navigation area. The physical data collected from the videotapes assisted with determining barge velocities, the number of barge impacts on lock walls, chamber pool fluctuations, and the general operating characteristics of locks during the winter months. Measurements of lock walls were also made at four lock chambers to determine the depth of deterioration and typical deterioration patterns that exist at each lock. From this information, a model to predict the deterioration of concrete in lock chambers can be developed and implemented.

14. SUBJECT TERMS

Abrasion	Deterioration	Lock walls	Time-lapse
Barge	Freeze-thaw	Physical data	Velocity
Concrete	Impacts	Pools	Videotape
Data collection	Lock chambers	Saturation	

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