

26th USSD Annual Meeting

May 1-5, 2006

Gates and Gate Failures

TOP OF PIER
EL. 18.5m (64.0')

HP EL. 17.67m (58.0')

PIER

WOODEN STOPLOGS
FOR DEMATERING ONLY

STOPLOG SLOT

By:

Thomas L. Kahl, P.E.
(Presenter)

SILL EL. 9.45m (31.0')

TOP OF PIER
EL. 15.84m (51.0')

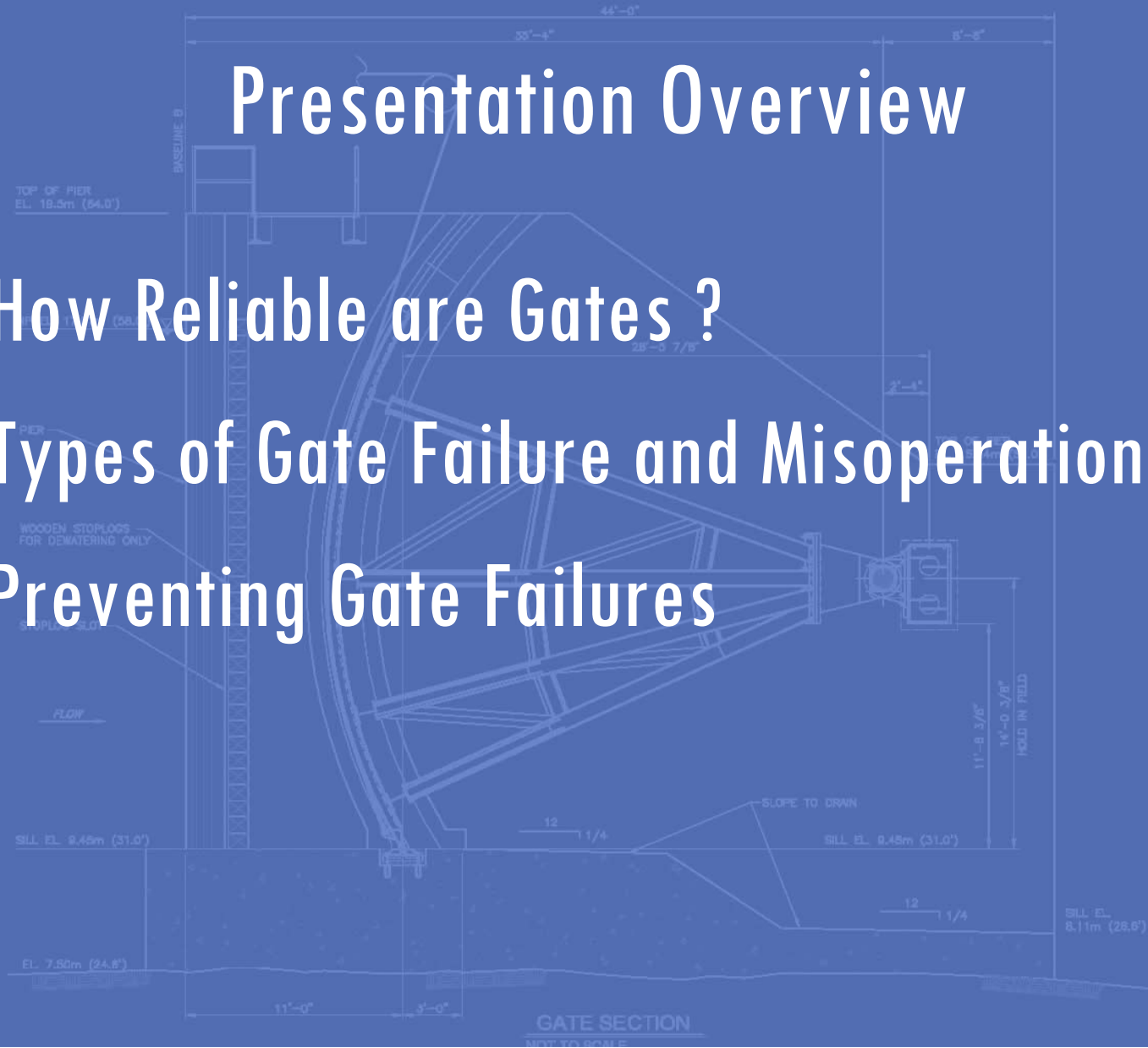


GATE SECTION
NOT TO SCALE

Kleinschmidt
Energy & Water Resource Consultants

Presentation Overview

- How Reliable are Gates ?
- Types of Gate Failure and Misoperation
- Preventing Gate Failures



Gate Reliability

National Performance of Dam Program (NPDP)

Few (3 since 1990) Gate Failures noted

(www.npdp.stanford.edu/DamDirectory)

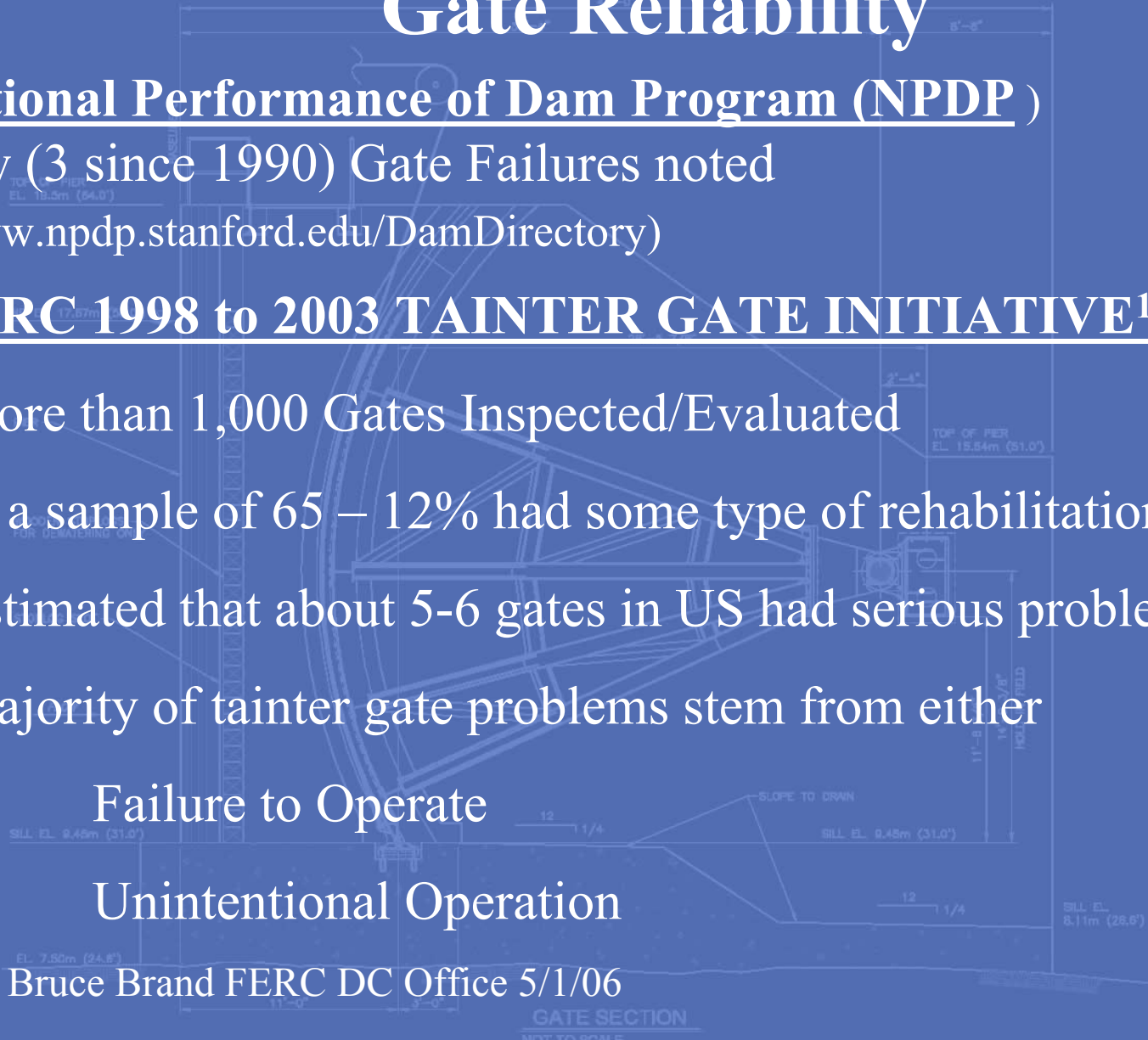
FERC 1998 to 2003 TAINTER GATE INITIATIVE¹

- More than 1,000 Gates Inspected/Evaluated
- In a sample of 65 – 12% had some type of rehabilitation
- Estimated that about 5-6 gates in US had serious problems
- Majority of tainter gate problems stem from either

Failure to Operate

Unintentional Operation

¹Per Bruce Brand FERC DC Office 5/1/06



Types of Gate Failures & Misoperation¹

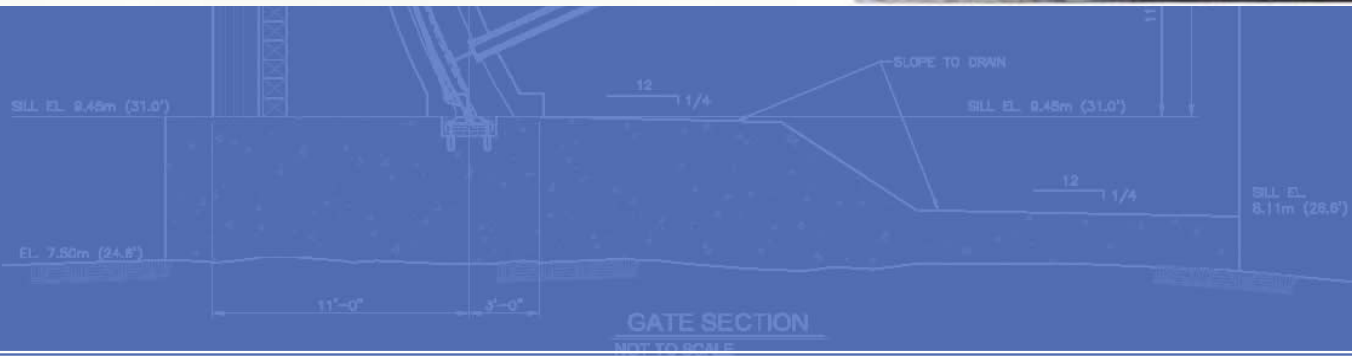
- Gates fail to open when directed.
- Gates open from equipment malfunction.
- Gates fail structurally with sudden discharge.
- Debris blockage impedes discharge.
- Gates operated incorrectly.

¹Water Operation and Maintenance Bulletin, No. 202, Dec.2002
<http://www.usbr.gov/pmts/infrastructure/inspection/waterbulletin/index.htm>

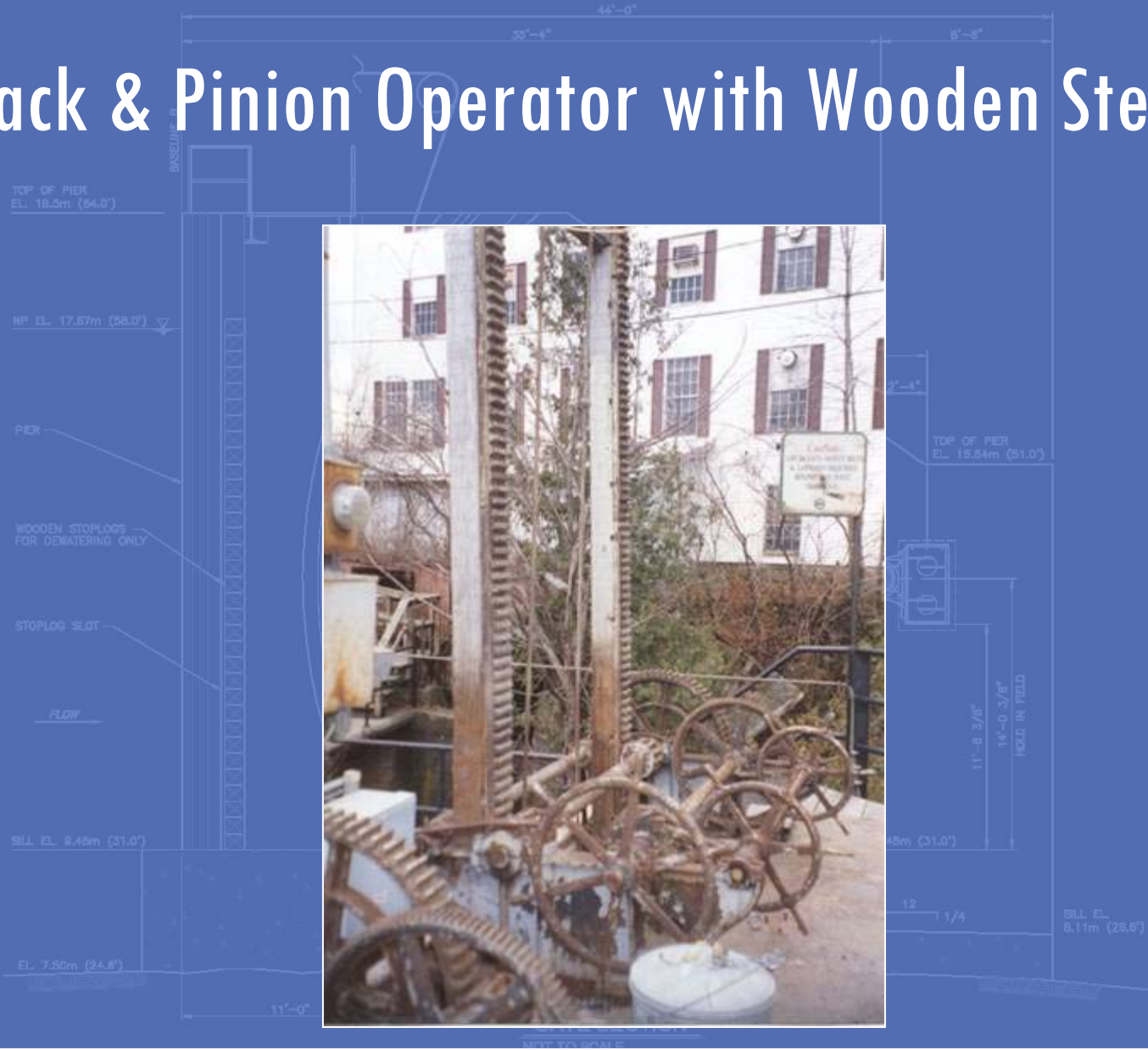
Broken Tainter Gate Chain Link







Rack & Pinion Operator with Wooden Stems





TOP OF
EL. 18.5

HP EL.

PIER

WOODEN
FOR DE

STOPLOC

PL

12 6 0 1

SILL EL. 9.45m (31.0')

12 1 1/4

SILL EL. 9.45m (31.0')

1 1/4

SILL EL.
8.11m (26.6')

EL. 7.50m (24.6')

11'-0"

3'-0"

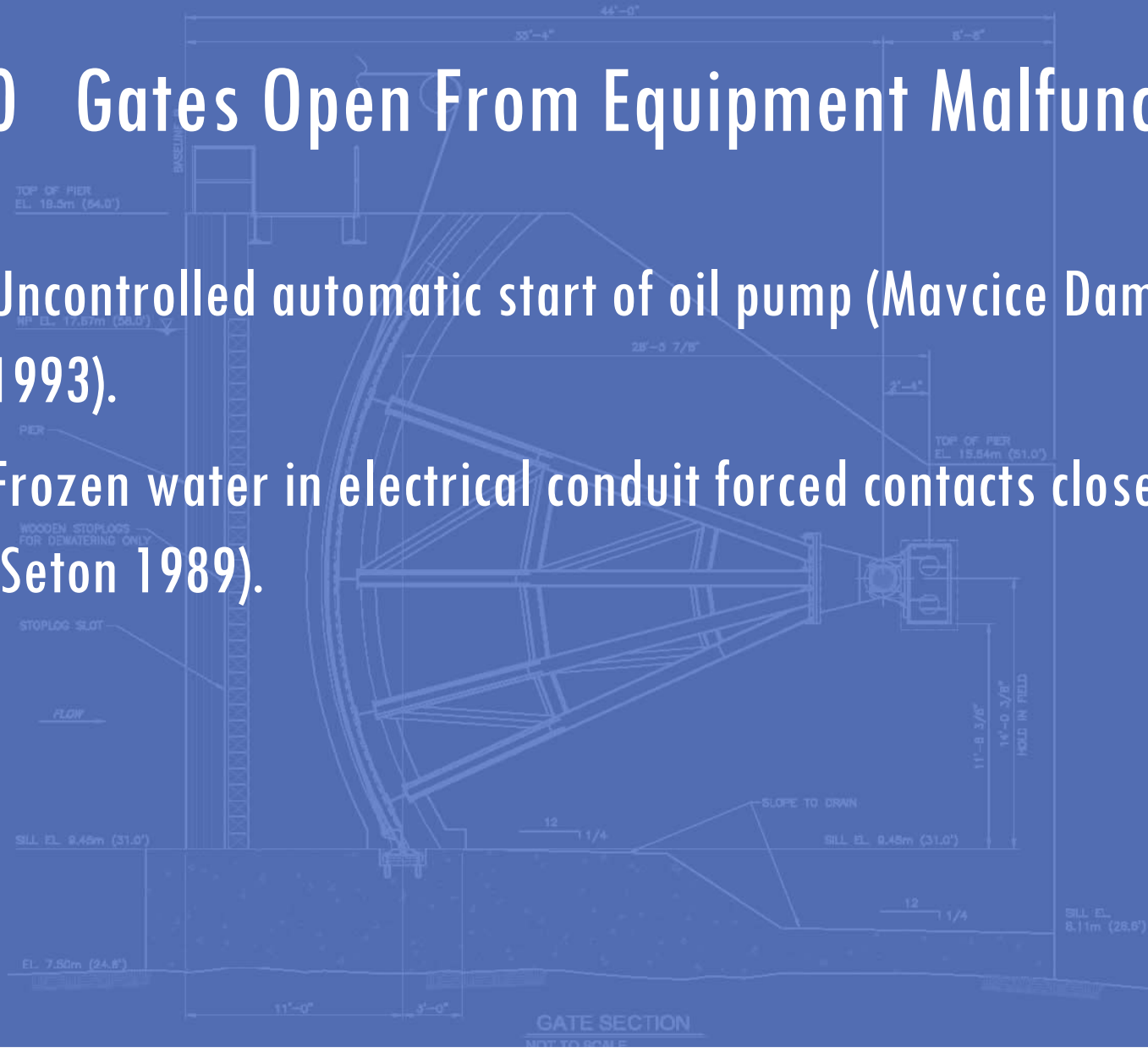
GATE SECTION

NOT TO SCALE

**Detail Of Ruptured Wooden Stem
Note Interior Decay**

2.0 Gates Open From Equipment Malfunction

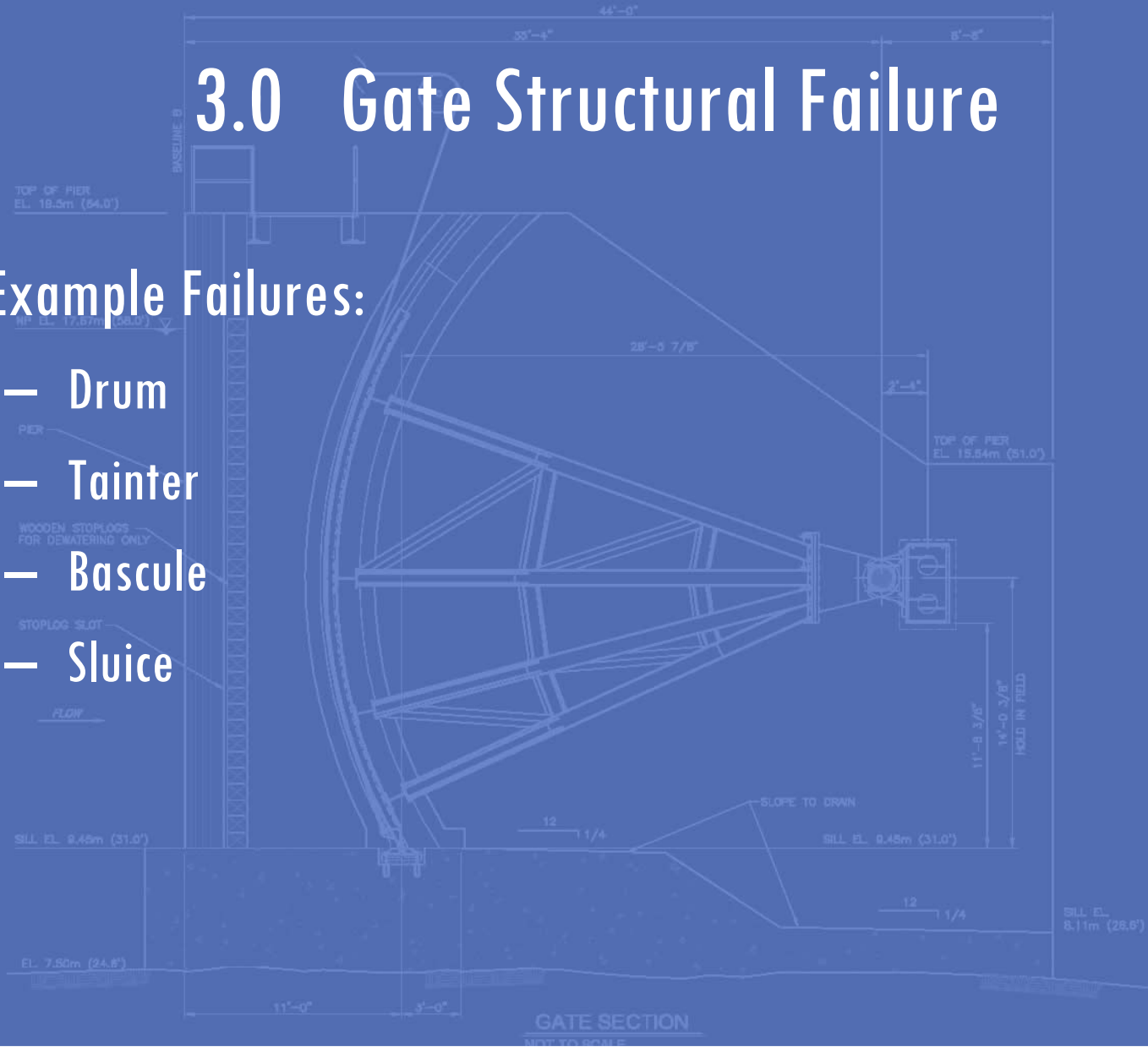
- Uncontrolled automatic start of oil pump (Mavcice Dam, 1993).
- Frozen water in electrical conduit forced contacts closed. (Seton 1989).



3.0 Gate Structural Failure

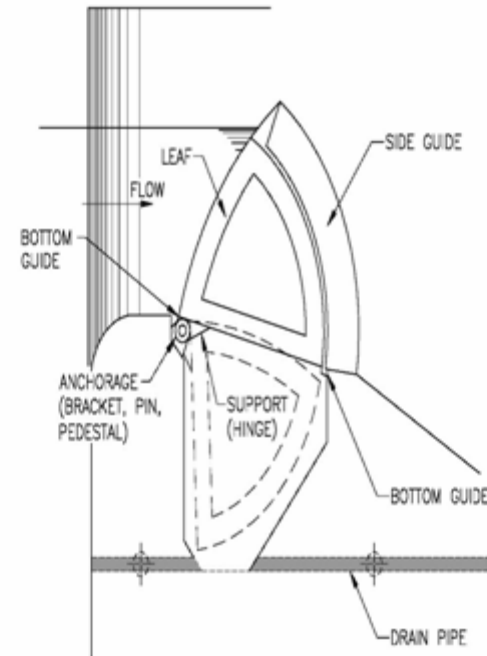
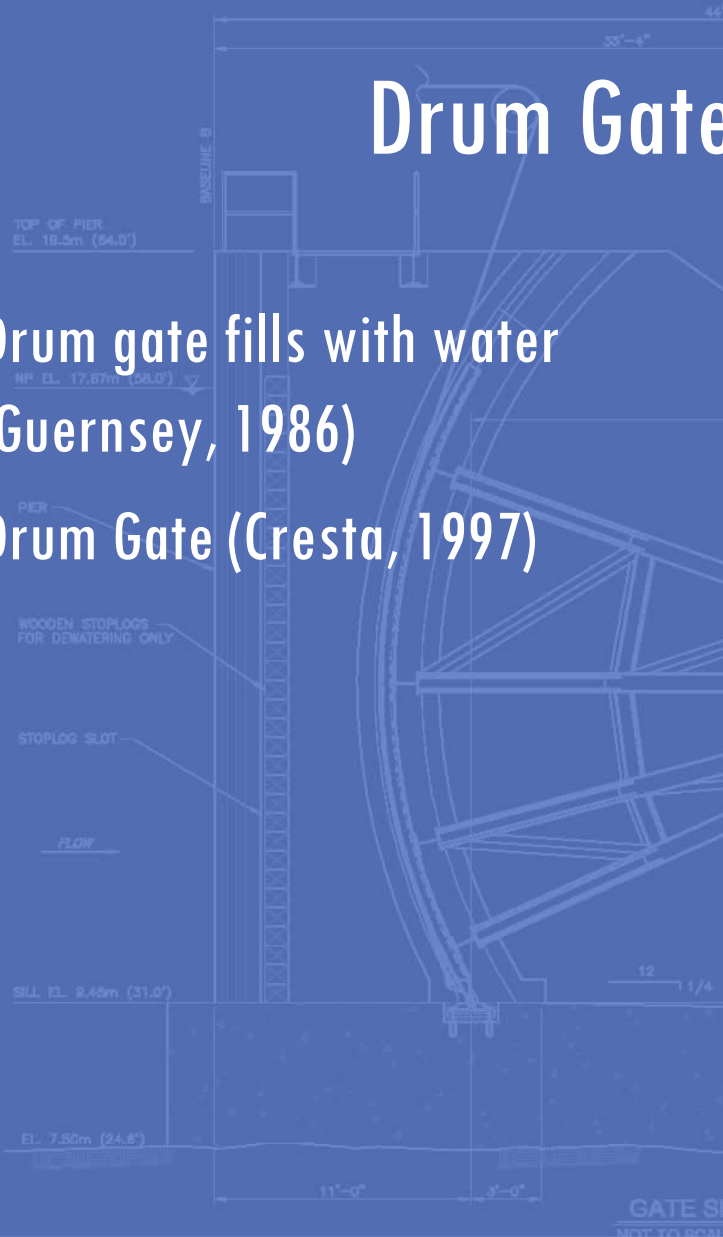
- Example Failures:

- Drum
- Tainter
- Bascule
- Sluice



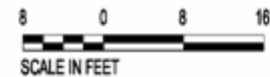
Drum Gate Failures

- Drum gate fills with water (Guernsey, 1986)
- Drum Gate (Cresta, 1997)



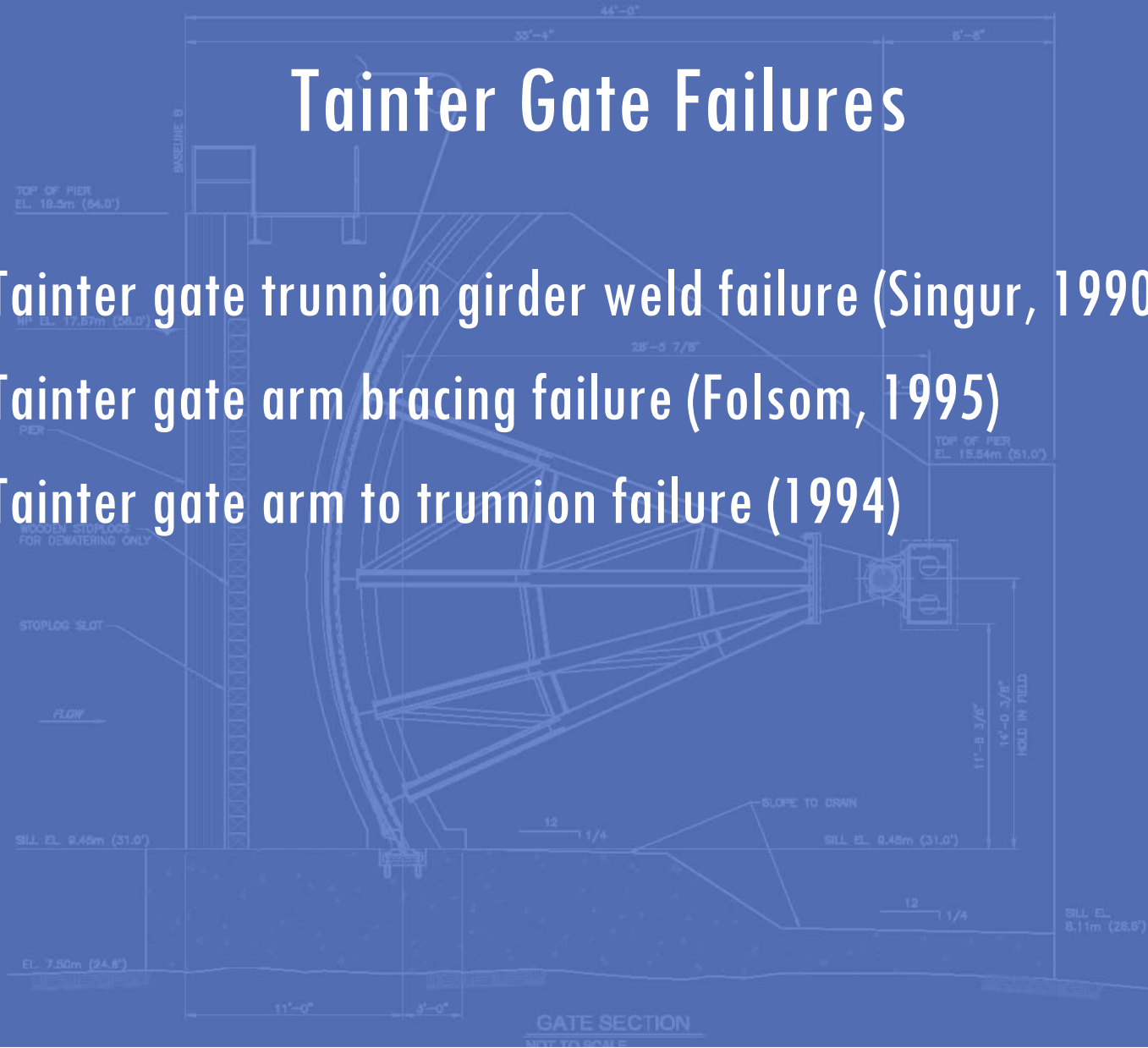
DRUM GATE DETAIL

1/8" = 1'-0"

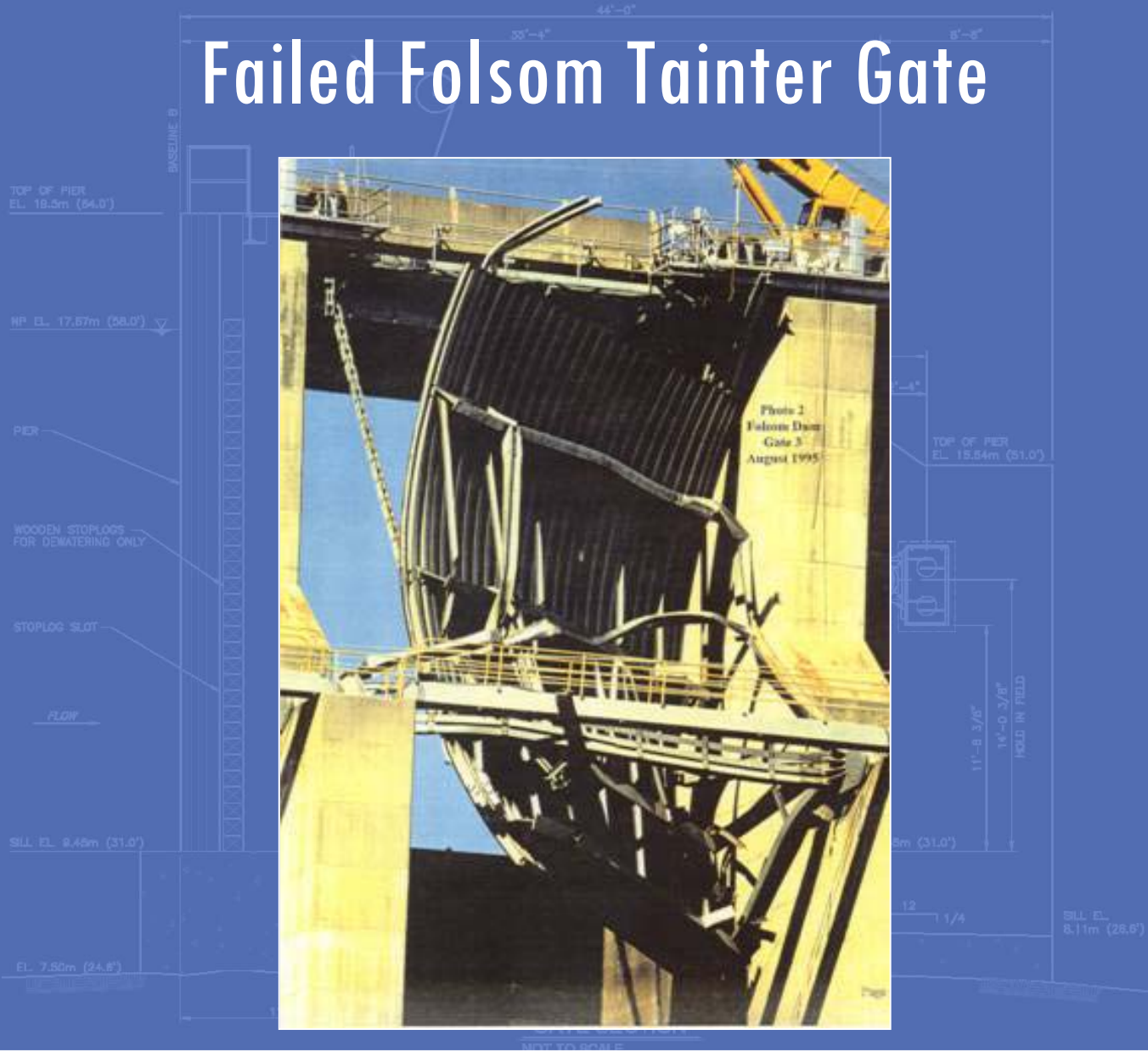


Tainter Gate Failures

- Tainter gate trunnion girder weld failure (Singur, 1990)
- Tainter gate arm bracing failure (Folsom, 1995)
- Tainter gate arm to trunnion failure (1994)



Failed Folsom Tainter Gate



TOP OF PIER
EL. 18.5m (59')

HP EL. 17.67m (58')

PIER

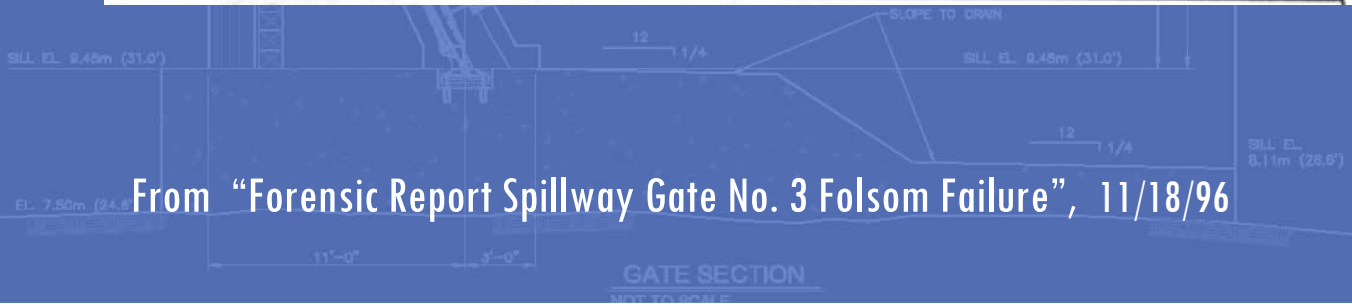
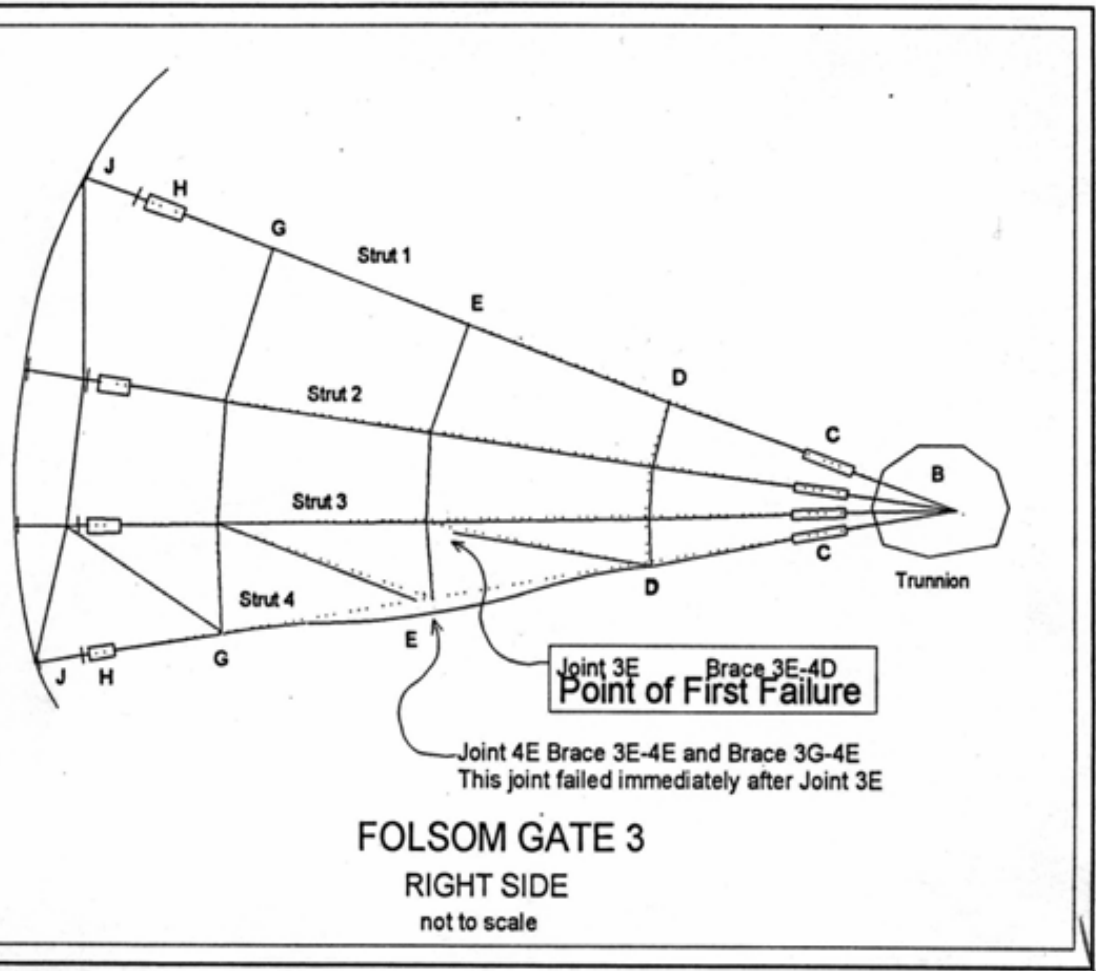
WOODEN STOP
FOR DEMATER

STOPLOG SLO

FLOW

SILL EL. 9.45m (31.0')

EL. 7.50m (24.5')



From "Forensic Report Spillway Gate No. 3 Folsom Failure", 11/18/96

Failed Tainter Gate Arm



GATE SECTION
NOT TO SCALE

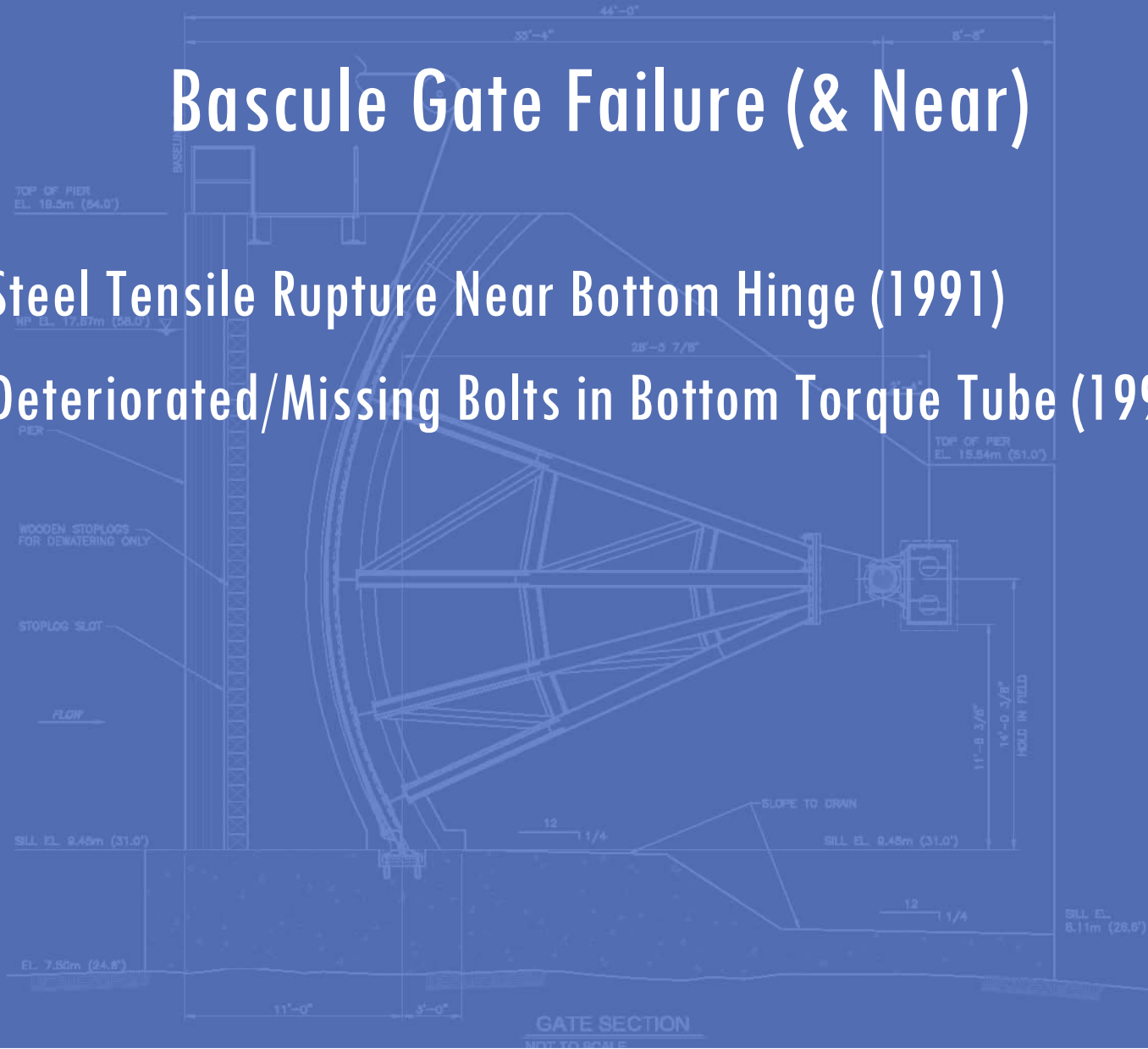
Detail of Failure



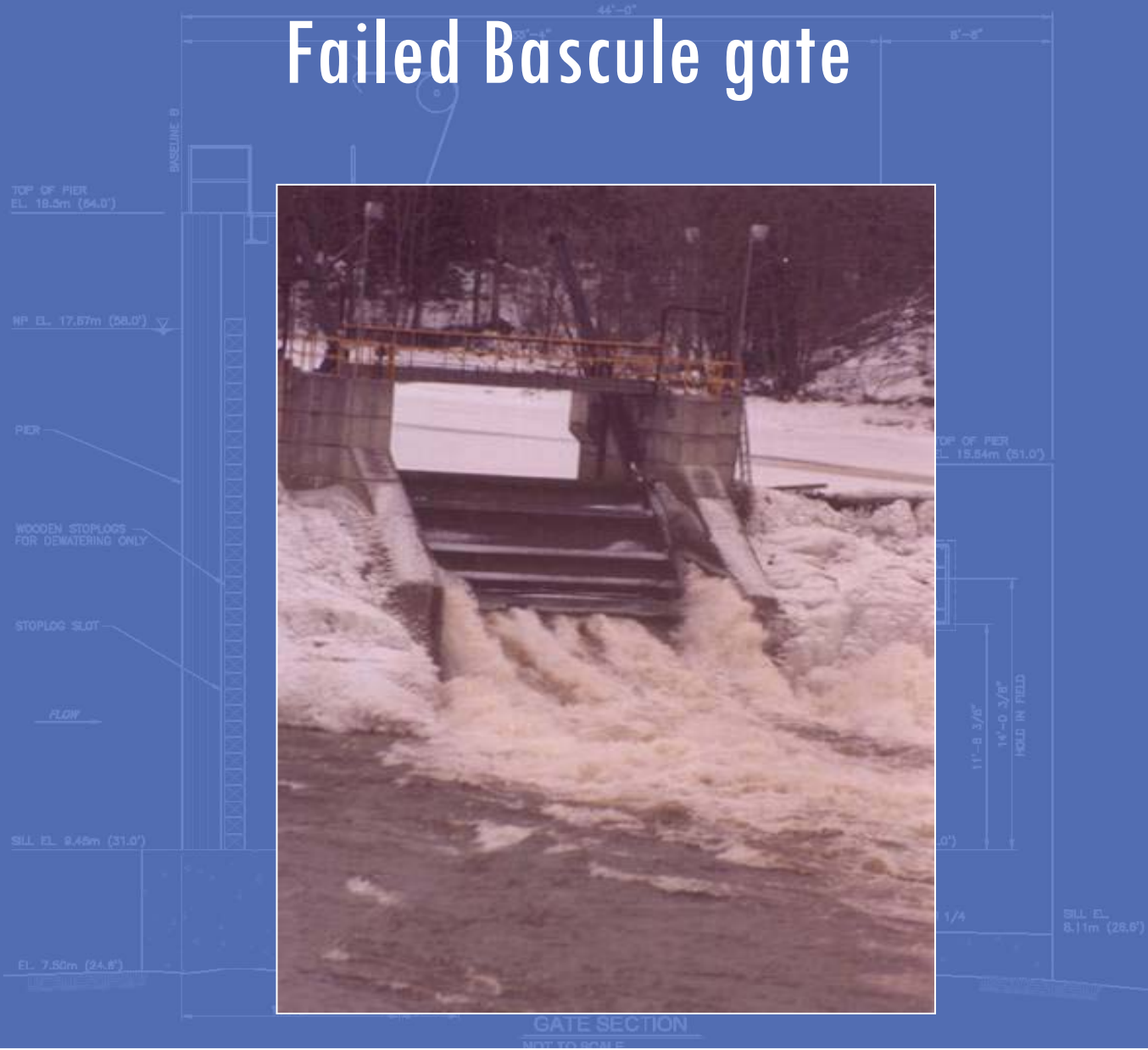
GATE SECTION
NOT TO SCALE

Bascule Gate Failure (& Near)

- Steel Tensile Rupture Near Bottom Hinge (1991)
- Deteriorated/Missing Bolts in Bottom Torque Tube (1999)



Failed Bascule gate



Gate Failed at Bottom of Side Beams

TOP OF PIER
EL. 18.5m (54.0')

BASELINE B

14'-0"

8'-0"



11'-0"

3'-0"

GATE SECTION
NOT TO SCALE

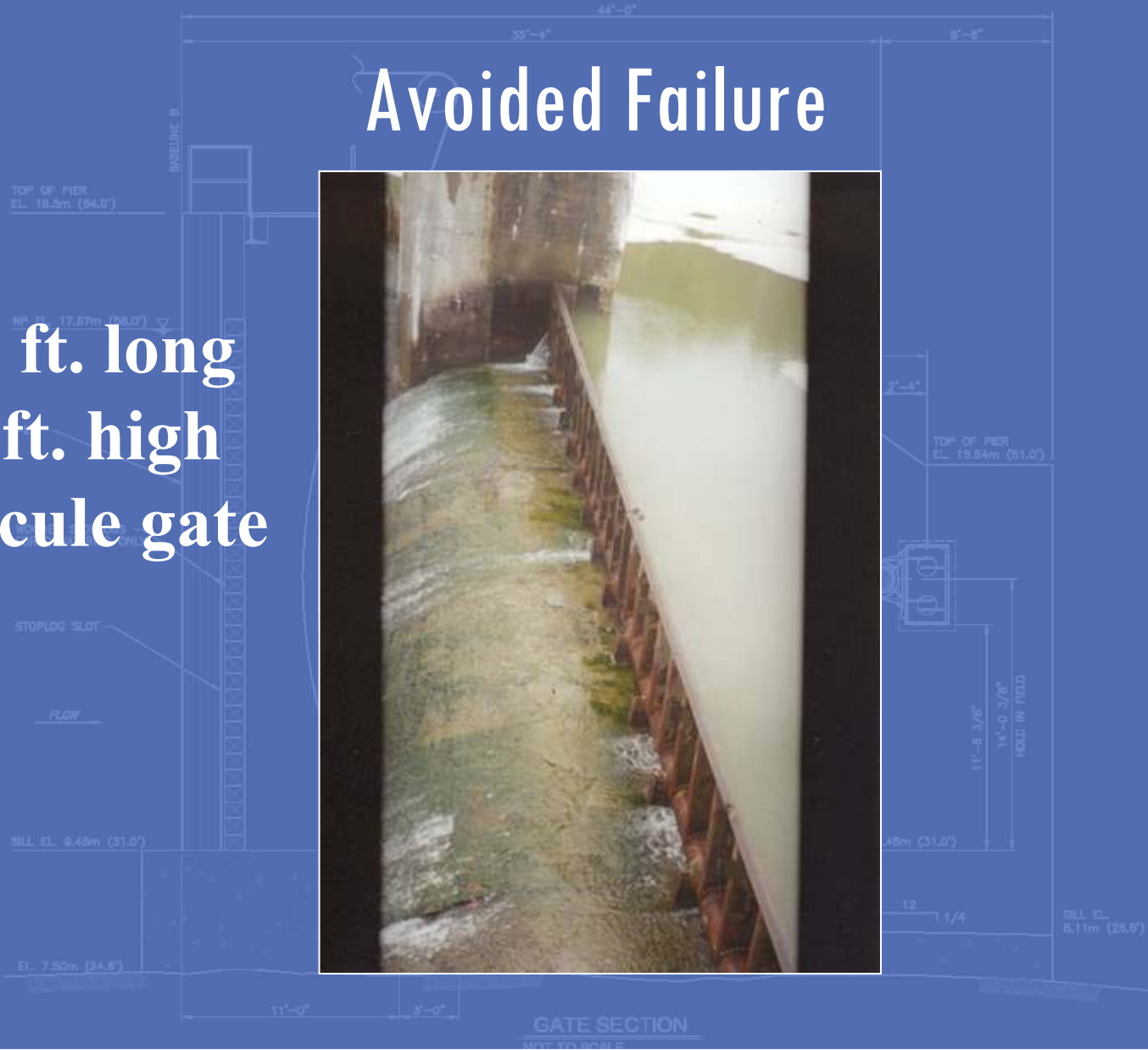
Detail Of Gate Arm Failure

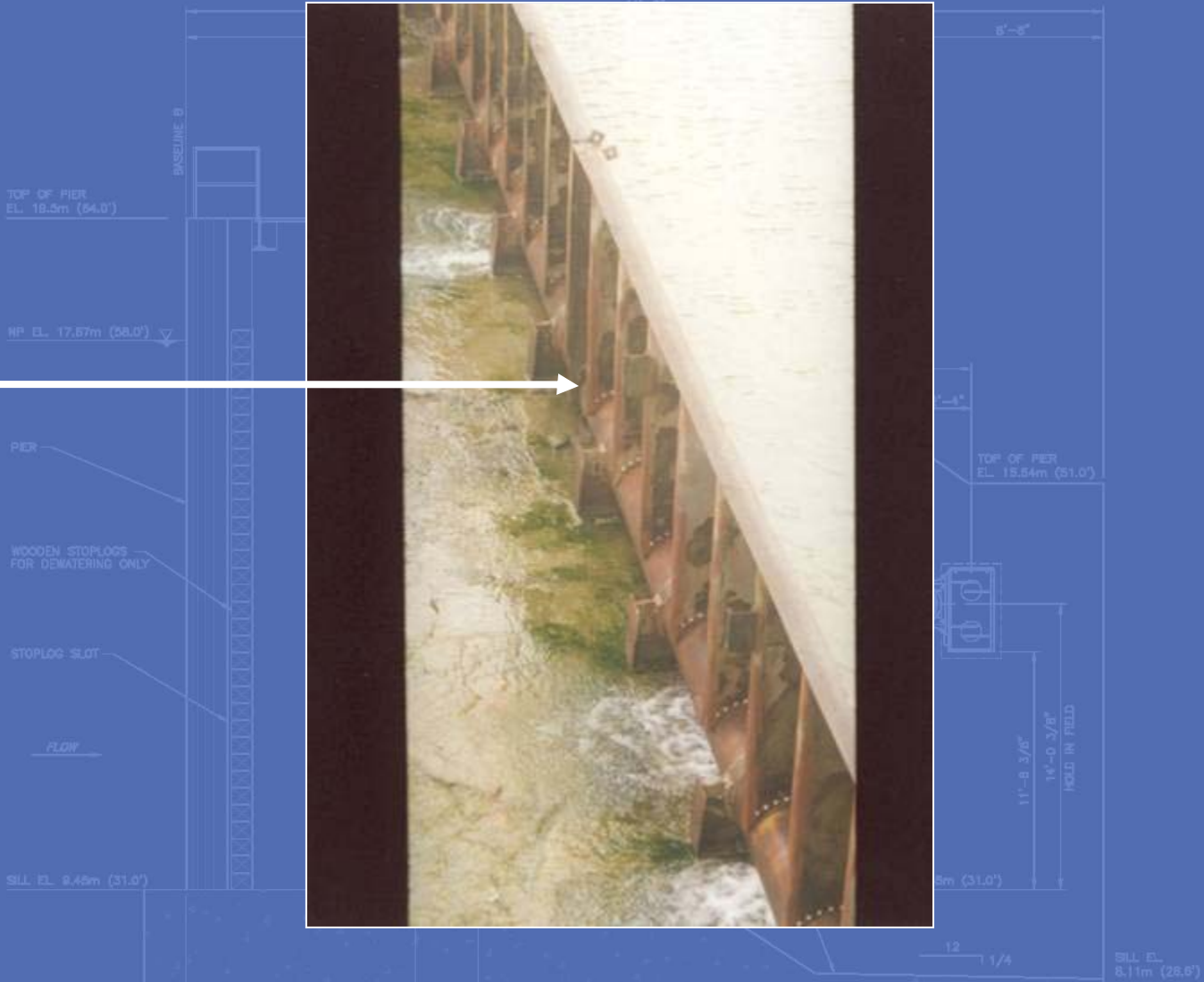


GATE SECTION
NOT TO SCALE

Avoided Failure

100 ft. long
x 6 ft. high
bascule gate

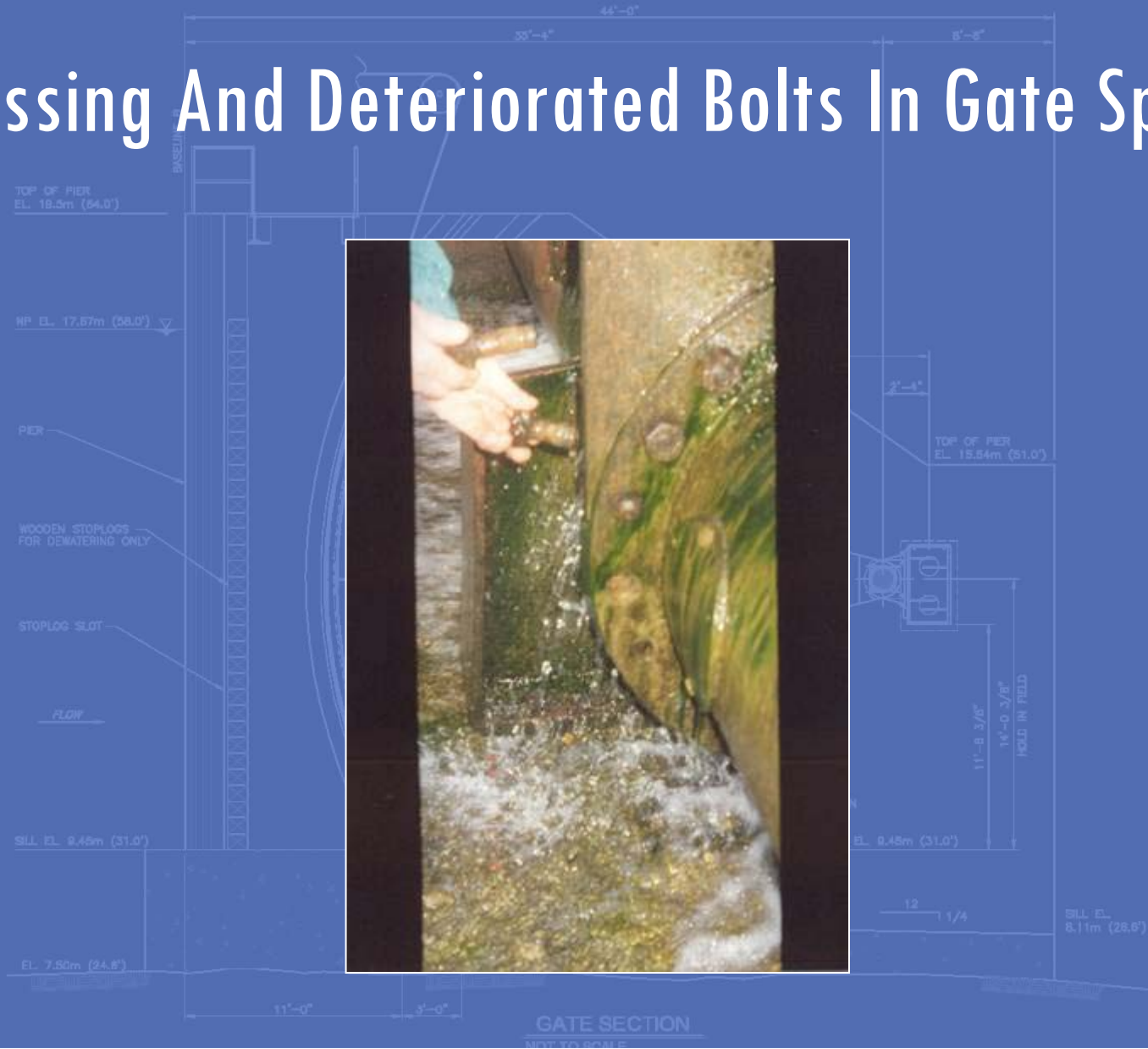




Bolted connection at gate's field splice

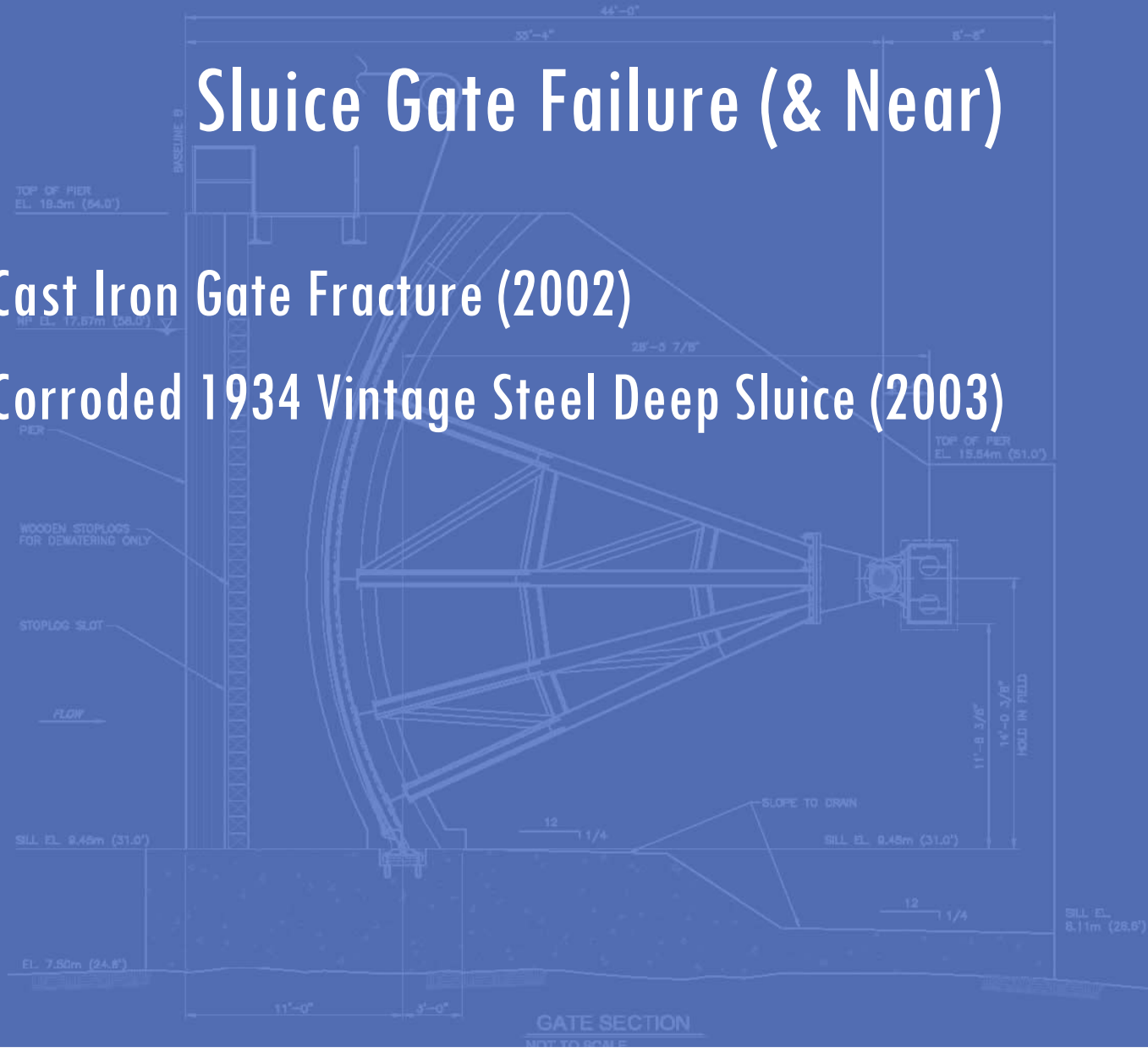
GATE SECTION
NOT TO SCALE

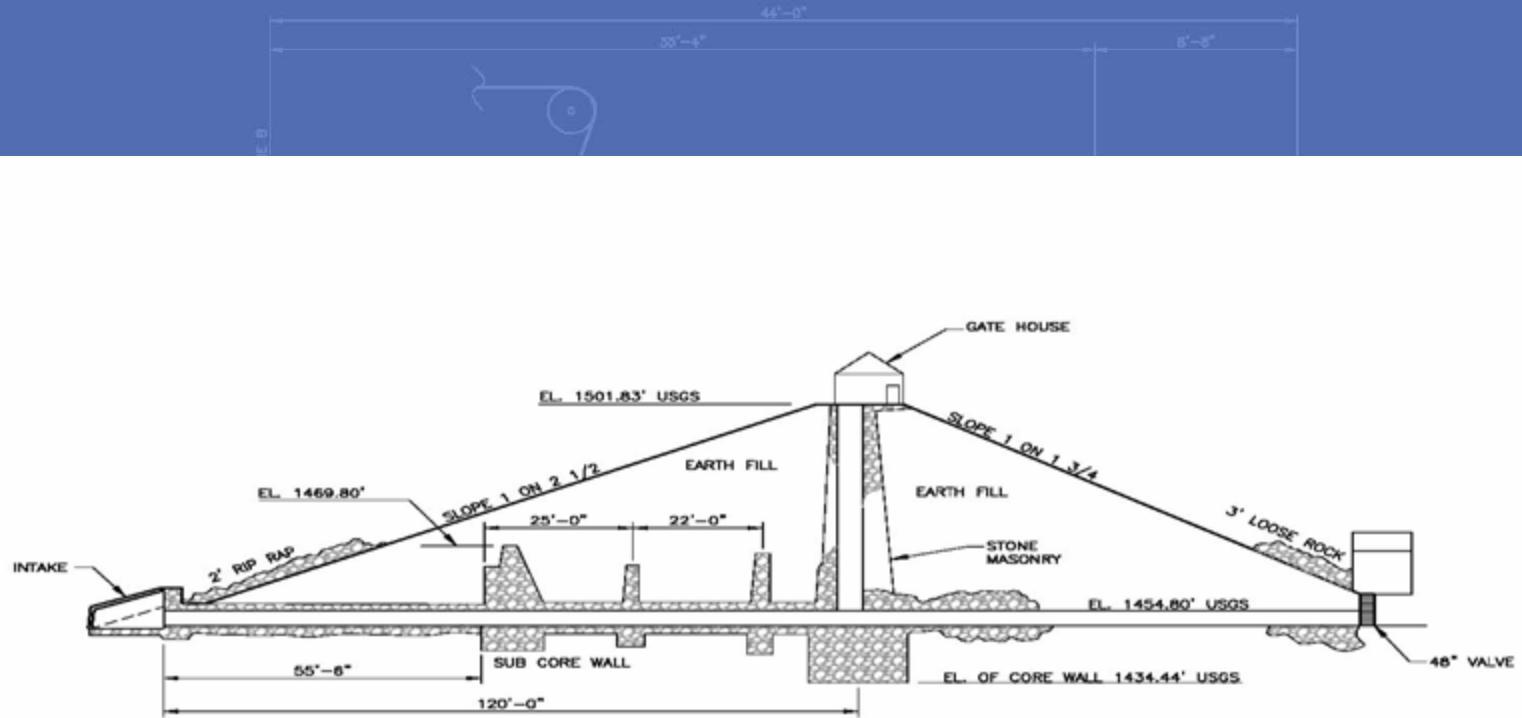
Missing And Deteriorated Bolts In Gate Splice



Sluice Gate Failure (& Near)

- Cast Iron Gate Fracture (2002)
- Corroded 1934 Vintage Steel Deep Sluice (2003)





EARTHEN DIKE SECTION

1" = 20'



EL. 7.50m (24.6')

11'-0"

3'-0"

GATE SECTION

NOT TO SCALE

SILL EL.
8.11m (26.6')

1 1/4

25" x 29" broken piece from 48" cast iron sluice gate



TOP OF PIER
EL. 18.5m (54.0')

BASELINE B

44'-0"

HP EL. 13.0

PIER

WOODEN
FOR DEM

STOPLOG

FL

SILL EL. 8.0

EL. 7.50

11'-0"

3'-0"

GATE SECTION

NOT TO SCALE

5.6'



BENCHMARK B
 TOP OF PIER
 EL. 18.5m (61.0')
 HP EL. 17.67m (58.0')
 PIER
 WOODEN STOPLOGS
 FOR DEMATERING ONLY
 STOPLOG SLOT
 FLOW
 SILL EL. 9.45m (31.0')
 EL. 7.50m (24.6')

TOP OF PIER
 15.84m (51.9')
 11'-8 3/8"
 14'-0 3/8"
 HOLD IN FIELD
 SILL EL.
 8.11m (26.6')

GATE SECTION
 NOT TO SCALE



GATE SECTION
NOT TO SCALE



11'-0" 3'-0"

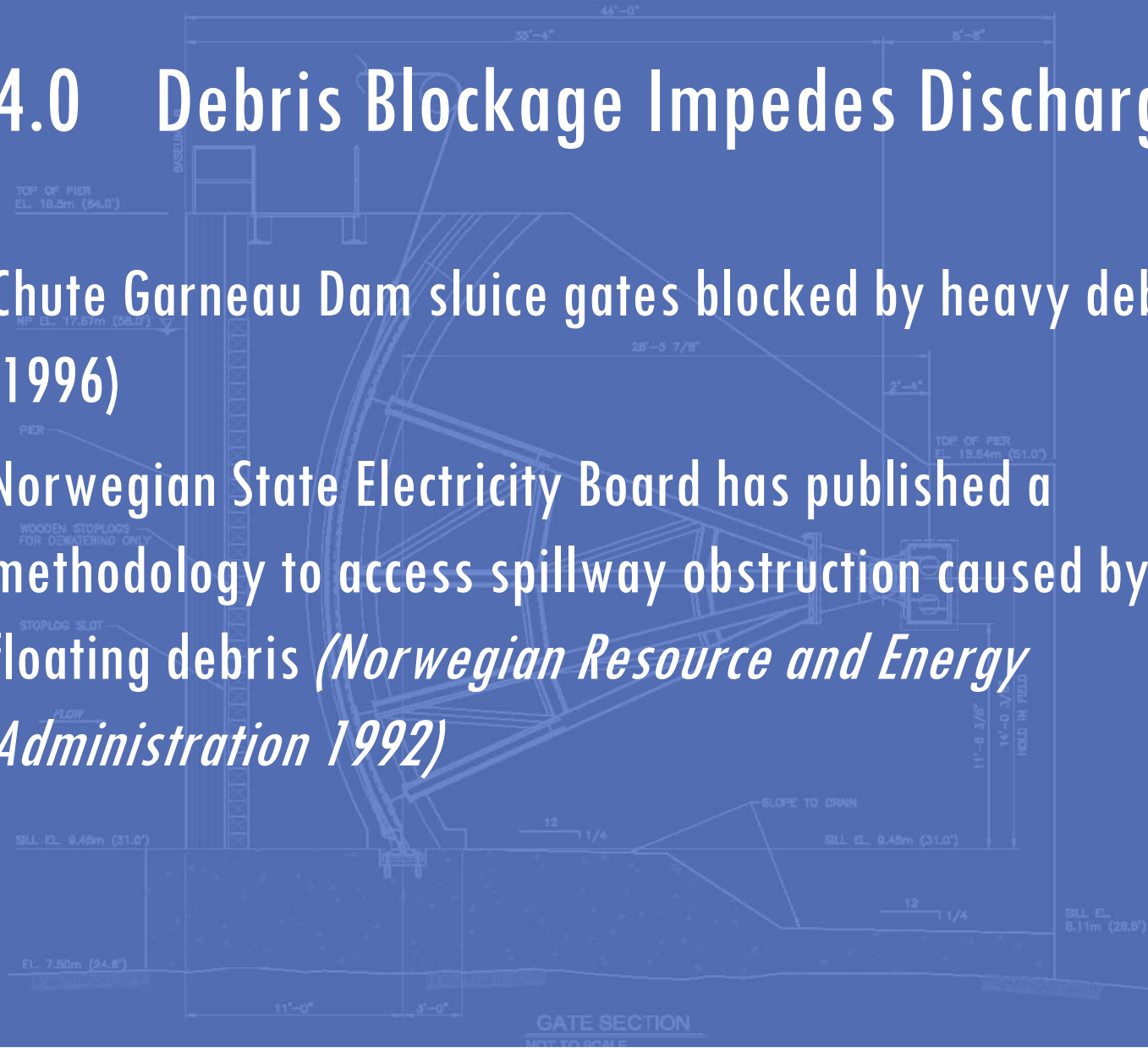
GATE SECTION
NOT TO SCALE



NOT TO SCALE

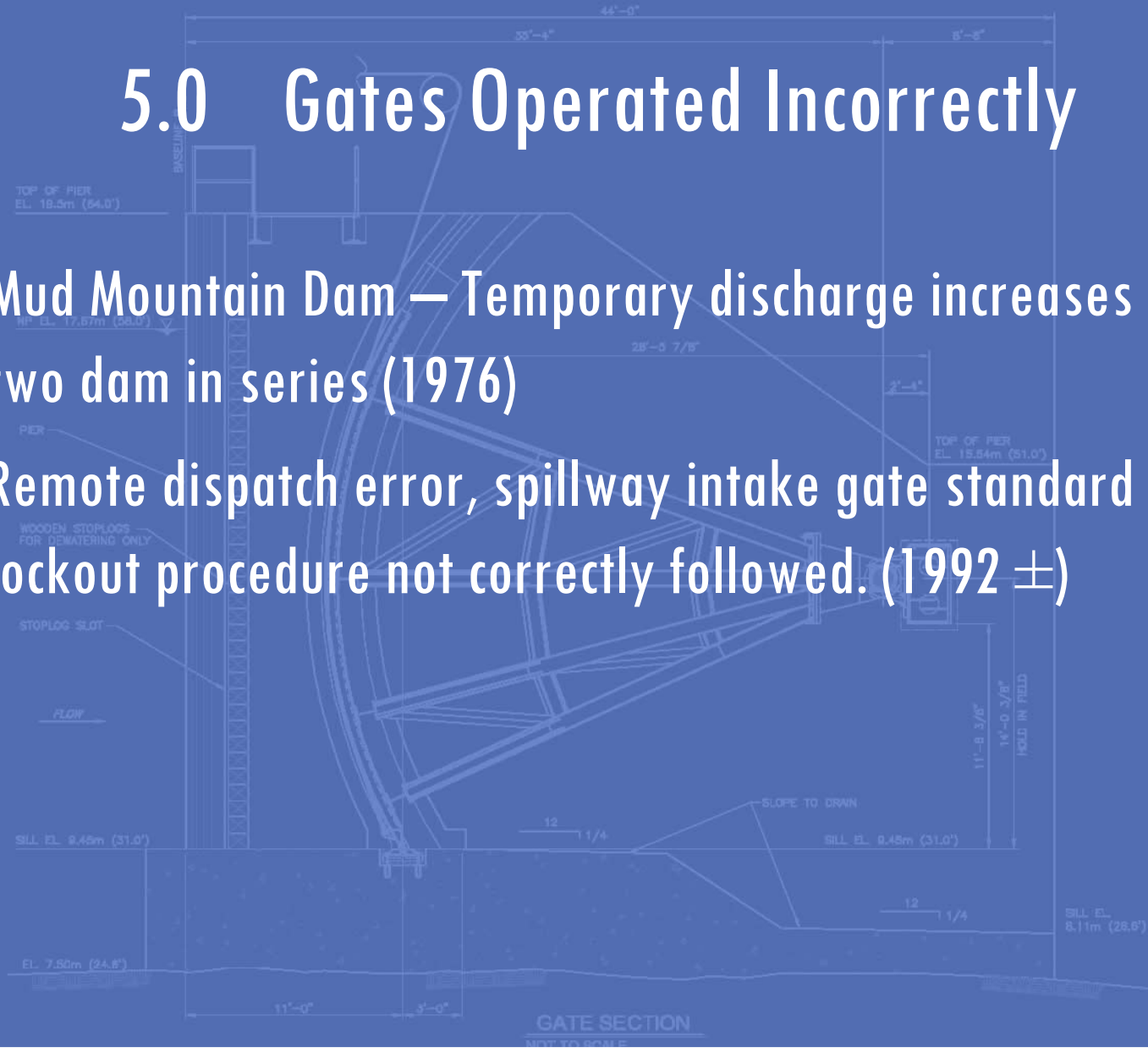
4.0 Debris Blockage Impedes Discharge

- Chute Garneau Dam sluice gates blocked by heavy debris (1996)
- Norwegian State Electricity Board has published a methodology to access spillway obstruction caused by floating debris (*Norwegian Resource and Energy Administration 1992*)



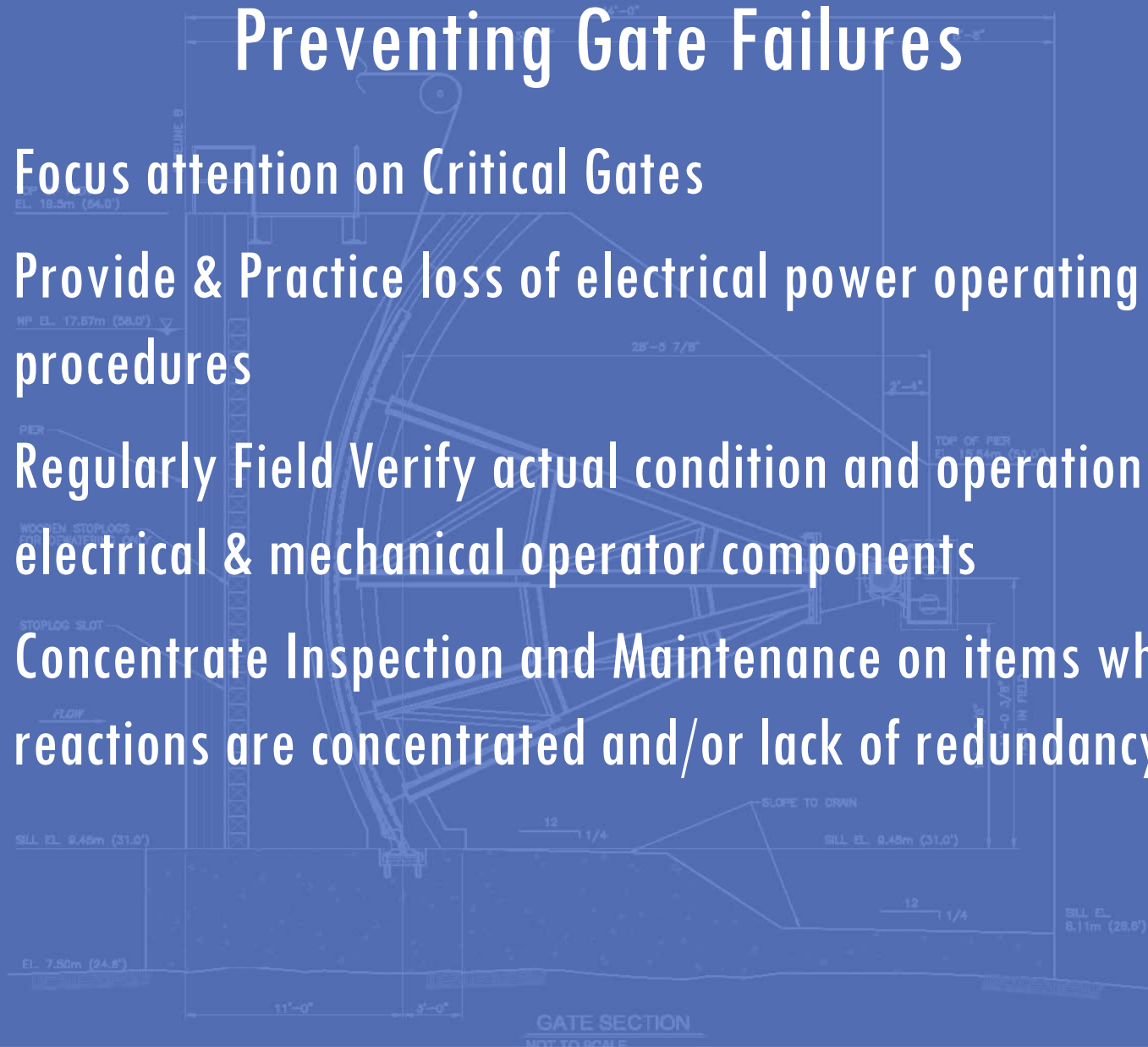
5.0 Gates Operated Incorrectly

- Mud Mountain Dam — Temporary discharge increases from two dam in series (1976)
- Remote dispatch error, spillway intake gate standard lockout procedure not correctly followed. (1992 ±)



Preventing Gate Failures

- Focus attention on Critical Gates
- Provide & Practice loss of electrical power operating procedures
- Regularly Field Verify actual condition and operation of electrical & mechanical operator components
- Concentrate Inspection and Maintenance on items where reactions are concentrated and/or lack of redundancy



Tainter Gate Operator Load Path

2-6

G) Power Source(s)

F) Controls

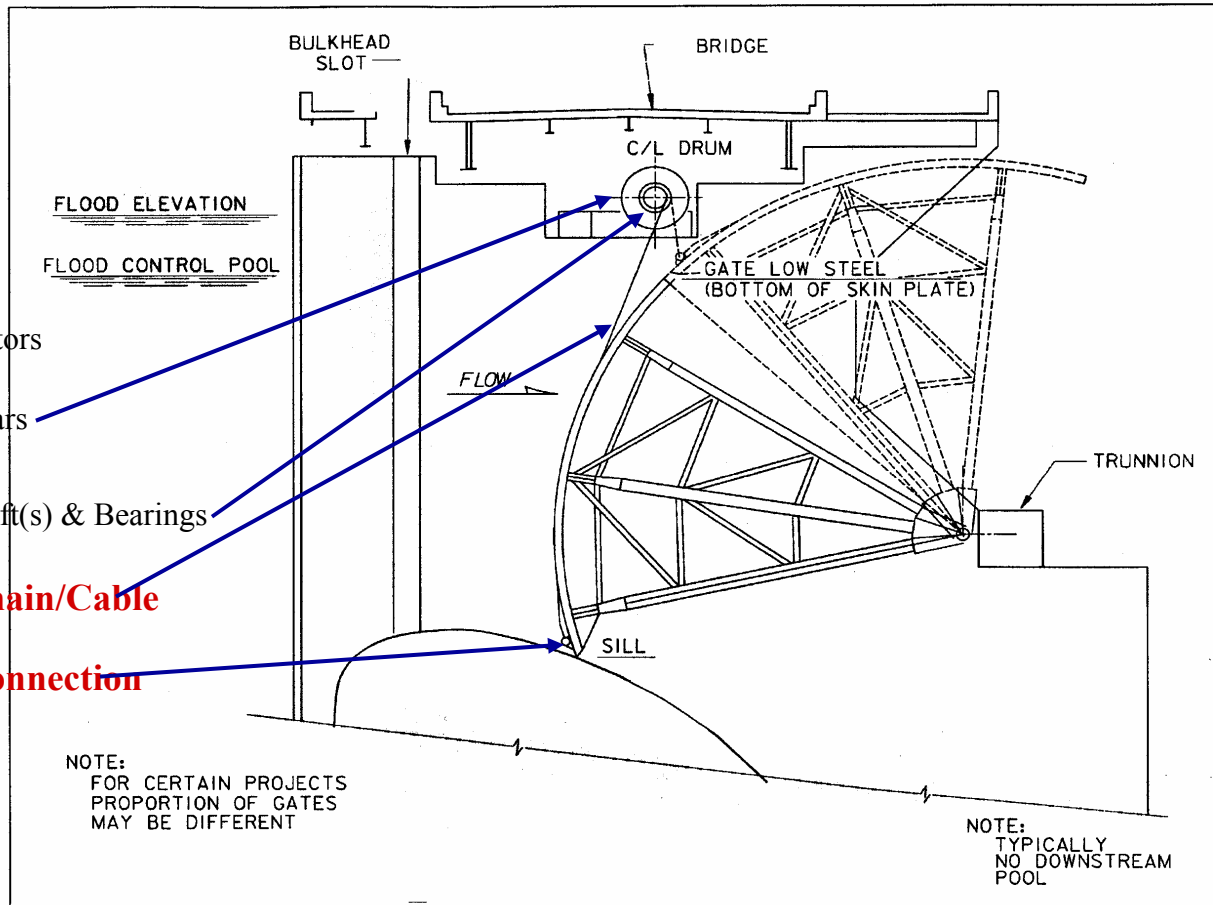
E) Motors

D) Gears

C) Shaft(s) & Bearings

B) Chain/Cable

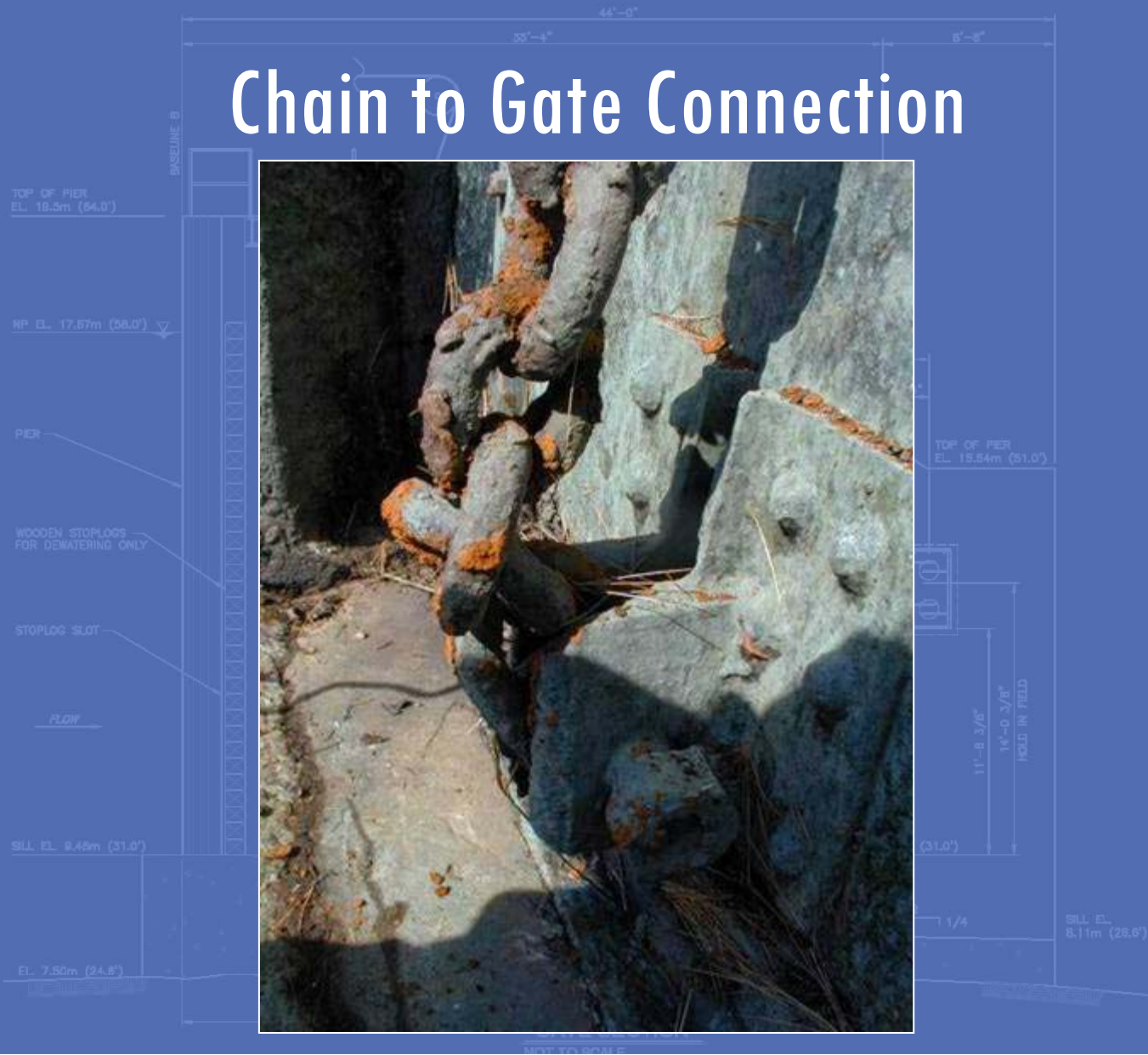
A) Connection



EM 1110-2-2702
1 Jan 00

Figure 2-5. Typical flood control or hydropower tainter gate

Chain to Gate Connection



Inspect Chains And Cables Particularly At Waterline

TOP OF PIER
EL. 18.5m (54.0')

BASELINE B

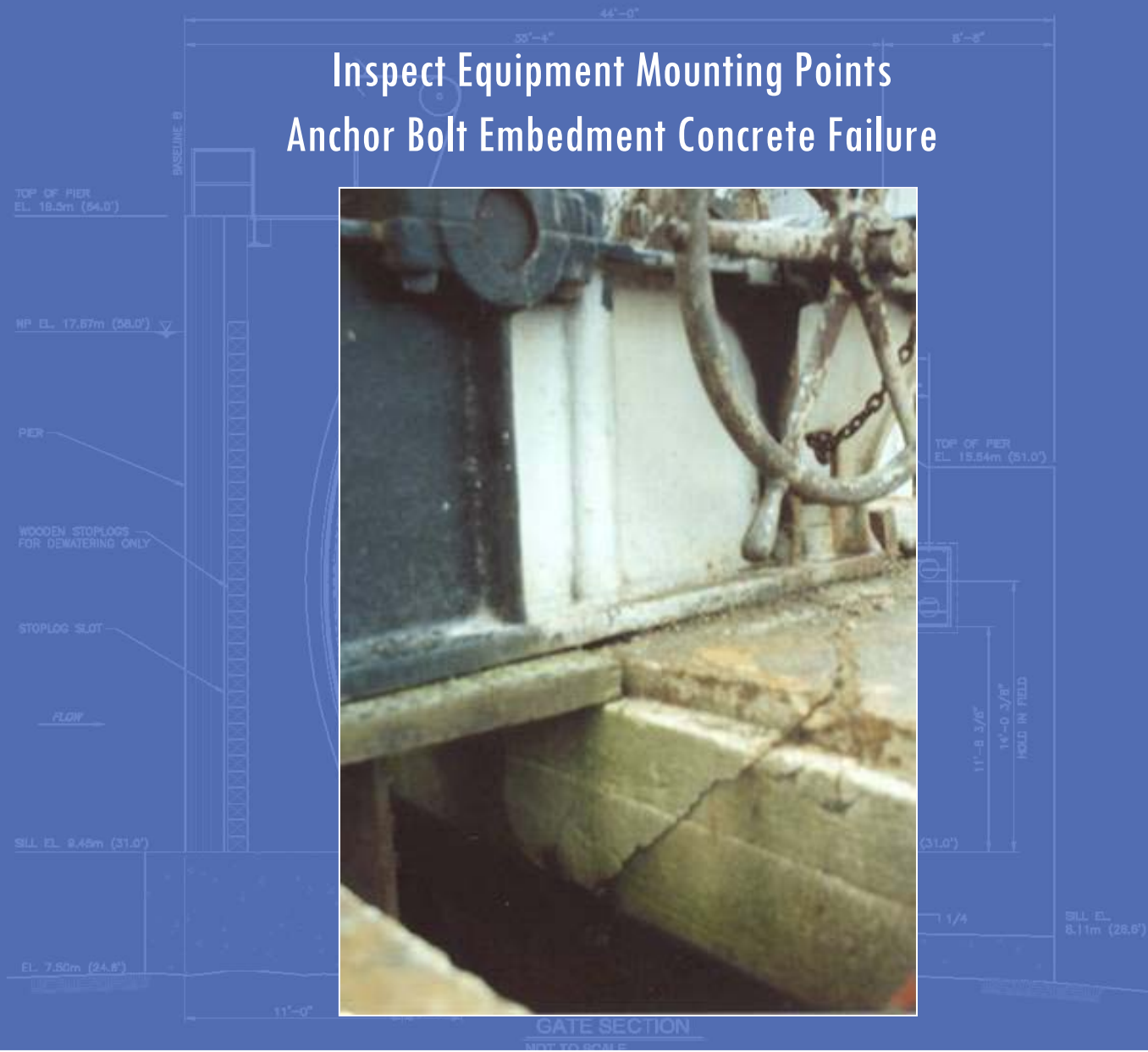
44'-0"

8'-0"



GATE SECTION
NET TO SCALE

Inspect Equipment Mounting Points Anchor Bolt Embedment Concrete Failure



Tainter Gate Structural Load Path

2-6

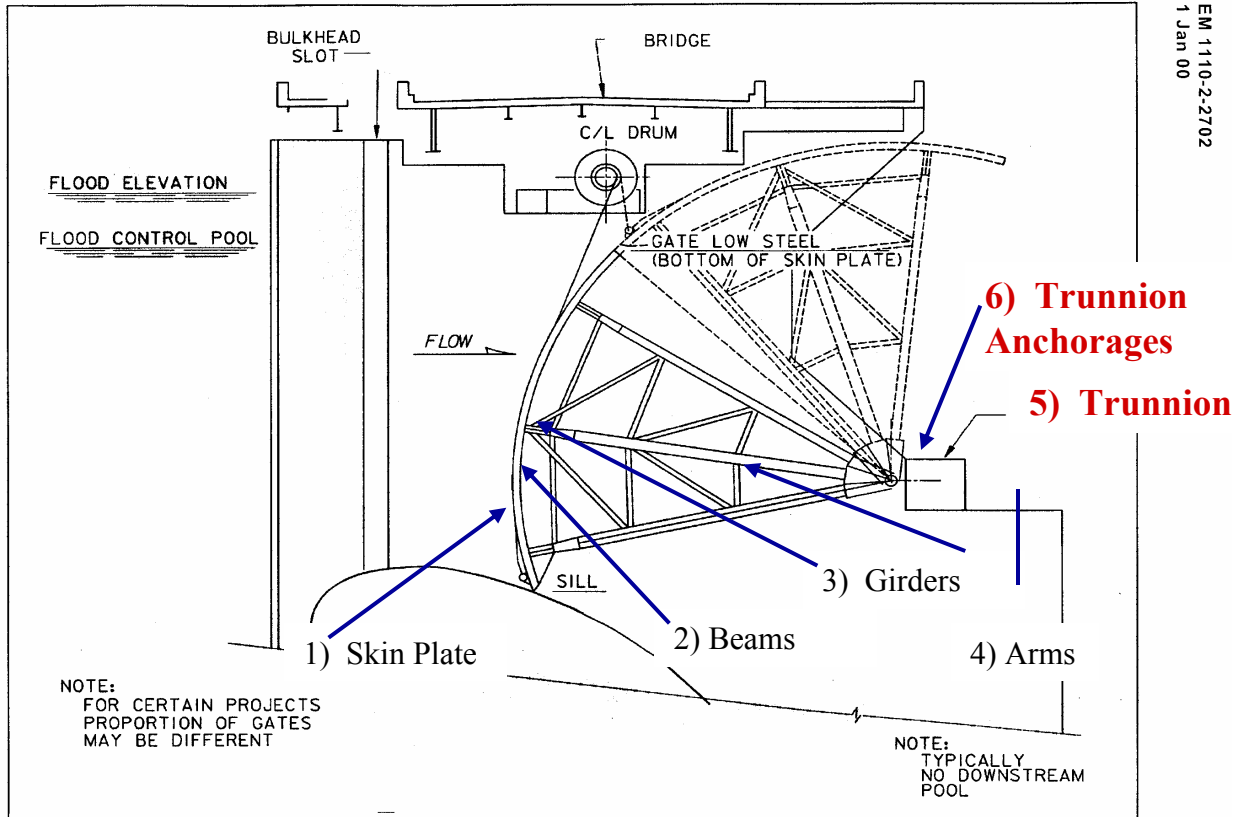
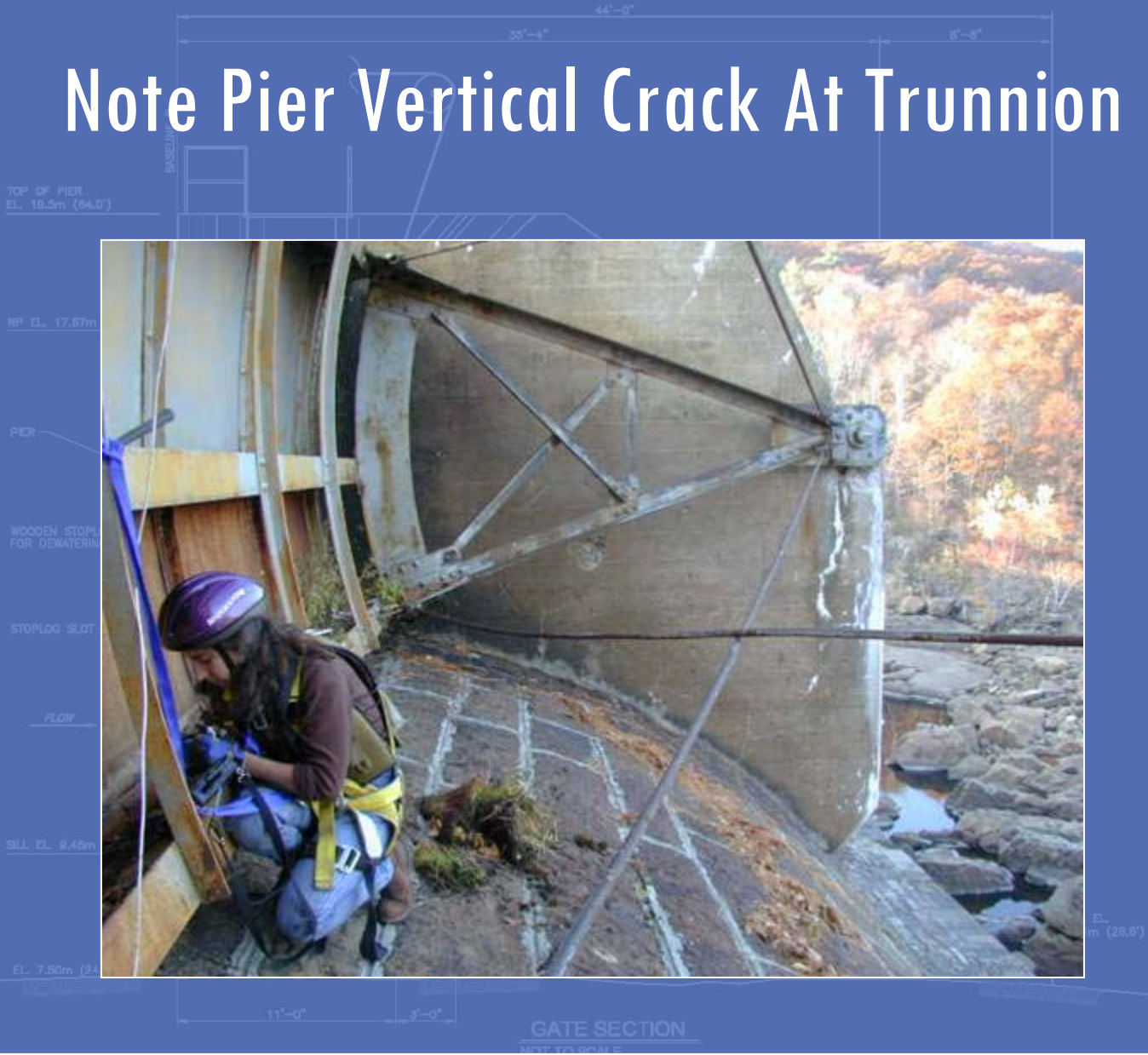


Figure 2-5. Typical flood control or hydropower tainter gate

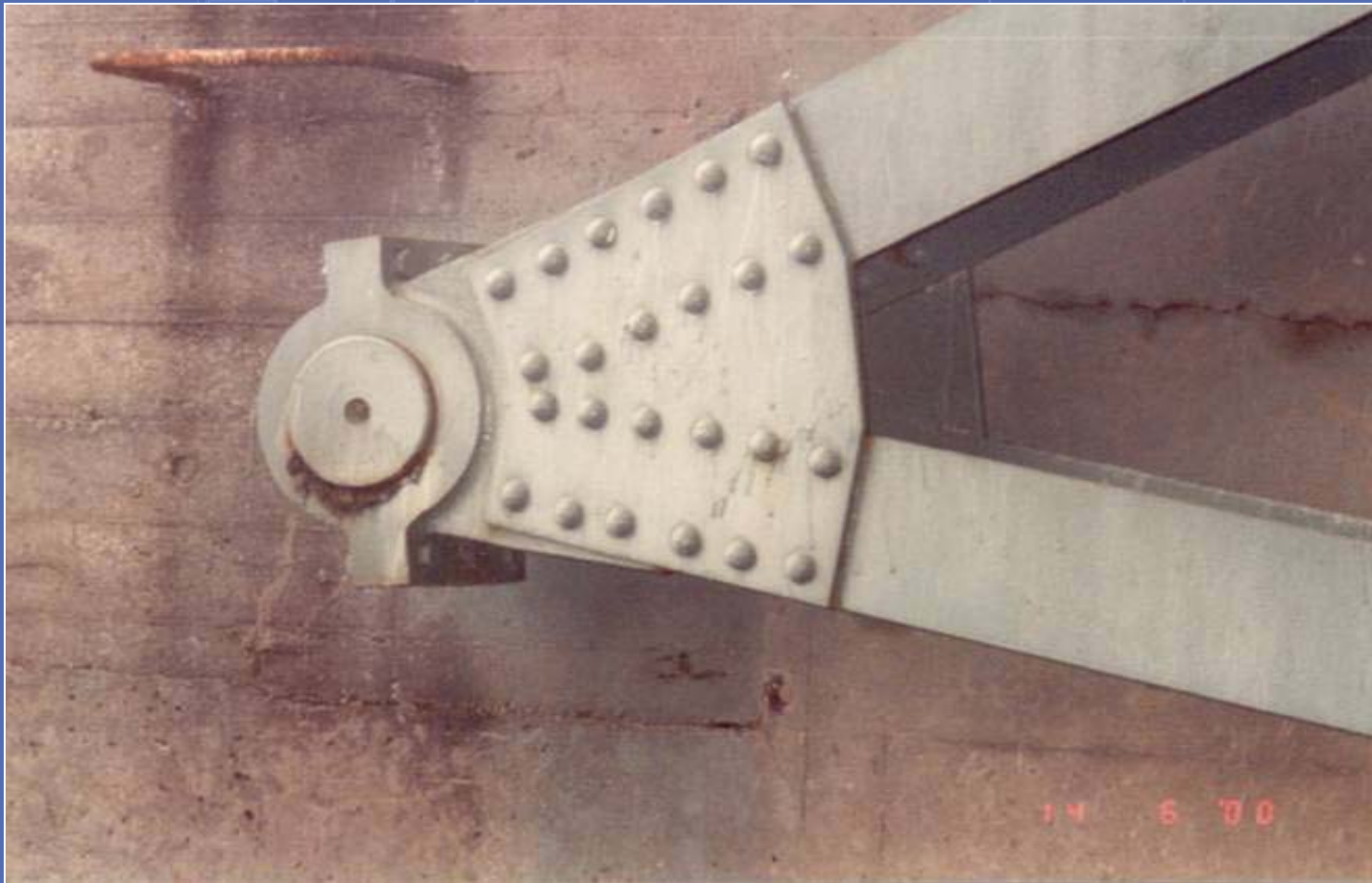
Note Pier Vertical Crack At Trunnion



Trunnion Grease Nipple



Extruded grease from 4 to 8 o'clock



PL. 1000 (2000)

11'-0"

3'-0"

GATE SECTION
NOT TO SCALE

Desirable Trunnion Grease Properties

TOP OF PIER
EL. 18.5m (54.0')

Table 11-3
Desirable Grease Properties for the Folsom Dam Trunnion Bearings. (Reference: "Lubricating Grease Guide," NLGI 3 Ed., 1996)

Purpose of Grease Property (a)	Examples of Composition						ASTM Test	
	Base Oil	Gelling Agent	Additives			ASTM Test	Desired Result	Maximum
			Type	%	Chemical			
Lubricity, that is, low static and kinetic friction for bronze on steel	Mineral or synthetic including polyol ester, jojoba oil, vegetable oils		Lubricity (reduction of friction)	2.5			Coefficient of static friction, fs, (breakaway), 0.08, (b) 0.12 Coefficient of kinetic friction at 5.1 mm/min (0.2-inch/min, ft, 0.10)	fs, 0.10, (b) ft, 0.12
Prevent rusting of steel	Mineral, or synthetic	Calcium, lithium or aluminum complex soaps, or calcium sulfonates, or polyurea	Rust inhibitors, calcium sulfonate	0.2 to 3	Metal sulfonates, amines		Pass- no rusting of steel after 48 hours in aerated water	Pass
Low corrosion of leaded bronze (Cu 83, Sn 8, Pb 8%)	Mineral, or synthetic	Lithium or calcium sulfonate and soaps, or polyurea	Corrosion inhibitors, metal deactivators	0.2 to 3	Metal sulfonates phosphites	D 4048 (copper strip)	1 to 1B	4C
Prevent scuffing of steel vs bronze	Mineral or synthetic	Lithium or calcium soaps, or polyurea	Antiscuff (EP)	1 to 2	Sulfur and phosphorous compounds, sulfurized fats, ZDDP	D 99-95, bronze pin vs steel disk	No scuffing, that is, transfer of bronze to steel. "EP" film formation	No scuffing
Resists wash-out by water	Mineral or synthetic	Polyurea or calcium hydroxystearate				D 1264-93	0 wash-out	1.9%
Does not "harden" in pipes	Mineral or synthetic	Lithium or calcium soaps or polyurea					No change in consistency with aging	No change
Easy to pump and distribute through tubing and grooves in bronze bushing	Mineral or synthetic, ISO 100 to 150	Polyurea, lithium or calcium soaps				a. D 217	a. NLGI 1 or 1.5, cone penetration 340 to 275, b. Pumps through 7.62 m to 0.0762 m (25' to 1/4") copper tubing	NLGI 2
Adherence to metal, and retention in areas of real contact of trunnion	Mineral or synthetic	Lithium or calcium soaps or polyurea	Tackiness agent		Polymers, iso-butylene or polyethylene	none	Slightly tacky between metals	Slightly tacky
Long life, oxidation stable	Mineral or synthetic	Polyurea	Oxidation inhibitors		Amines, phenols, sulfur compounds	D 942-90	Pass, also no acid formation, odor, or discoloration.	Pass
Low bleeding, oil does not separate from grease excessively	Mineral or synthetic	Lithium or calcium soaps or polyurea	High-viscosity base oil			D 1742-94 and Federal Test	Limited "bleeding" of oil, less than 0.1%	1.6% in 24 hr, 3% in 48 hr.

(a) Applied to low carbon (SAE1045) steel pin 812.7 mm (32") diam., rotating in trunnion bronze bushing, at 5.1 mm/min (0.2 in/min) and 816,461 kg (1.8 million pounds) load.

(b) Only known bench test with Pin (bronze pad)-on-Disk (1045 steel) tribometer, at Herguth Laboratories, P.O. Box B, Vallejo, CA 94590 run at 50 N (11-2 lb of force) load, 5.1 mm (0.2 inch) per minute sliding velocity, and room temperature.

Douglas Godfrey, WEAR ANALYSIS
San Rafael, California

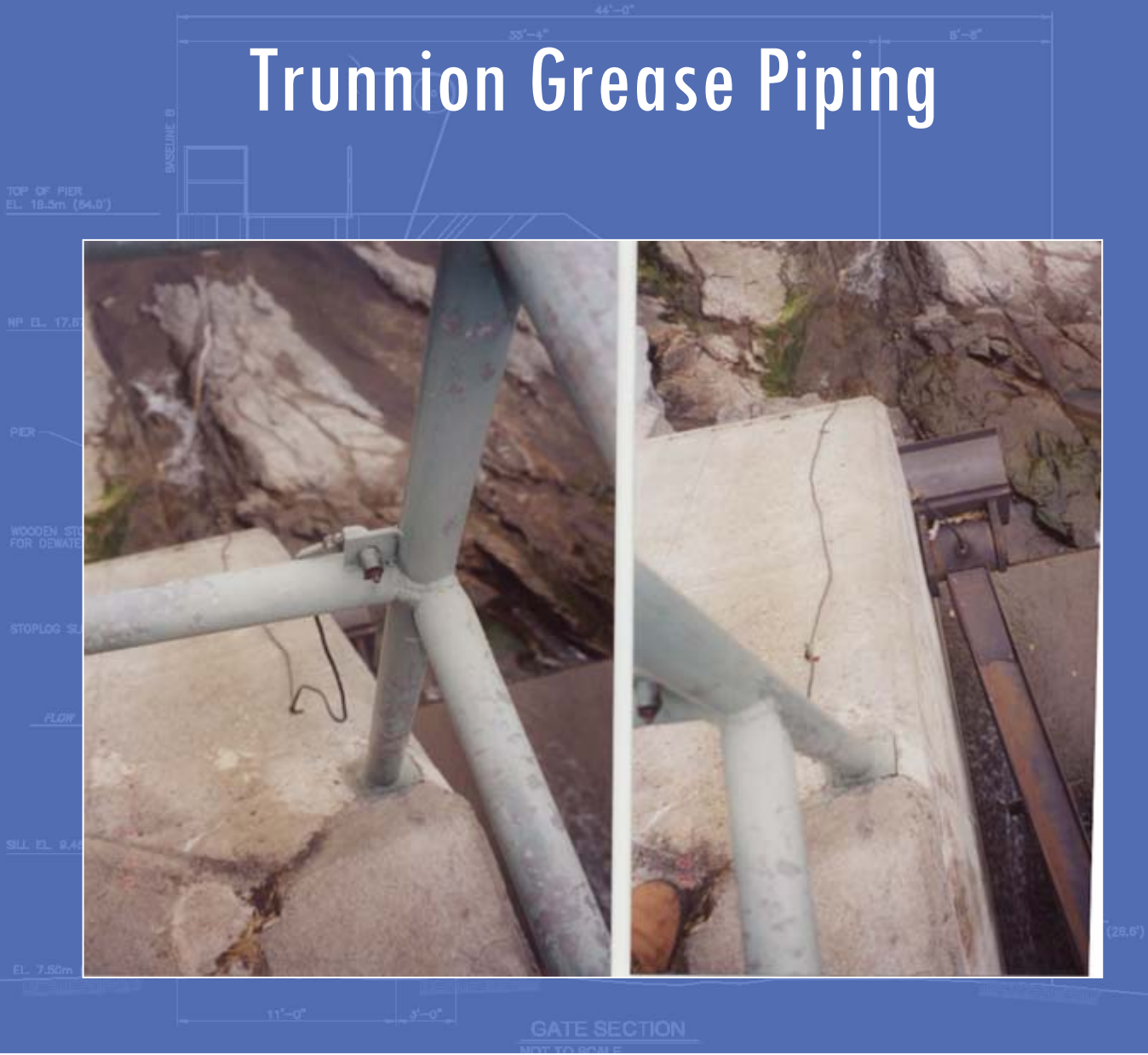
EM 1110-2-1424
28 Feb 99

EL. 7.50m (24.6')

Difficult Trunnion Access



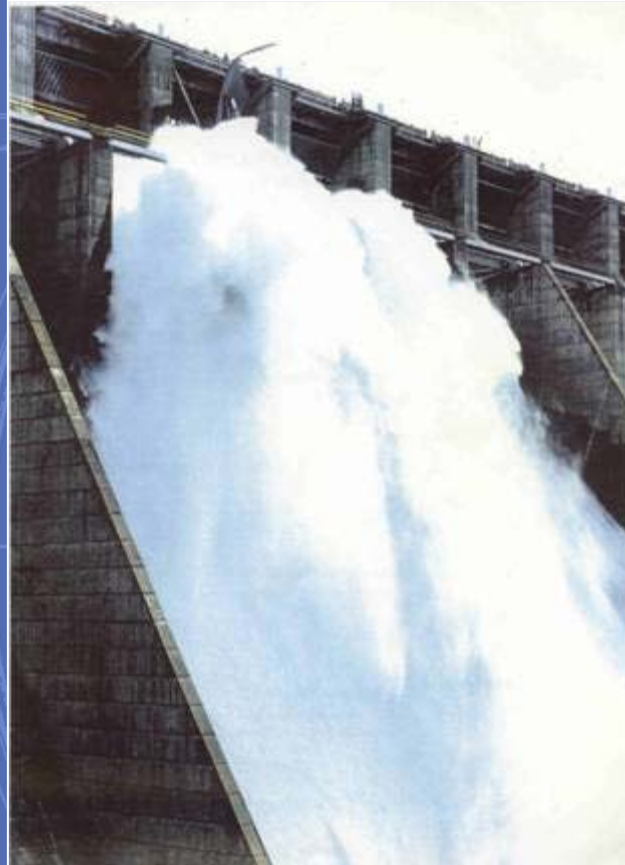
Trunnion Grease Piping



New Platform For Safe Gate Access



Gates are typically very reliable



but failure consequences can be severe



Contact (e.g. For Copy of Slide Show)

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