Panama Canal Gate Seal Problems

USACE 2016
Vicksburg, Mississippi

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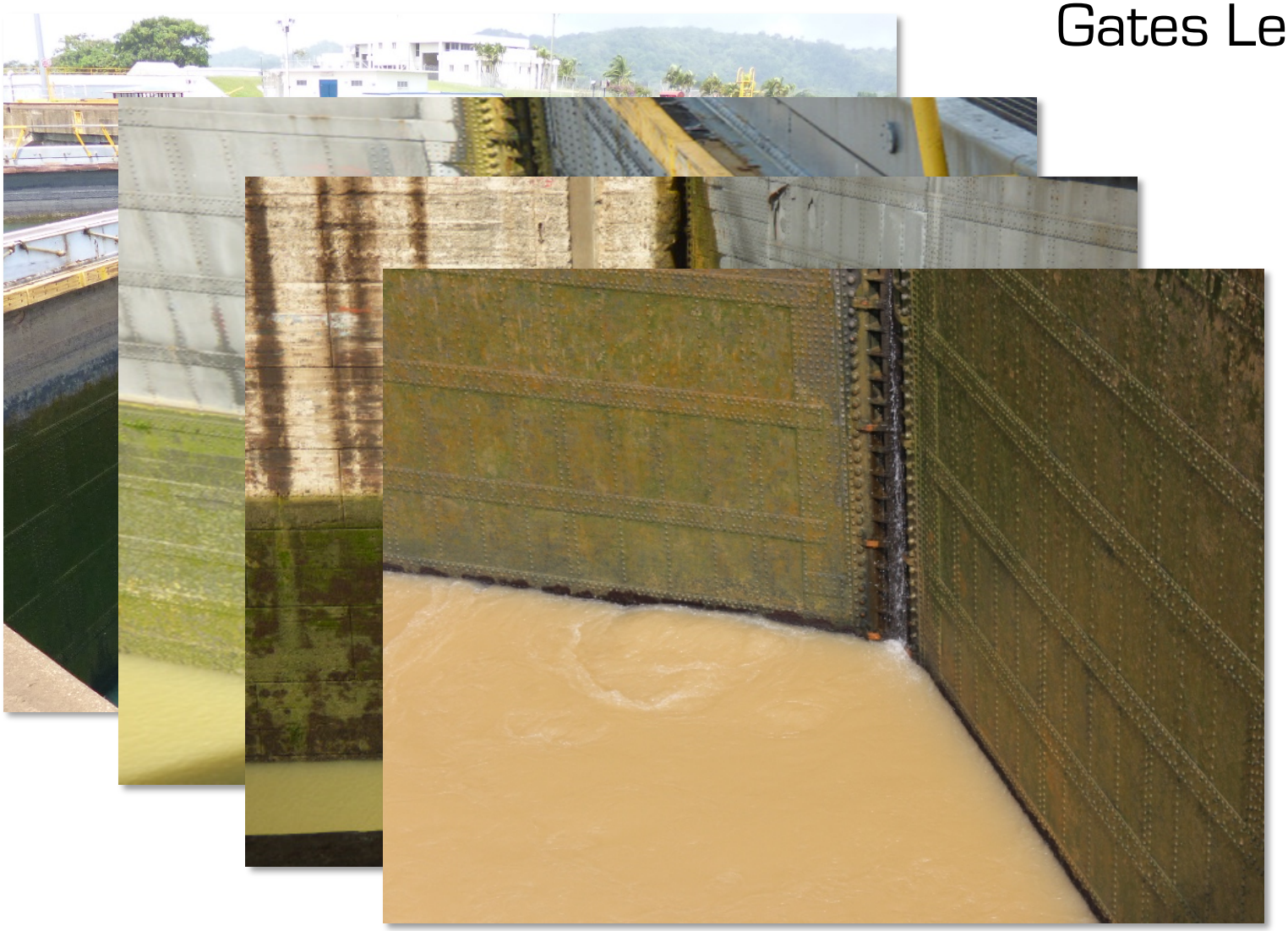
Locks Overhaul Engineer

Gates Leaks



Leaks by rubber seals

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Our main problem:
Important leakages on rubber seals.

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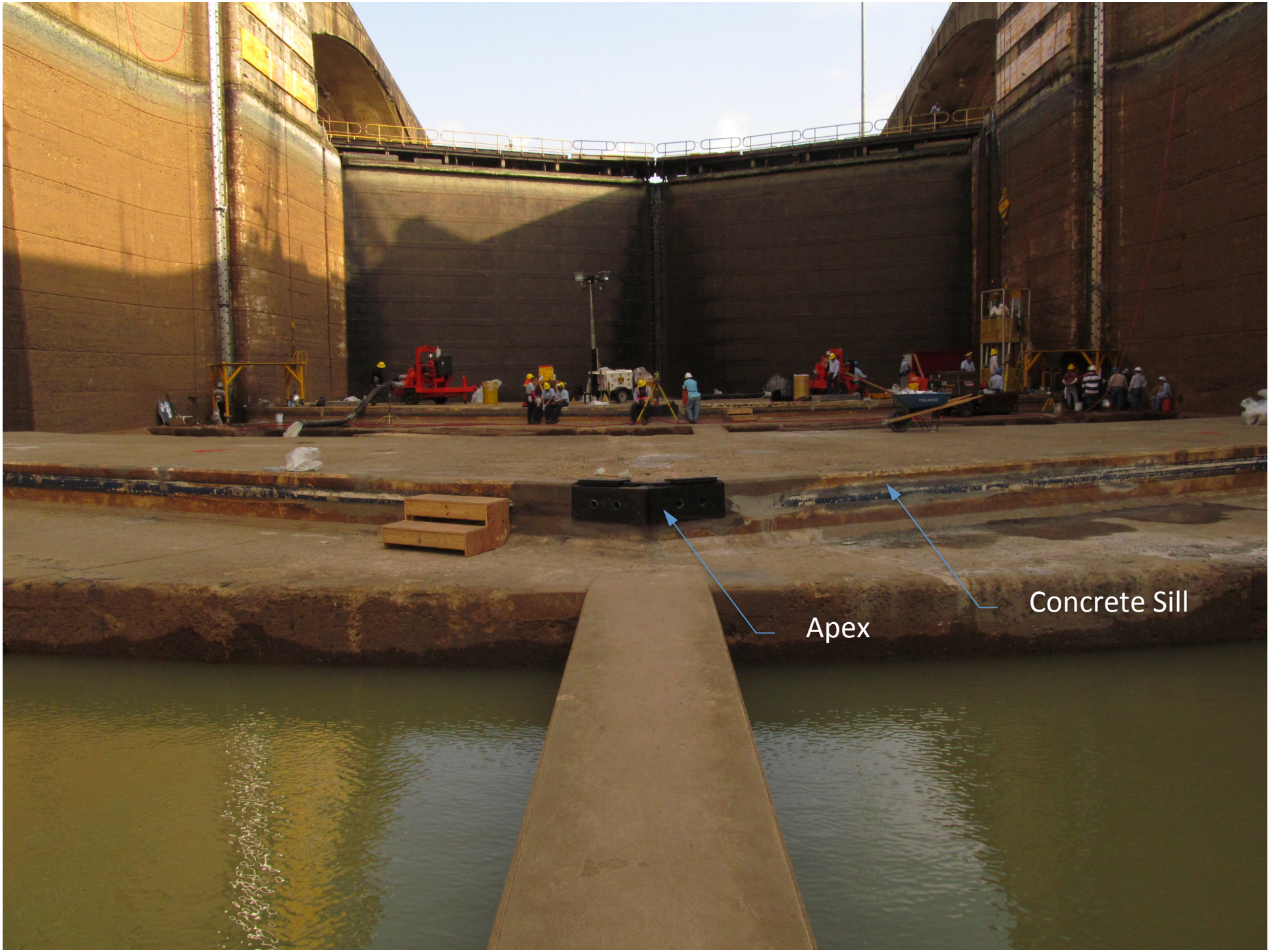
Concrete Sill
Apex

Technical and Historical Data

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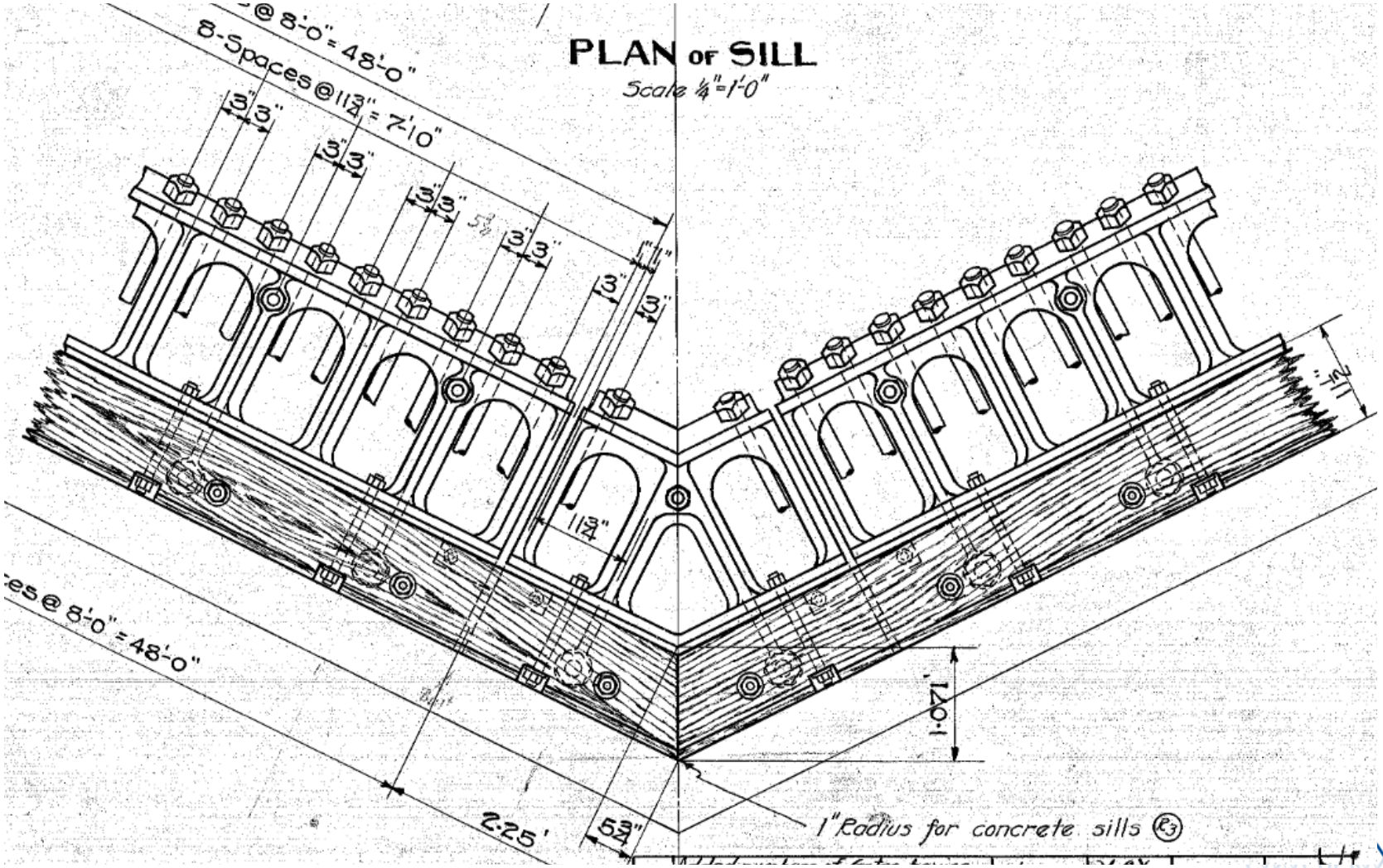
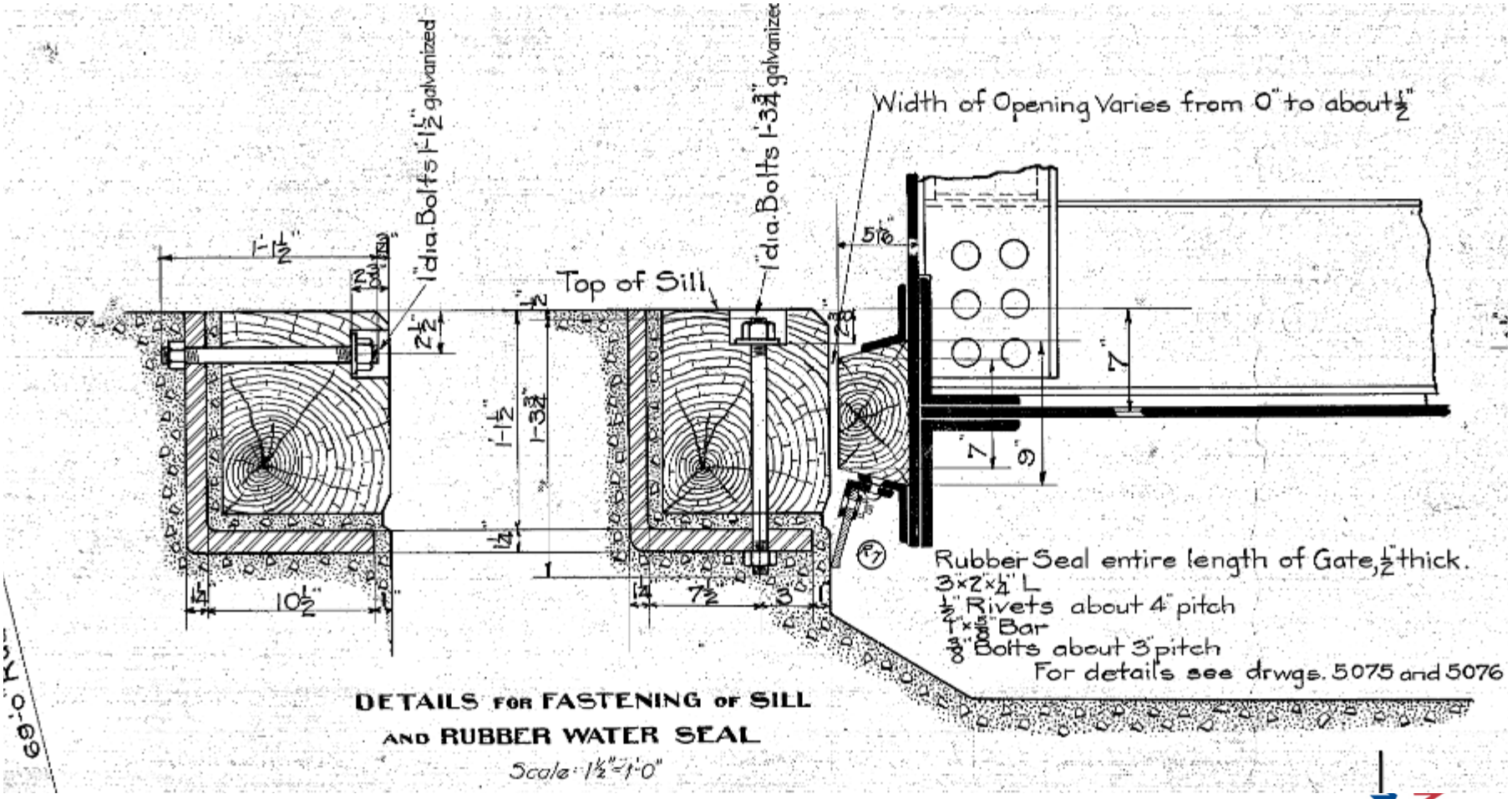
Original Drawings, 25 mar 1914, Wooden Seal



Original Drawings, 25 mar 1914, Wooden Seal



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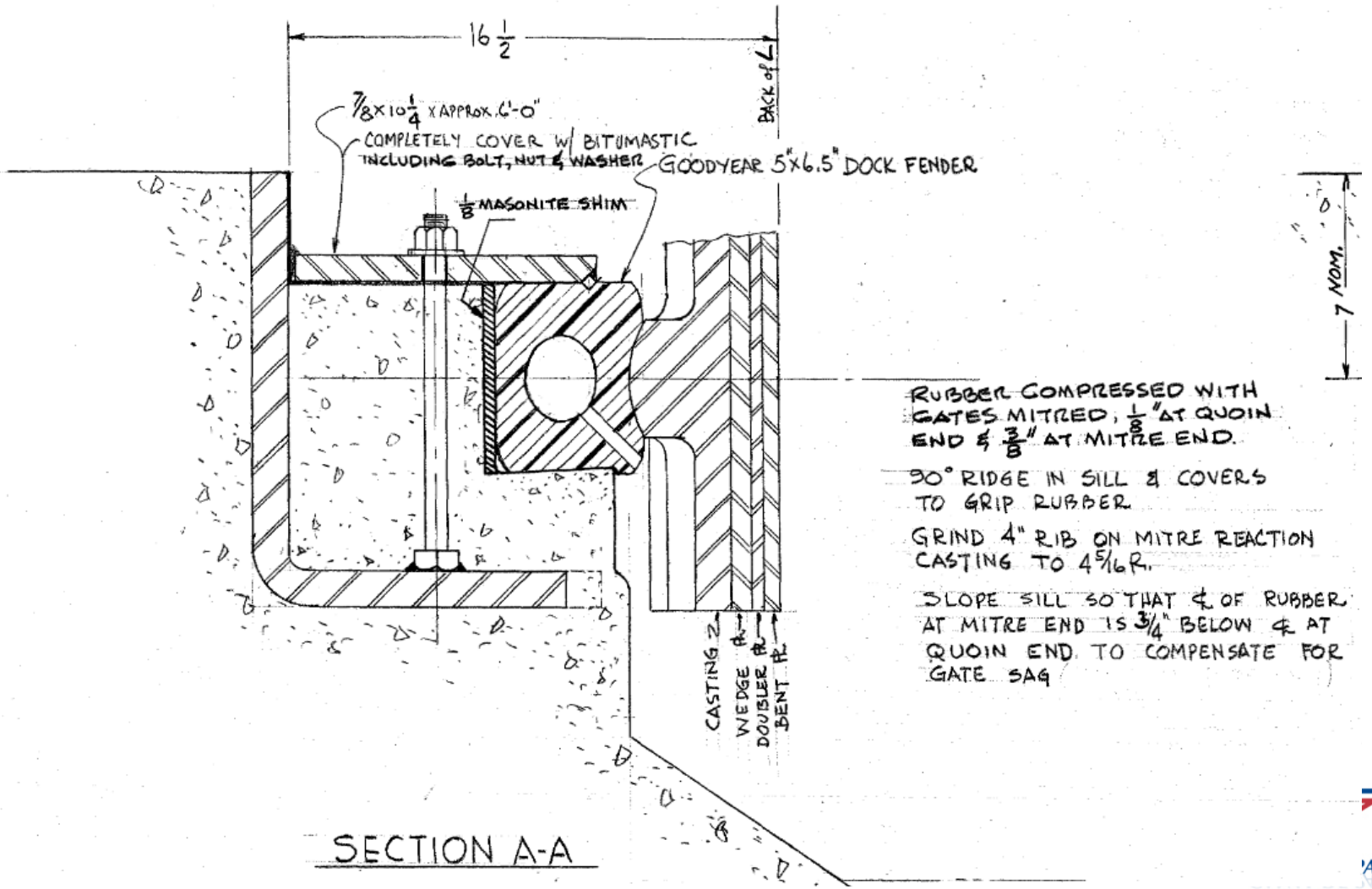
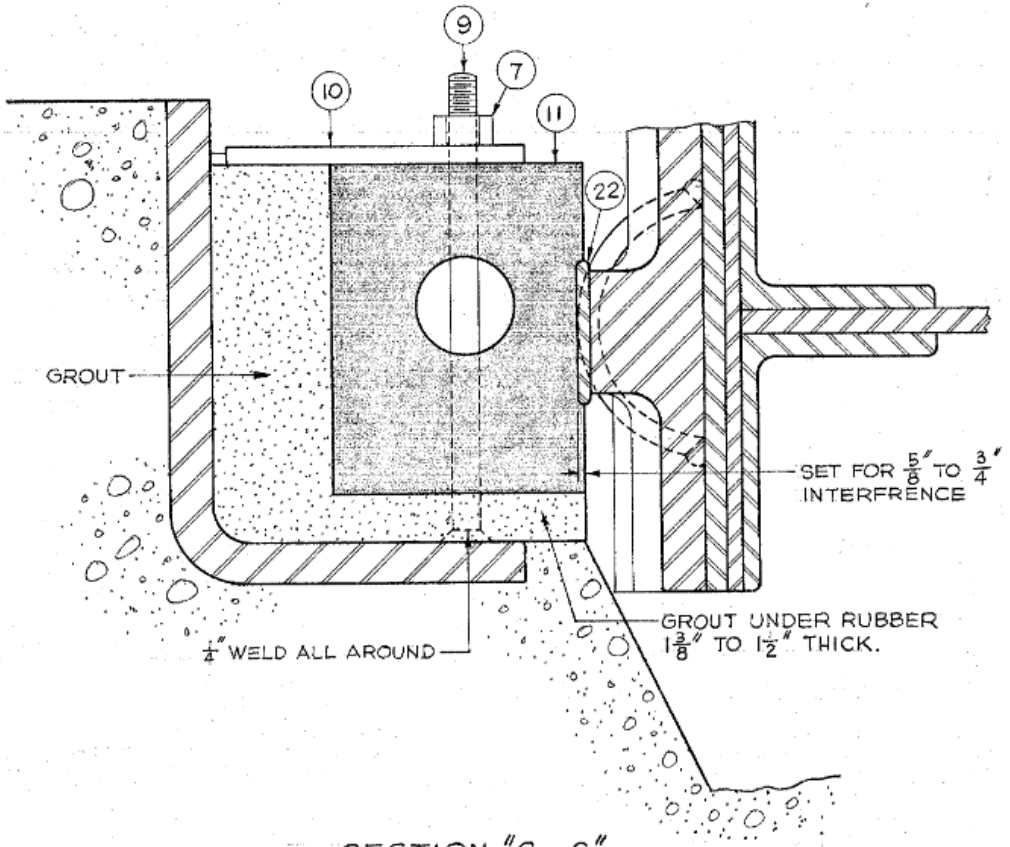
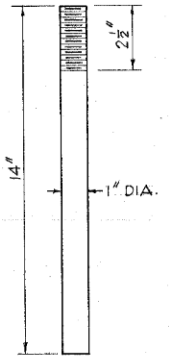
First apex change, 19 Jun 1956



Second apex change, 3 Sep 1957, Rev. 1958, 1963



SECTION "C - C"
SCALE: 3"=1'-0"



DETAIL OF PART (9)
SCALE: 3"=1'-0"

9	8	SEE DETAIL	STUD BOLT, STEEL
10	2	SEE DETAIL	STEEL PLATE, SEE DRAWING NO. 5088-222.
11	2	SEE DETAIL	RUBBER FENDER, SEE DRAWING NO. 5088-222

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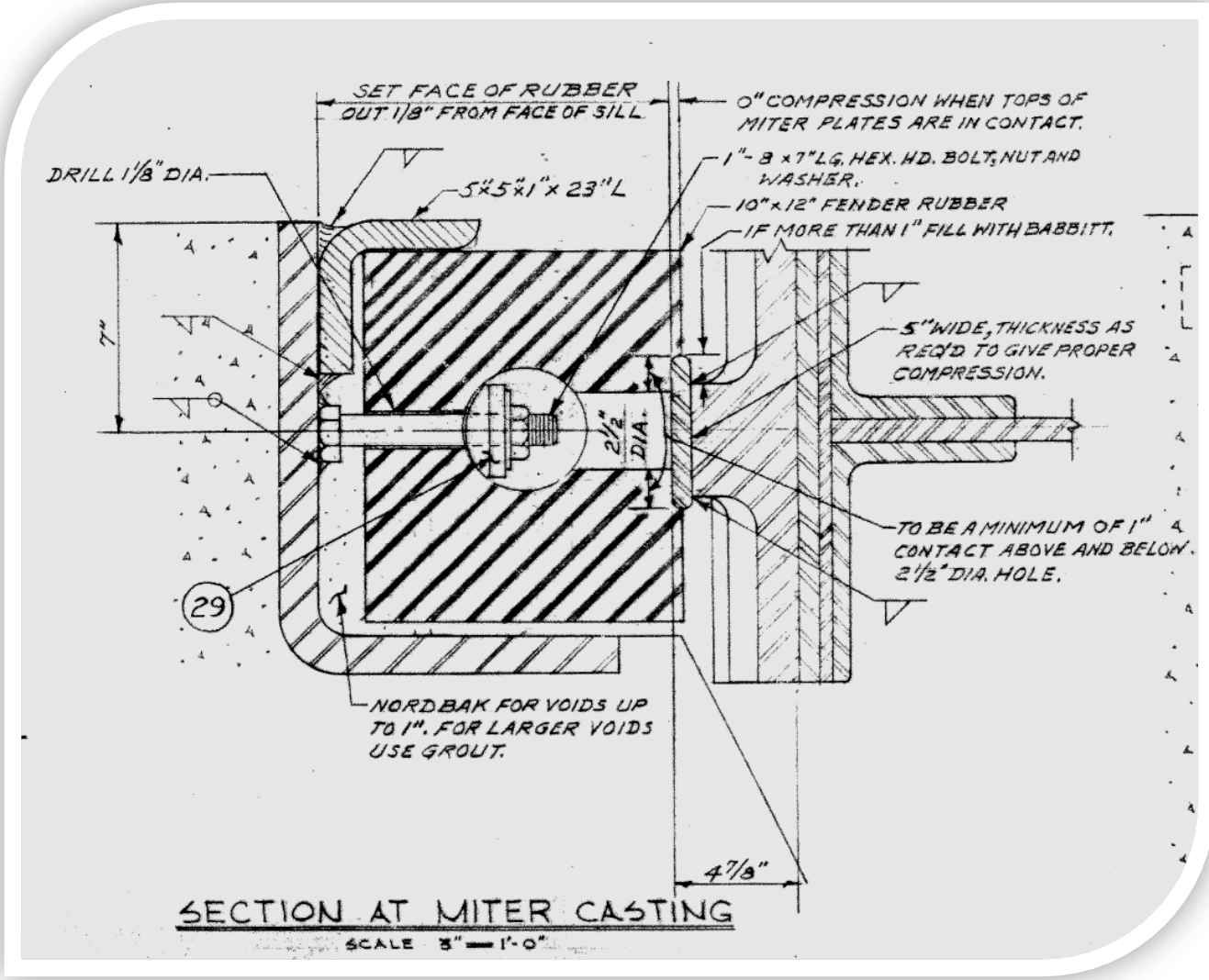
Third apex change, 11 Apr 1969, Rev. 1999, 2001



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Seal damages

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Apex Inspections

Developed Inspections

- 432 diving inspections done in Pacific Locks between 2012 and 2015.
- 81 of them with some apex issue relationship, maintenance or repair.
- 18.7% from total amount.

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Sill and apex damage exposed during dry chamber works.

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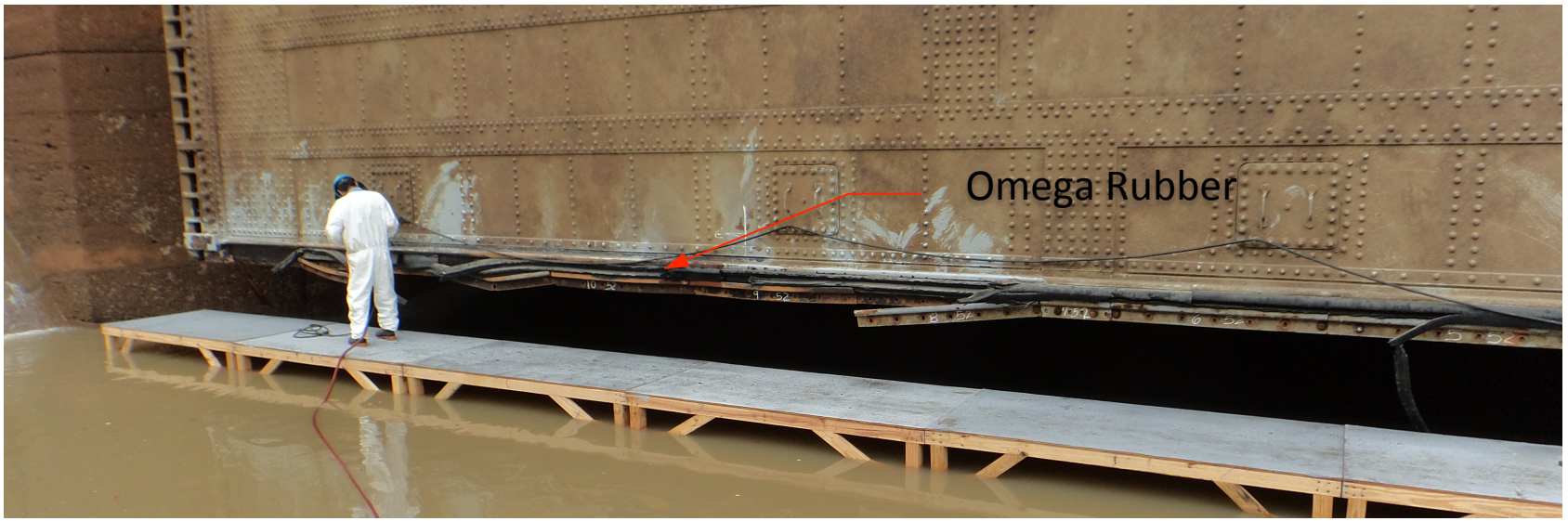

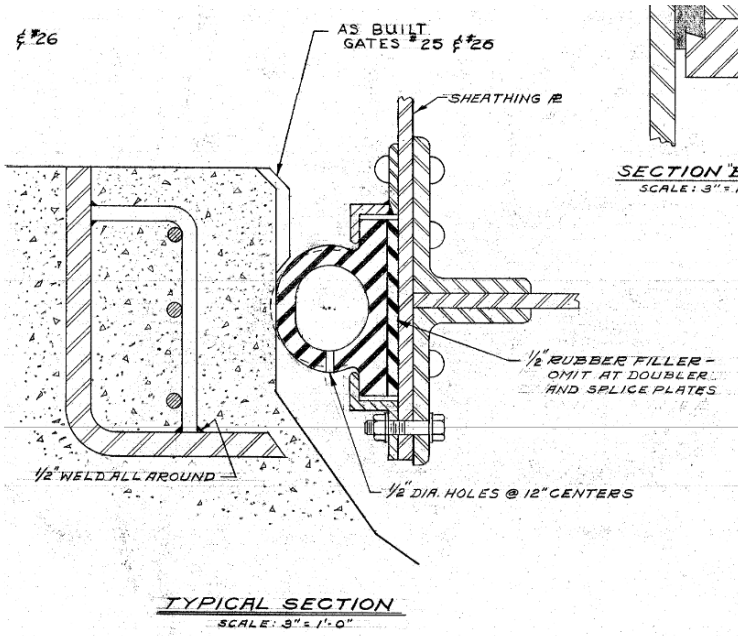

Omega Rubbers

- These are part of the rubber seal installed directly on gate. Works together with Apex.
- Severe damage is presented in some conditions, including the fixing hardware.

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Premises and Hypothesis

- As indicated in design drawings:
  - The maximum apex deformation is 1/8”
  - There are no compression when tops of miter plates are in contact.
- In regular operation the perfect mitering is not achieved and a gate over travel is a normal condition.
- As shown in evidences, the apex damages are consequence of the pressure induced by miter gates which is greater than the one specified in designs. Permanent deformations are observed.
- The excessive apex deformation increase the omega seals damage, also affecting the gate hardware and the concrete sill.
- Hypothesis: If we can develop something for decrease the apex deformation, we can protect the rubber seals obtaining a better gate sealing.

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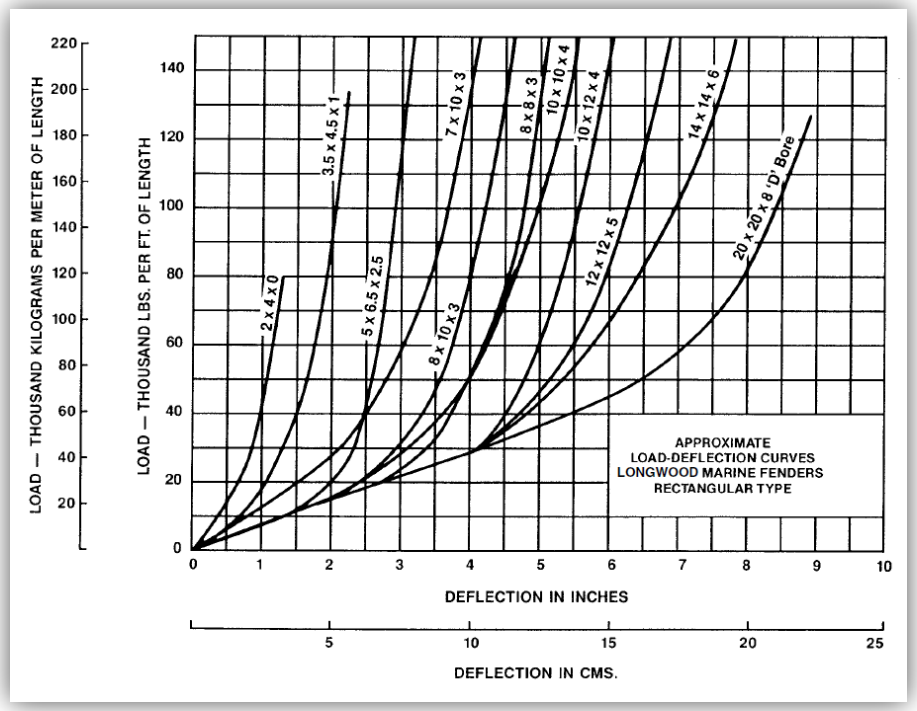
- An apex seal is mainly a commercial rectangular fender with a 10” x 12” section.
- As per fender tables, this section may have a maximum deformation of 6”.
- We search different alternatives for increase the loading capacity, minimizing the deformation.
- If we can achieve this combination, we can limit the gate over travel.



Force-deformation graph.
Square fenders, Longwood Marine

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Apex Tests

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Apex Tests

- Some used fender sections were located, with a cross section similar to the specified in apex design and were cut to a sample length of 14”
- The cavities were filled with different materials to compare them with the original hollow section.
- The only available equipment for us is a concrete test press. We simulated the gate behavior on the rubber apex and applied load over the specimen.
- We only made 3 test types:
  - Hollowed section sample
  - Vulcanized rubber filled sample
  - Nordbak® filled sample.

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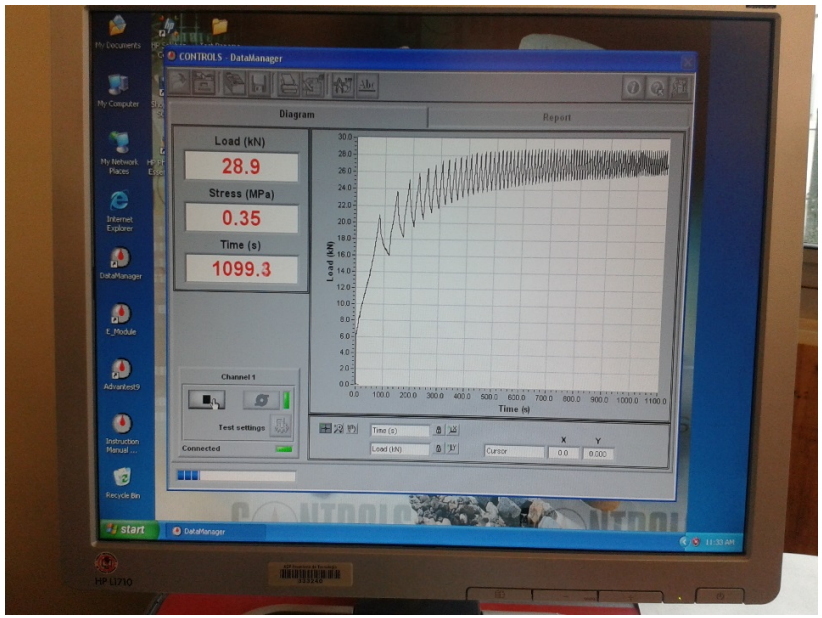
Equipment used for test



Original Hollowed section test

Test with vulcanized rubber fill

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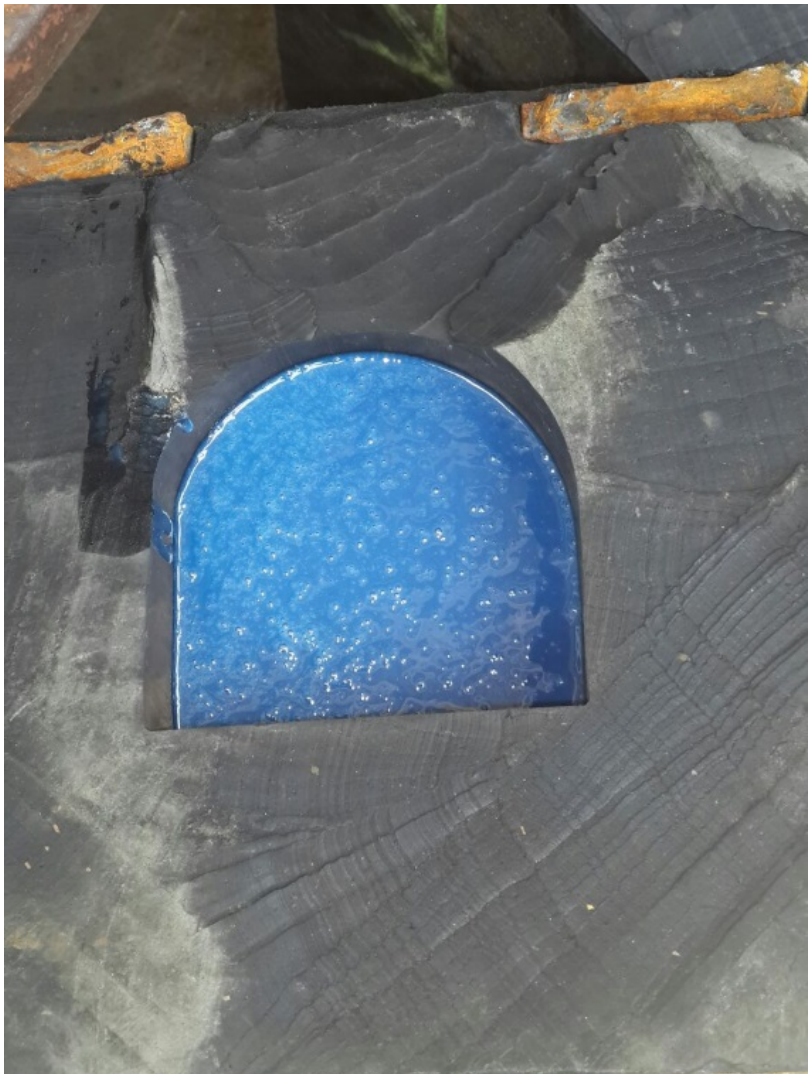
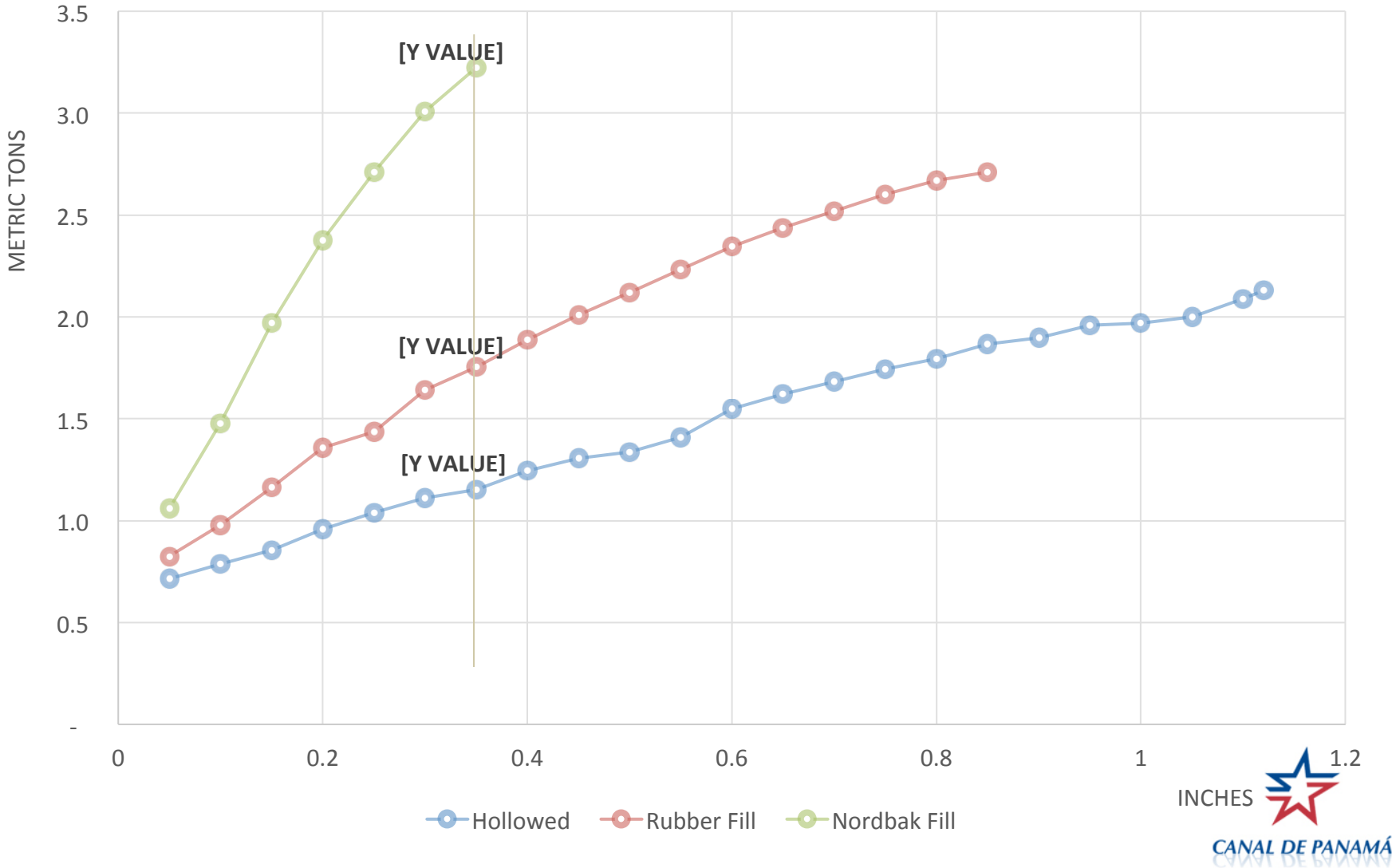
Test with Nordbak® fill



Apex samples behavior



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Rubber test conclusions

- The sample filled with vulcanized rubber, have an increased capacity of 52% if compared with the hollowed section.
- The sample filled with Nordbak®, shows an increased capacity of 180% if compared with the original hollowed section.
- If the gates don´t have a perfect mitering and with 1 feet of water head, the gate force over the apex is 870 kg. The gate´s movement momentum is not considered in this value.
- A Nordbak® filled apex with 9mm deformation, will have a load capacity of 6,400 kg.

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Fixing hardware

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Apex Installation

- As per current design, two marine brass bolts were used in each section.
- The modified apex was used for it´s first time.
- The gate works properly for approximately 3 weeks.
- The bolts failed by shear and a big leakage started.
- No damage on apex.
- New question:
  - Why do we have a shear stress?

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Gate sagging

GATE N°	WITH WATER HEAD		MITERED		OPEN 2.5 '		Gate Movement (in mm)
	Miter Side (feet PLD)	Quoin Side (feet PLD)	Miter Side (feet PLD)	Quoin Side (feet PLD)	Miter Side (feet PLD)	Quoin Side (feet PLD)	
100	55.147	56.286	55.089	56.283	55.08	56.282	**17.68**
101	55.09	56.277	55.04	56.273	55.024	56.272	**15.24**
102	55.184	56.358	55.094	56.354	55.098	56.355	**27.43**
104	55.105	56.451	55.063	56.45	55.057	56.449	**12.80**
105	55.004	56.413	54.955	56.408	54.951	56.409	**14.94**
106	54.947	56.332	54.864	56.329	54.867	56.328	**25.30**
107	54.935	56.353	54.847	56.343	54.844	56.342	**26.82**

Vertical gate movement = potential shear failure

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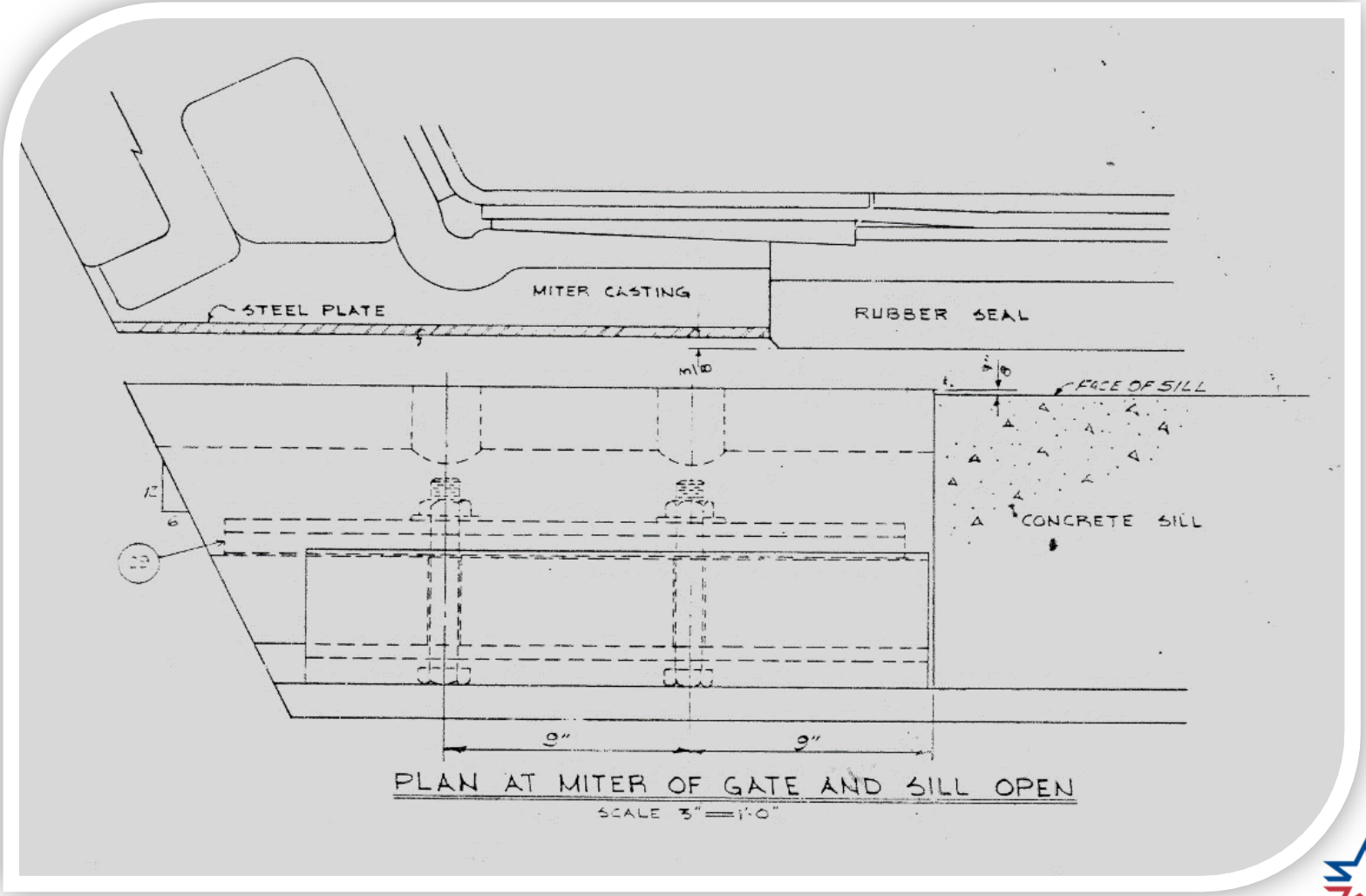
Drawing 5088-222A, 11 Apr 1969, Rev. 1999, 2001



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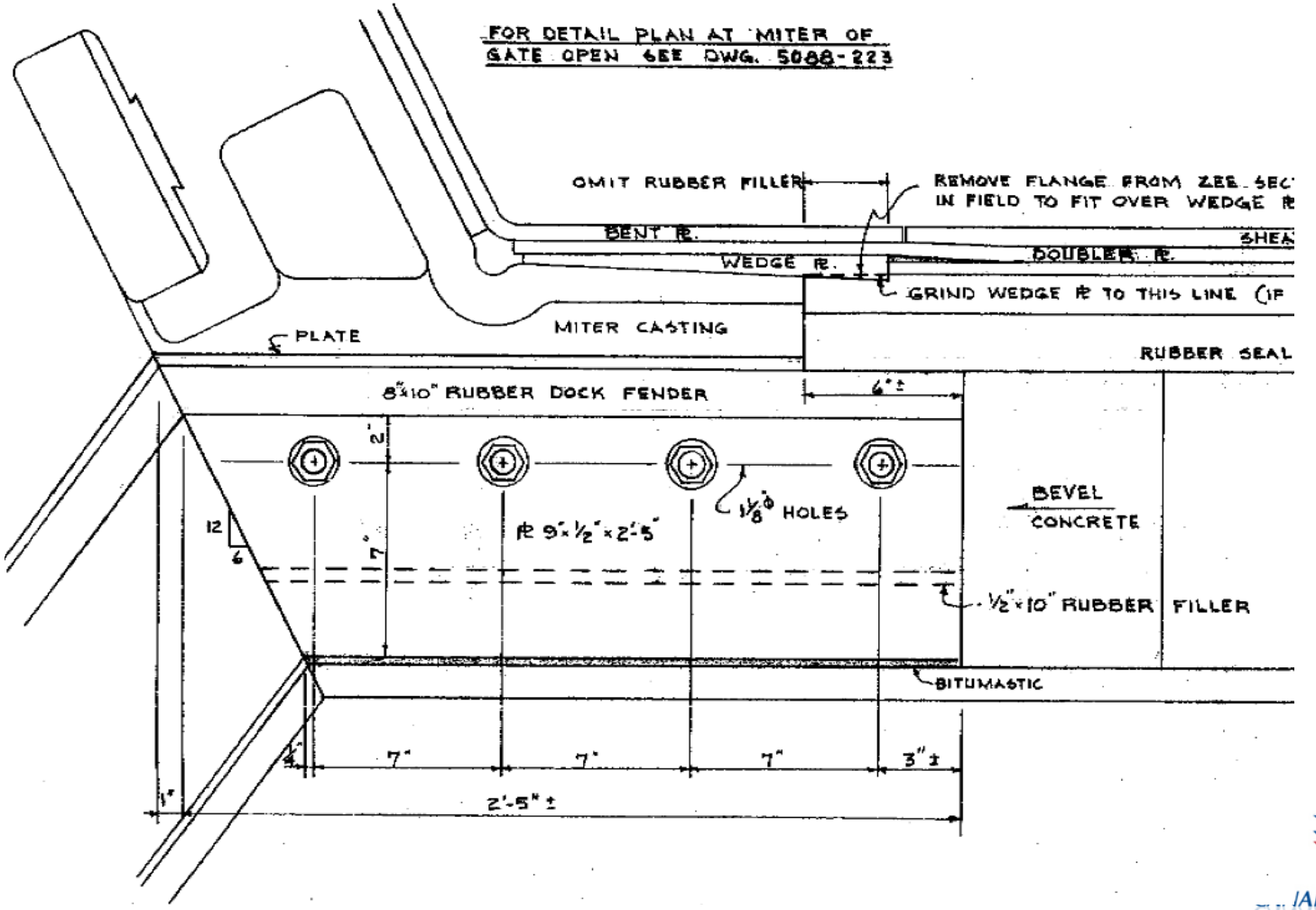
Drawing 5088-222, 3 Sep 1957



1”diam. Bolts capacities

Material	Rockwell Hardness	Fu (ksi)	Fv (ksi)	Fy (ksi)	2 bolts shear capacity (kips)	2 bolts tension capacity (kips)	4 bolts tension capacity (kips)
A36 Steel	67-83	58	20.9	36	32.83	43.63	87.26
A307-04 A Steel	100	60	21.6	40	33.93	48.48	96.96
SAE Grade 5 Steel	102-108	120	43.2	85	67.86	103.02	206.04
Monel Alloy 400	60-80	78.5	48.5	46	58.78	55.75	111.50
C46400 Naval Brass	55-80	48	34	16	41.21	19.39	38.78

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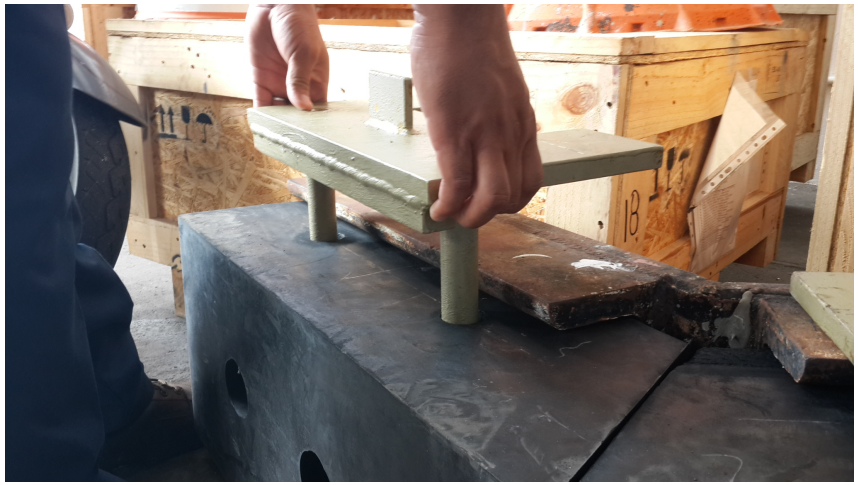
How was the vertical movement restricted?



- Our divers developed a device for emergency repairs, used for hold the apex, keeping the vertical movement. They named it “saber-tooth”.
- It was modified bringing more vertical capacity, combined with a gate stopper and keeping the original design.

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The final installed product

- This apex was installed in 8 gates during the last Pedro Miguel Locks dry chamber.
- Has presented a good performance and no seal leaks have been reported.


THANKS
MUCHAS GRACIAS