

RED HILL FUEL STORAGE TANKS

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Facts About the Red Hill Storage Tanks

- Construction began Christmas 1940, completed September 1943
- Project included 20 cylindrical tanks 100 feet diameter, 250 feet high
- Design capacity of 6 million barrels fuel oil (255 million gallons)
- Final cost: \$42 million
- 16 men died during construction
- Project also pumps 30 millions gallons per day of drinking water to surrounding area

Factors Leading to Construction

- Prior to the attack on Pearl Harbor all of the Navy's fuel was stored in unprotected above ground tanks at Pearl Harbor, next to the submarine base
- When RADM Chester Nimitz was Commander of the Bureau of Yards & Docks (in 1940) he wanted the Navy's 2-1/2 year supply of fuel oil protected from aerial attack
- Standard practice was to dig a trench and bury the tanks, but this was impractical to store 255 million gallons of fuel oil

Initial Plan

- The Navy's plan was to dig a series of tunnels and insert the tanks
- Finding a suitable site was problematic, Oahu is underlain by the Koolau Volcanic series, and these flows are full of vugs, clinker, underground streams, and pools
- Navy engineers finally settled on Red Hill, about two miles from Pearl Harbor, as it was mostly homogeneous basalt

Location of Red Hill and Pearl Harbor

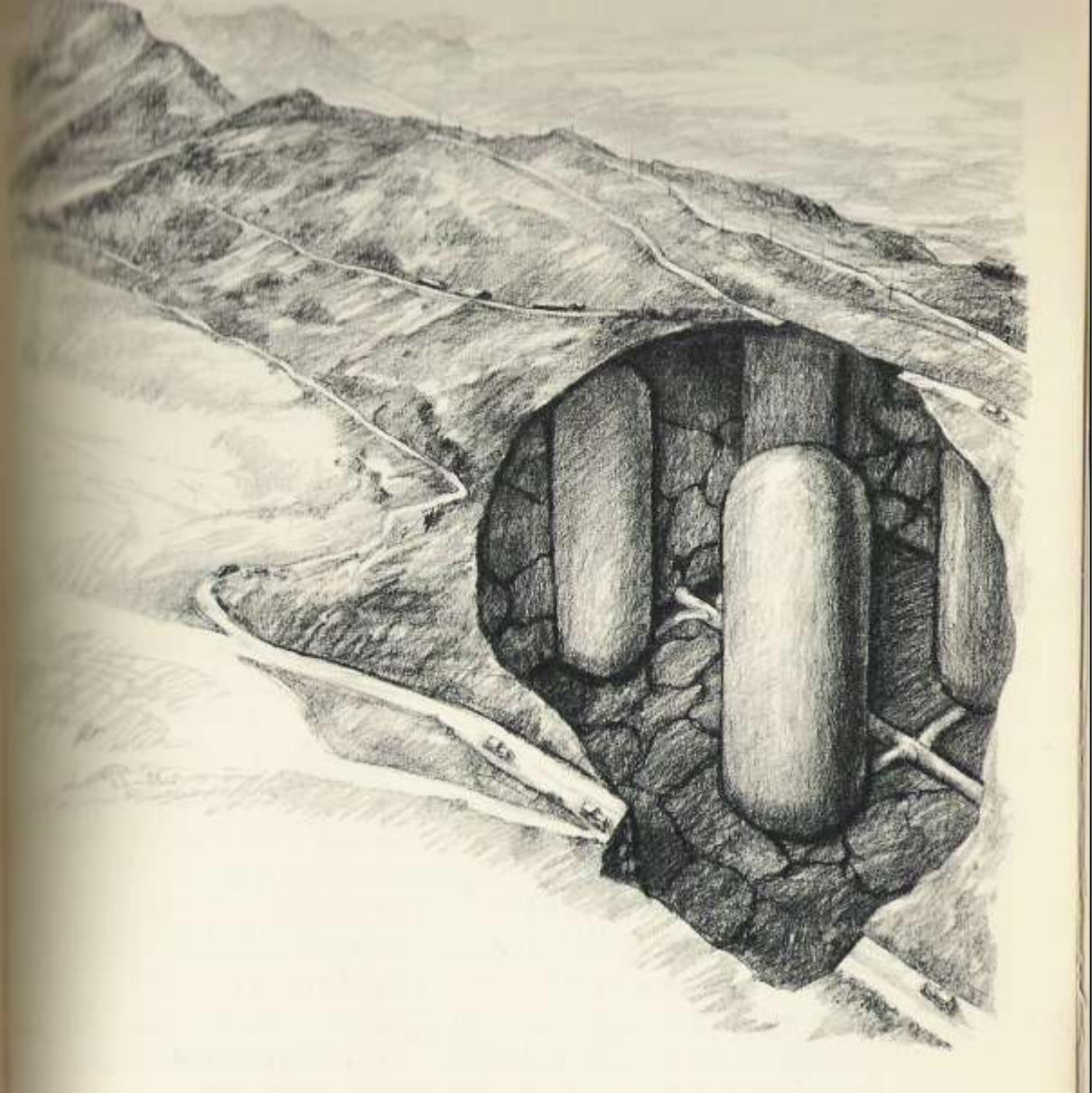


Red Hill

- Red Hill was not owned by the Navy, it was then under cultivation for sugar cane and pineapple plantations
- The Navy leased the land, cleared and leveled it, then began construction of temporary work camps
- Eventually the plantation owners were forced to sell out to the Navy through direct condemnation.

Planning and Development

- **Consultant engineer James P. Growden came up with excavating large vertical tank chambers instead of horizontal tunnels**
- **This would increase the volume of material that could be excavated simultaneously and decrease the number of heavy equipment needed for hauling muck. It also decreased the unit cost for rock removal substantially**



Design Concept for the vertically arrayed storage tanks

**Nothing like this
had ever been
attempted
previously**

**The contractor
used gravity to
“flow” rock muck
to the base of
each cavity**

Vertically Aligned Cylinder Tanks

- The tanks were set up in two parallel rows with two main access tunnels, one above the other, bisecting the rows
- Smaller tunnels, or adits, branched from these main axis tunnels to the tank cavities.
- To determine the depth necessary to protect the fuel from Japanese aerial attack, the engineers gathered data from the Army, multiplied it four-fold and rounded the figure off to 100 feet of rock cover

Sidehill entrance to the tank excavations and lower access tunnel, as sketched during construction



Access Tunnels

- Once the tank invert level and radius of curvature were determined digging could commence.
- Both the upper and lower access tunnels were excavated simultaneously
- They were constructed like the horseshoe shape of railroad tunnels, flat floors and walls, with an arched ceiling
- The tunnels were rough hewn then lined with concrete for increased strength

Chamber Adits

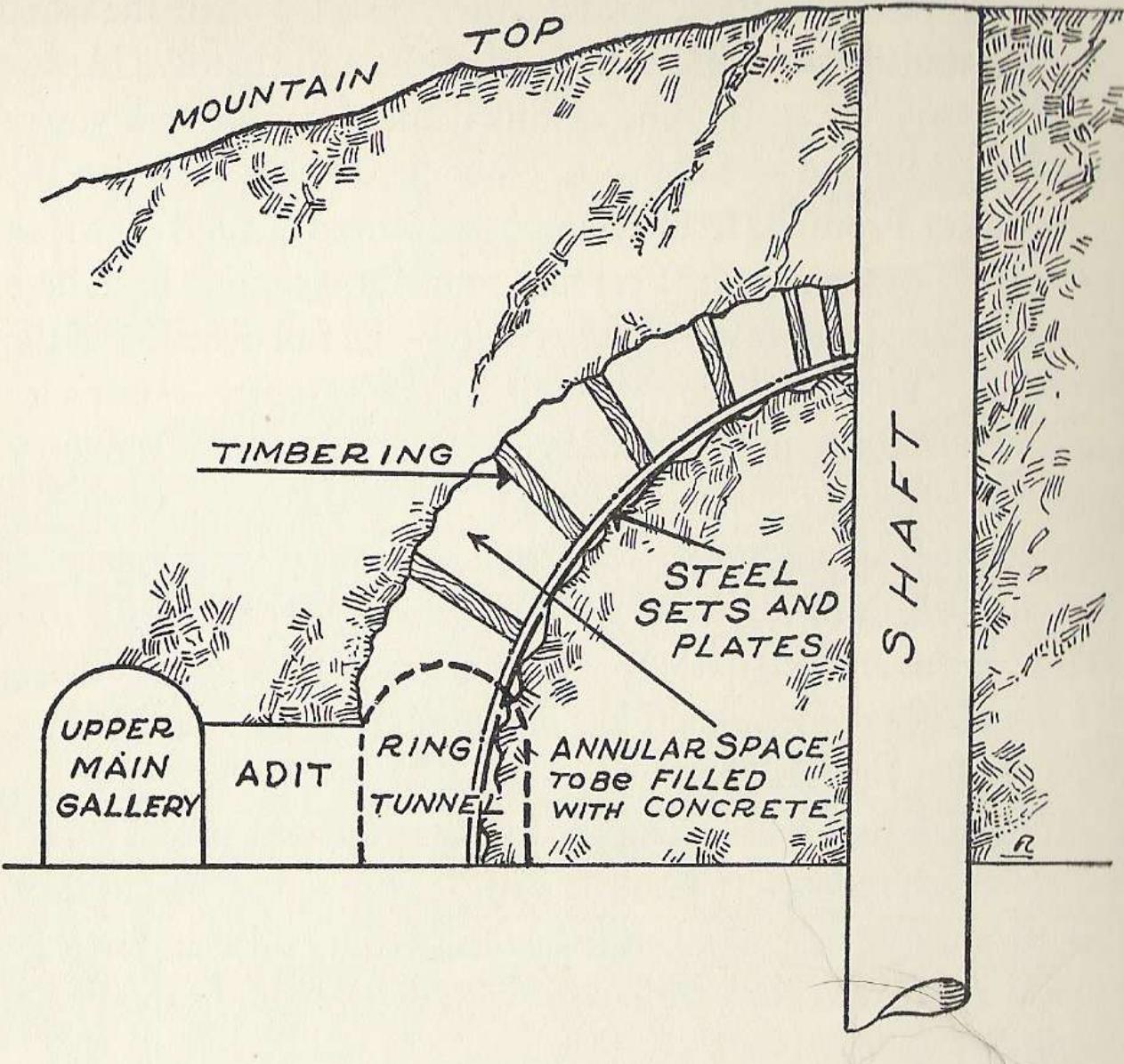
- As the main access tunnels moved past the location of an proposed storage chamber, more workers began digging the branch lines, or horizontal adits
- The adits were smaller, man sized, and were shored with steel H-beams bolted together and sprayed with cement
- The lower adit was excavated as far as the center point of the tank and the upper adits were stopped when they reached the outer radius

Beginning Tank Chamber Excavation

- In the upper adit, once the outer radius of the tank had been reached, a ring tunnel was dug around the radius of the tank chamber
- Upon completing the ring tunnel, the miners dug upwards in a hemisphere from all points around the ring, narrowing as they reached the central shaft
- Meanwhile, a central shaft 8 feet in diameter was excavated through the central axis of the chamber, down to the lower adit

How Each Chamber Excavation Began

The upper dome of each fuel chamber was excavated first, starting with a ring tunnel, then working upward, towards the central shaft



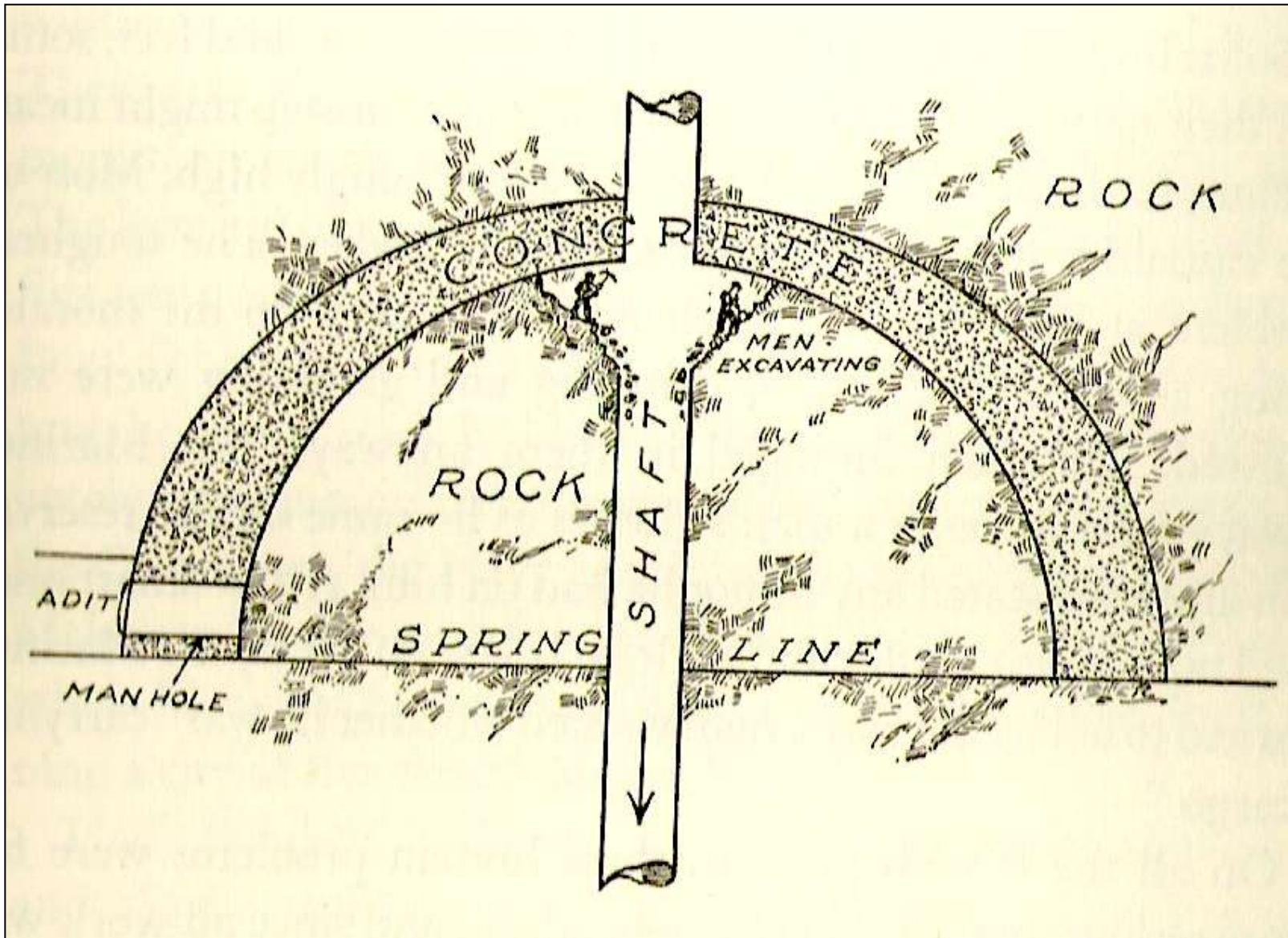
Forming the Upper Dome

(1 of 2)

- **Each section of the dome had to be braced with timber, prefabricated above ground in the exact curvature of the dome**
- **This allowed the miners to dig to a template reducing time of excavation**
- **I beams were then sent down and assembled to form ribs around the dome**
- **Sections of steel plate cut to piece together and form the dome were sent down and welded together**

Forming the Upper Dome (2 of 2)

- The wood shoring had to be shortened and replaced to account for the H-beam steel sets and liner plates
- A pipe network extending down the central shaft and radiating around the dome was constructed for placing concrete to line the tank chambers
- Each chamber dome required 70 hours of continuous pouring for 5000 cubic yards of concrete



After the upper hemisphere dome was concreted, miners could begin mucking the upper tank chamber, dropping muck by gravity through the central shaft, as shown

Tank Excavation

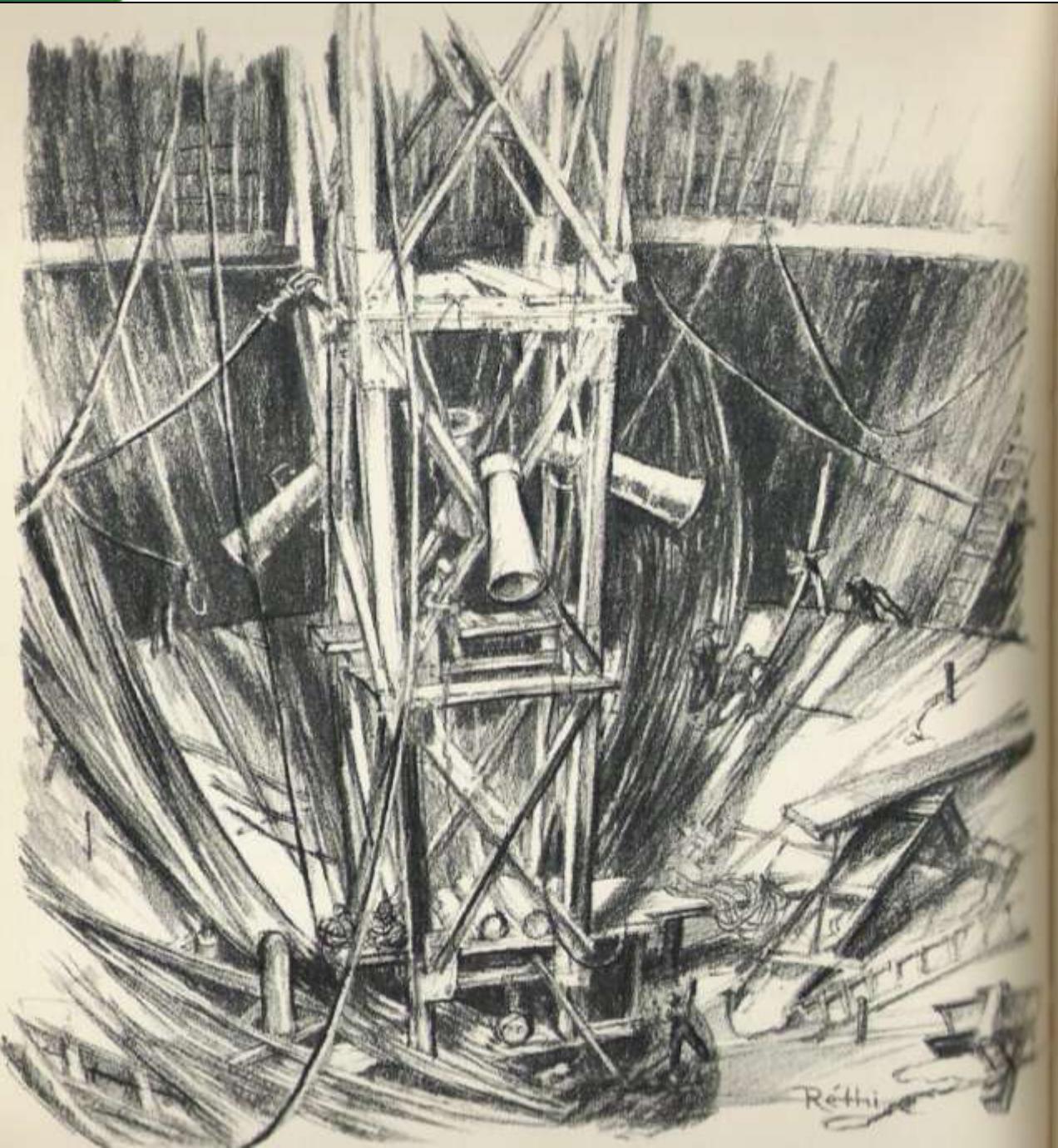
(1 of 2)

- As soon as the upper hemisphere concrete had set, workers were lowered down the central shaft to begin excavation of the tank chamber
- The miners dug outwards in all directions under the dome, keeping a 30 – 45 degree slope to the center of the shaft, so muck would slide into the shaft by gravity, greatly reducing mucking labor and transport for the project
- At the bottom of the vertical shaft rock screens (grizzlies) broke up falling rock so it could be transported on conveyors

Tank Excavation (2 of 2)

- In the lower adits an elaborate conveyer belt system was constructed to carry mucked rock out of the excavations
- The central tank shafts were expanded in a cone under the upper dome until the desired diameter was reached
- Following the deaths of a few workers falling down the central shaft, planks were rigged to the dome for them to stand on

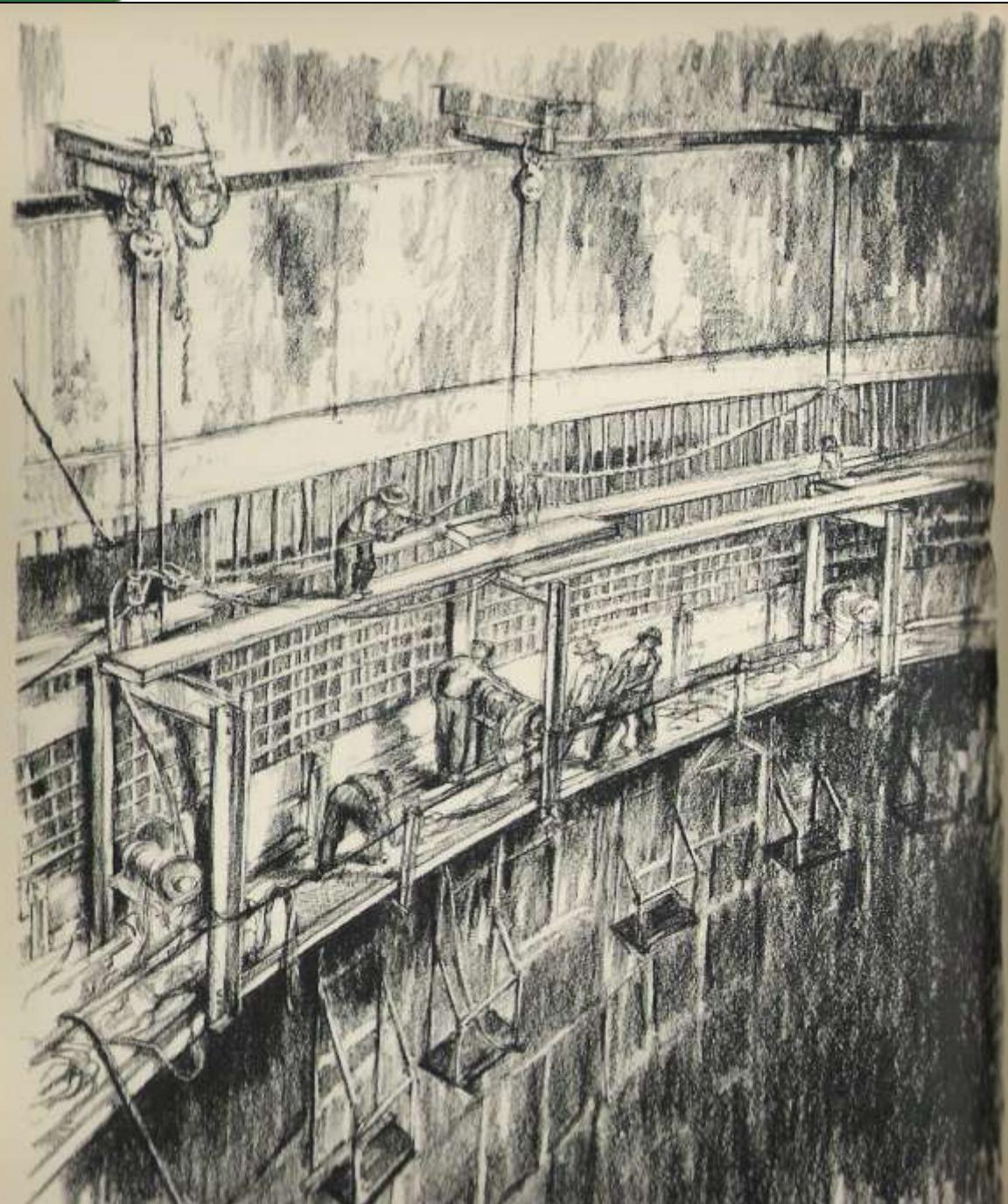
**Sketch of a
tank's lower
hemisphere
under
construction
being lined
with concrete
with an inner
steel lining**



Finishing Excavation

- The miners continued to dig downwards in a cone until they reached the lower hemisphere of the tank chamber
- The lining for the lower hemisphere was placed similarly to the top
- Any cracks or holes found during excavation were grouted and sealed

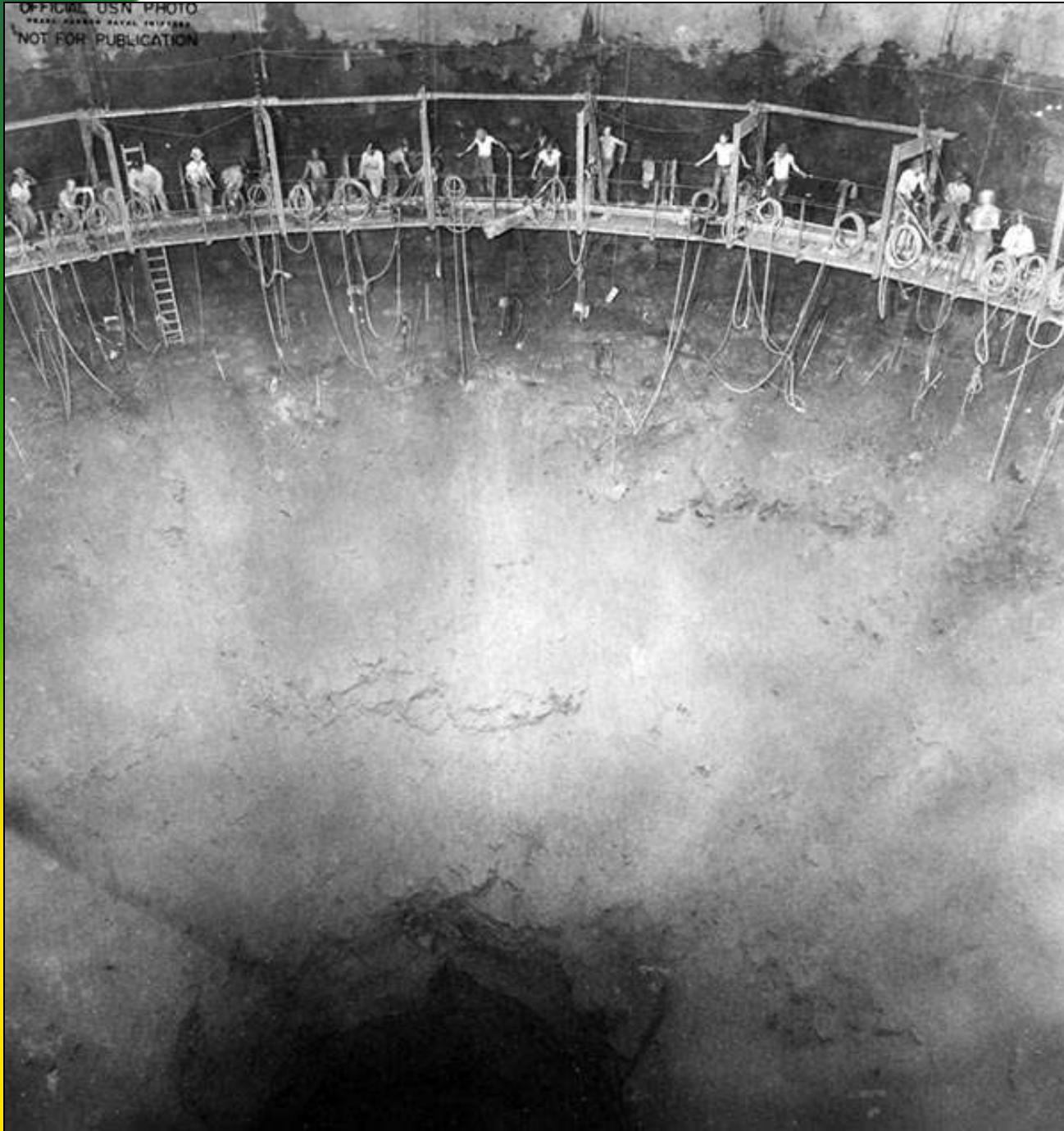
**Lining the
walls of the
tank chamber
Reinforced
concrete was
placed against
the rock and
smooth
continuously
welded steel
plate formed
the inner liner**



Constructing the Tank Liner

- Rings of steel ribs were constructed above ground and sent into the shaft for assembly
- Once a skeleton was assembled through the entire shaft, steel plate was welded around the ribs to form the tank's inside liner
- Concrete was poured into the space between the tank liner and the rock

OFFICIAL USN PHOTO
PROPRIETARY MATERIAL
NOT FOR PUBLICATION



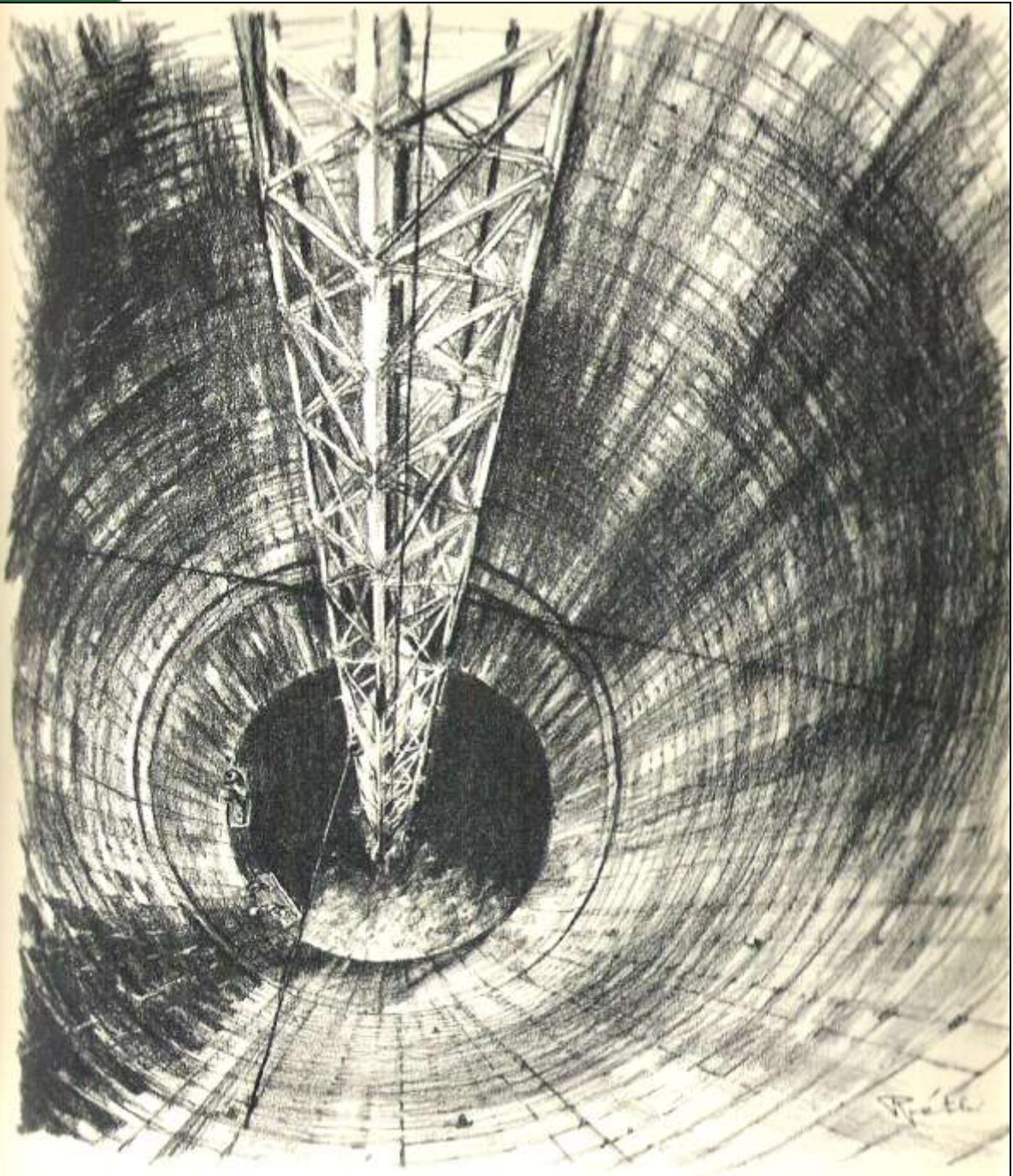
**Construction
of the Tank
Walls
This view
shows the
concrete liner
being poured
against the
rock face near
the bottom of a
chamber**

Finishing the Tank Chambers

- Once the concrete had set, high pressure grout was injected into the tension cracks and spaces remaining between the concrete and the tank
- The Navy filled each tank with water to perform leak tests
- If there was more than a $\frac{1}{2}$ inch drop in 24 hours from a pipe on top the tank chamber, they failed the test

Checking for Leaks

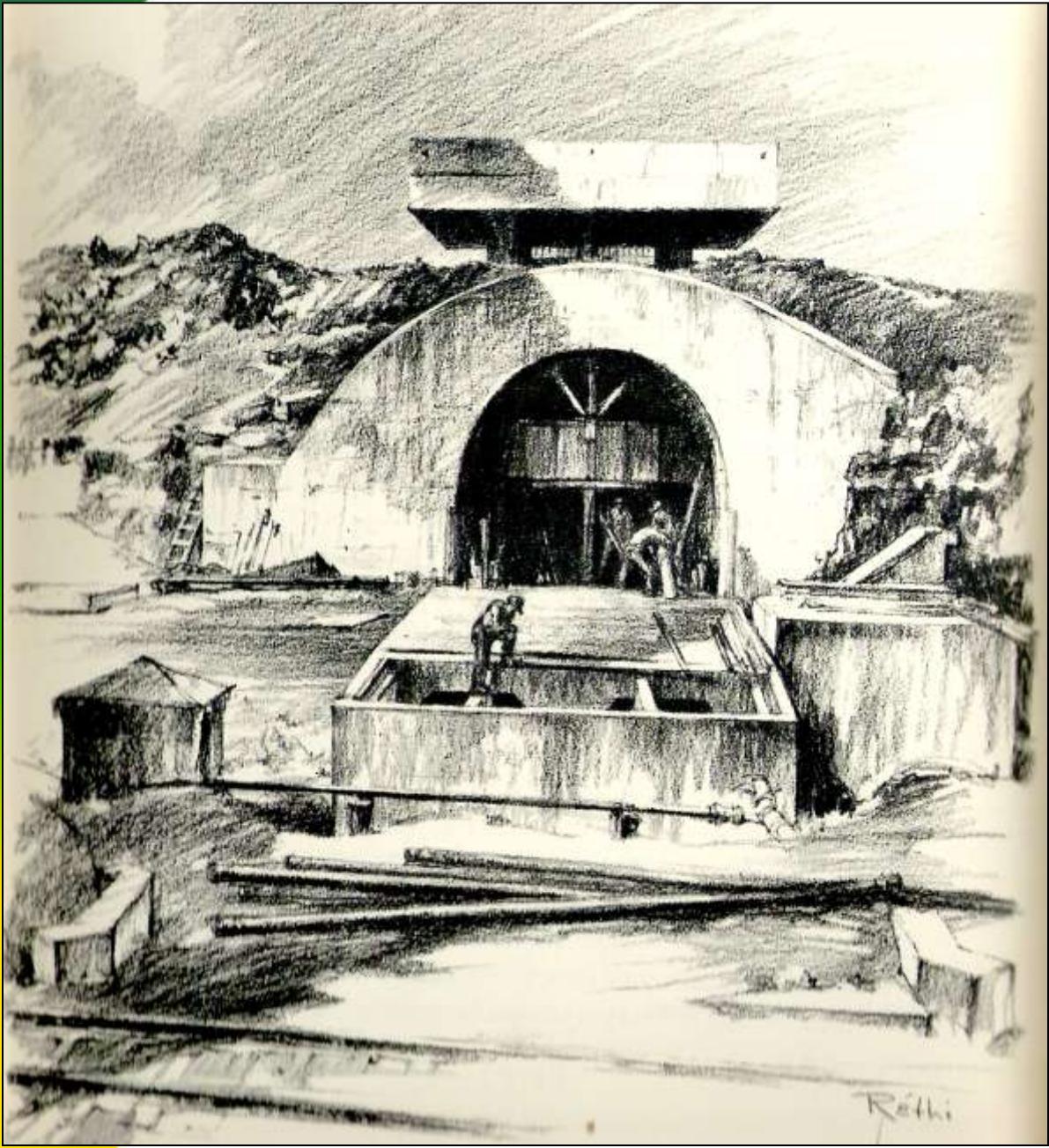
**This sketch
shows water
being fed
into the tank
chamber for
a leak test**



Fixing Leaks

- In order to locate the leaks, the tanks were filled very slowly with water, as high pressure air was injected outside the tank
- Welders in boats on the slowly rising pool of water would look for the bubbles of air entering the tank's steel lining, signal for the water level to be lowered and then weld the seam
- Two men drowned when the water level was raised too quickly and their boat capsized

Protected Entrance to one of the Permanent Access Tunnels



Finishing Construction

- When each tank was complete the top was closed and the access shafts above the tank chambers were filled with concrete
- The Navy also had constructed a tunnel from the Red Hill Fuel Storage Facility to Pearl Harbor and installed a high pressure pipe line to handle the flow of oil to the harbor
- The entrance to these tunnels are all hardened, being concrete encased with blast doors. Additional doors are also installed throughout the portal tunnels to prevent accidental discharge of fuel

Environmental Problems

- Despite all the leak testing during construction (60+ years ago), leaks still occur
- Several sites have been used over the years for storage of waste
- Environmental remediation is underway to remove contaminated soil and create a leak proof spill site

References

- **Builders for Battle: How the Pacific Naval Air Bases Were Constructed,**
David O. Woodbury, E.P. Dutton & Co.,
New York, 1946, 415 pages.
- http://www.asce.org/history/build_redhill.swf
- Dr. Rogers' consultations for Navy Facilities Engineering Command Western Division