WATERSTOP FAILURE IN TUNNEL AT COMPLEX 1-C, LARSON AIR FORCE BASE, TITAN I FACILITY

MISCELLANEOUS PAPER NO. 3-534

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U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

Preface

The Waterways Experiment Station (WES) was requested by the Corps of Engineers Ballistic Missile Construction Office (CEBMCO), Los Angeles, California, to send a representative to a meeting to be held at Larson Air Force Base on 27 August 1962 for consultation and recommendations for sealing off the inflow of ground water into the tunnel at Complex 1-C, Titan I Facility, Larson Air Force Base. This letter report presents the results of the meeting.

The visit was requested by telephone call from the CEBMCO Directorate to Mr. T. B. Goode of WES on 25 August 1962 and subsequently authorized by teletype, ENGMA-AT-2-0335, from CEBMCO, dated 27 August 1962. The report was written by Mr. Goode under the general supervision of Messrs. W. J. Turnbull, W. G. Shockley, and J. R. Compton of the Soils Division, WES.

Director of the Waterways Experiment Station during the preparation of this report was Colonel Alex G. Sutton, Jr., Corps of Engineers. Technical Director was Mr. J. B. Tiffany.

U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
OFFICE OF THE DIRECTOR
VICKSBURG, MISSISSIPPI

EFER TO WESSE 28 September 1962

MEMORANDUM FOR RECORD:

SUBJECT: Water Stop Failure in Tunnel at Complex 1-C, Larson Air Force Base, Titan I Facility

1. Mr. P. A. Rosholt, CEBMCO Directorate, Los Angeles, California, called me about 8:40 p.m., 25 August 1962, and stated that a failure had occurred in the water stop between the tunnel and equipment terminal in Launcher No. 3 of the subject missile complex, and that ground water was flowing into the tunnel at a rate of about 20,000 gallons per hour. He then requested that I attend a meeting to be held at Larson AFB on 27 August for consultation and recommendations for sealing off the inflow of ground water into the tunnel. I told Mr. Rosholt that I would discuss the matter with Mr. W. G. Shockley, Assistant Chief, Soils Division, WES, and unless I called back I would attend the meeting as requested. I then called Mr. Shockley and advised him of Mr. Rosholt's call; it was agreed that I should visit Larson AFB as requested.

2. I arrived at Larson AFB at about 9:30 a.m., 27 August, attended a briefing meeting in the CEBMCO Area Office from 9:45 to 10:30 a.m., inspected the tunnels and water stops in the subject missile complex from about 11:30 a.m. to 4:30 p.m., and then attended a conference in SATAF Headquarters, Larson AFB, from 7:00 to 10:00 p.m. The morning of 28 August was spent in informal discussions of grouting equipment and procedures with CEBMCO and Seattle District personnel at Larson AFB. I departed Larson AFB for Vicksburg about 2:00 p.m., 28 August.

3. The meeting in the CEBMCO Area Office was attended by Colonel Charles A. Carrol, CEBMCO, Los Angeles; Messrs. Aaron Sheldon, John M. Wells, D. R. Moody, and Woodrow Glenn, Seattle District; Mr. Charles D. Tiersch, BSD/BSSFT, Los Angeles; and the writer. Mr. Tiersch briefed the group on the construction of the subject missile complex, the trouble experienced with water stops prior to the failure, the measures taken to strengthen the water stops, the water stop failure, and the emergency repairs made to stop the inflow of ground water into the tunnels.

4. Excavations for the tunnels and other structures at the site were made by open cut methods. Some excavations extended below a depth of 60 ft and no ground water was encountered. Construction of the complex was essentially completed during 1961. Irrigation of farm lands adjacent to the complex was started in the spring of 1961 and some trouble was experienced with ground water during the midsummer of 1961. The ground water has continued to rise and in some places it is now within 6 ft of the ground surface. The hydrostatic pressure in the deeper parts of the complex is approximately 25 psi.

5. The design of the complex required that a 4-in. open space be left between the metal tunnel liners and the metal rings on adjacent concrete structures. This space was sealed by placing a neoprene water stop around the outside circumferences of the tunnel liners and metal rings on the concrete structures, as shown in inclosure 1; this would afford flexibility at the joints in the event of large ground movements; the flexibility of the joints is referred to as the hardness factor. A typical connection between the tunnel liners and concrete structures is shown in inclosure 1.

6. After the ground water started rising around the tunnels, it was observed that some of the water stops were bulging inward as a result of hydrostatic pressure and it was felt that they should be strengthened. As a result, some of the water stops were reinforced by so-called strap fixes placed on the inside of the tunnel around the upper 300-degree area of the circumference of the tunnel. The water stop in the bottom 60-degree area of the circumference of the tunnel was reinforced by covering it with novaculite. The strap fixes consisted of a steel strap, approximately the width of the gap between the tunnel liner and the metal ring attached to the concrete structures, placed against the water stop with narrow metal straps welded at 1-ft intervals to hold it in place. A typical strap fix is shown in inclosure 1.

7. At 4:30 p.m. on Friday, 24 August, a 14-in.-long, 4-in.-wide piece of the water stop in the bottom of the tunnel between the tunnel liner and equipment terminal at Launcher No. 3 was forced inward into the tunnel and torn loose by hydrostatic pressure, permitting inflow of ground water into the tunnel at an estimated rate of 20,000 gallons per hour. When the failure occurred, AM-9 grout was being injected through the tunnel liners to stop leaks around bolt heads inside the tunnel at a point several hundred feet distant from the failure area; it was not felt that these grouting operations had anything to do with the failure. The location of the failure is shown in inclosure 2.

8. Immediately following the failure, labor forces and materials were mobilized and emergency repairs were started; the inflow of ground water was brought under control during the late afternoon of 25 August. The repairs consisted of placing plywood strips over the hole in the water stop and over the intact water stop in the bottom of the tunnel a distance of about 3 ft on each side of the hole. The plywood strips were held in place by vertical braces extending to the top of the tunnel. After the braces were in place, the plywood strips and the immediate areas on both sides of the water stop were covered with sand bags. As soon as the sand bags were in place, the injection of AM-9 grout was started; between 500 and 1000 gallons of grout were injected through the tunnel liner into the area adjacent to the failure. The grout was proportioned so as to obtain

a 3-1/2-minute set and pumped at pressures ranging from 45 to 60 psi. The inflow of ground water had been reduced to only a few gallons per minute when repair operations were stopped late in the day on 25 August. No work was performed on 26 August, but grouting was resumed the morning of 27 August.

9. The failure area and most of the tunnels in the complex were inspected in company with Colonel Carrol, Messrs. Sheldon, Wells, Moody, Glenn, and Tiersch, and Mr. G. T. MaHoney, BSD/BSSFT, Los Angeles. When the group arrived at the site of the failure, AM-9 grout was being injected through the tunnel liner adjacent to the failure at a pressure of about 60 psi and the inflow of ground water had been reduced to an estimated 3 to 4 gallons per minute. It was decided to continue injecting grout until such time that all inflow of ground water was stopped or it was determined that it could not be completely stopped with AM-9 grout. The floor of the tunnel between the equipment terminal and a sump located about 20 ft south of the equipment terminal, and the bottom of the sump were covered with gelled grout and backfill material. The backfill material entered the tunnel through the break in the water stop before the emergency repairs were completed. It was estimated that 4 to 6 yd of backfill material had flowed into the tunnel. The material was gravelly and contained some 2-in. particles. The gelled grout had flowed out through the break in the water stop after injection of AM-9 grout was started.

10. Following the inspection of the failure site, most of the other tunnels in the complex were inspected to observe the condition of some of the other water stops and to check for leaks around bolt heads in the tunnel liners. All of the tunnels had been grouted with AM-9 grout injected through holes spaced on about 4-ft centers in an effort to stop troublesome leaks around the bolt heads. No leaks of any consequence were observed and it did not appear that any of the water stops were in immediate danger of failure where they could be observed above the walkways in the tunnels. The water stops below the level of the walkways were not inspected. It was concluded that the chemical grouting of the tunnels was very satisfactory insofar as stopping leaks around bolt heads was concerned.

11. The failure area was inspected again late during the afternoon, at which time all inflow of ground water had stopped. The grouting contractor was instructed to stop grouting the failure area and to resume grouting operations in the area he had been working in prior to the failure.

12. The conference in SATAF Headquarters was attended by the 18 people listed in inclosure 3. General Kelley was conference moderator. The primary topics discussed were the cause of failure in the water stop, permanent repairs to the failed water stop, and measures to be taken to prevent possible

failure of other water stops in the complex. A résumé of the pertinent matters discussed, conclusions, and recommendations is given below.

13. Available information indicated that the water stops were designed to withstand an external hydrostatic pressure of 25 psi and that the hydrostatic pressure on the water stop at the time of failure was probably about 12 psi. Subsequent to the failure it was determined that no shift had occurred in the as-constructed positions of the tunnel liner and equipment terminal. It was the consensus that the water stop failed either as a result of deterioration of the material in the water stop or because the strength of the water stop was less than 25 psi when installed. General Kelley instructed that specimens of the water stop material be obtained and tested.

14. After considerable discussion, it was decided that it would not be economically feasible to repair the failed water stop or replace it by methods that would preserve the hardness factor between the tunnel liner and equipment terminal. In view of this, it was decided to temporarily sacrifice the hardness factor at this location and repair and strengthen the water stop around the entire circumference of the tunnel by covering it with a pan fix. This would be accomplished by covering the water stop around the entire inner circumference of the tunnel with a metal ring having the cross-sectional shape of a steel channel and then welding the flanges of the ring to both the steel ring around the end of the tunnel liner and the steel ring attached to the equipment tunnel, as shown in inclosure 1; then a connection for injecting grout would be installed in the web of the ring and the space between the ring and water stop would be pressure-grouted with AM-9 grout. This would prevent leakage in the event ground motion occurred of sufficient magnitude to crack the welds.

15. A question was raised as to whether or not a large void might not exist beneath the tunnel liner in the vicinity of the break as a result of soil piping through the break into the tunnel, leaving the end of the tunnel liner unsupported. During the discussion that followed, information was furnished by Mr. Tiersch to the effect that in some cases the tunnel trench had been overexcavated and concrete cradles had been installed to support the tunnel liners. In some instances a considerable length of liner was cantilevered out toward the equipment terminal and some doubt existed as to whether the backfill material placed in the dry between the bottom of the excavation and the tunnel liners up to the spring line was supporting the tunnel liners, as the backfill may have consolidated when it became saturated. In view of this, it was the consensus that after the pan fix had been placed over the water stop, 2-in.-diameter holes should be drilled through the bottom of the tunnel liner and probings should be

made to determine whether or not the bottom of the tunnel liner was in contact with the soil or merely supported by AM-9 grout. In the event a void did exist, a series of 2-in.-diameter holes would be drilled adjacent to the failed water stop and grout injection pipes would be installed, after which an attempt would be made to force portland cement grout into the void and force the AM-9 grout out through the adjacent holes. If the AM-9 grout could not be removed by this method and replaced with portland cement grout, it was the consensus that a hole about 1 ft square should be cut in the bottom of the tunnel and the AM-9 grout removed from beneath the tunnel liner by means of a hoe or other tool that could be inserted through the hole, then the hole sealed and pressure-grouted with cement grout. It was recommended that the grout used for this purpose be mixed in the proportions of 1 bag of type II portland cement to 1 cu ft of water and 4 lb of bentonite. It was also recommended that the grouting pressures should not exceed 25 to 40 psi.

16. The question was raised as to what could be done to ensure the integrity of the other 34 water stops in the complex without sacrificing the hardness factor between the tunnel liners and adjacent concrete or other rigid structures. It was concluded that any method of strengthening the water stops which would preserve the hardness factor would be extremely costly, but that pan fixes could be placed over the water stops at relatively moderate cost. No decision was made as to how strengthening the water stops would be accomplished, as General Kelley stated that higher echelons of the Air Force than those present at the conference would have to be contacted for a decision as to whether the hardness factor would be sacrificed in favor of economy or whether the water stops would have to be strengthened or replaced by methods that would preserve the hardness factor. It was the consensus that regardless of how the water stops were strengthened, probings to determine whether voids existed beneath the tunnel liners should be made at each water stop, and that any voids discovered should be pressure-grouted with portland cement grout.

17. General Kelley instructed Colonel Carrol to initiate action for starting repair work on the failed water stop on 28 August, as outlined in paragraphs 14 and 15 above.

T. B. GOODE
Engineer
Chief, Inspection & Exploration Section

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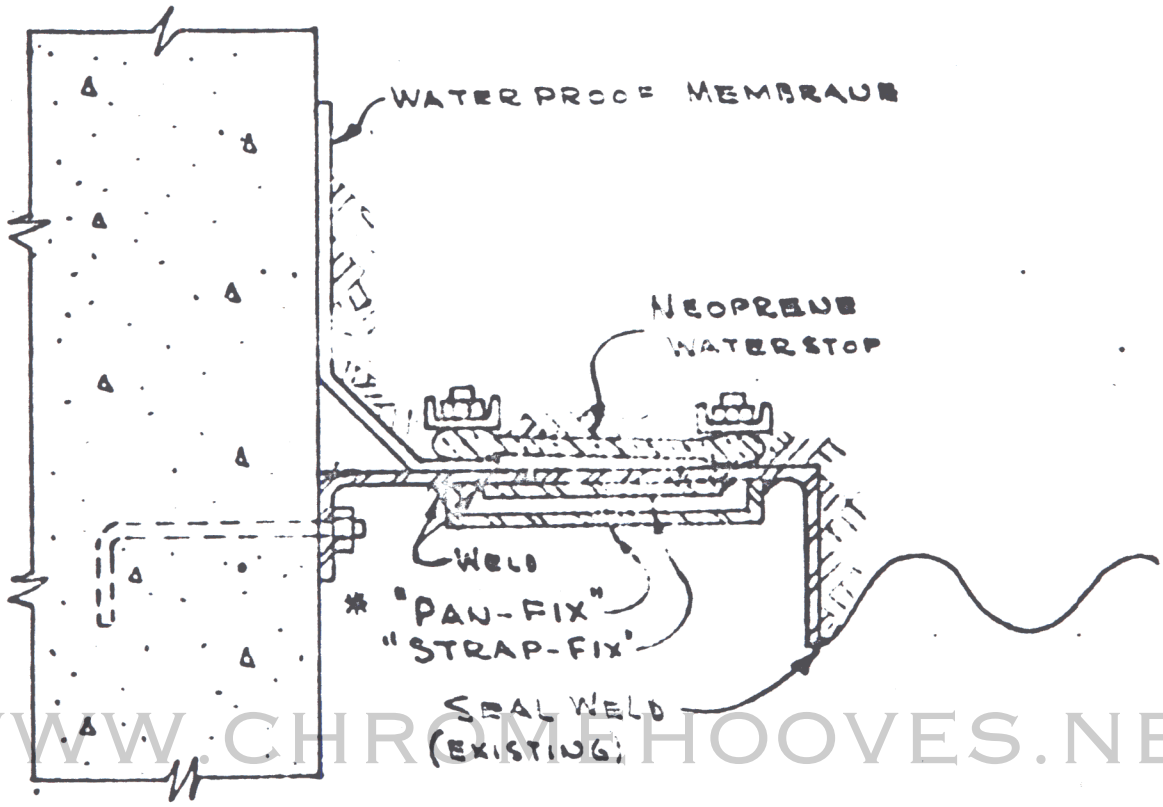
Copies furnished:
OCE (ENGMC-ER) (w/o incl 2)
CEBMCO, Los Angeles
1 cy ATTN: Engineering Division (w/o incl 2)
1 cy ATTN: Atlas F Directorate (w/o incl 2)

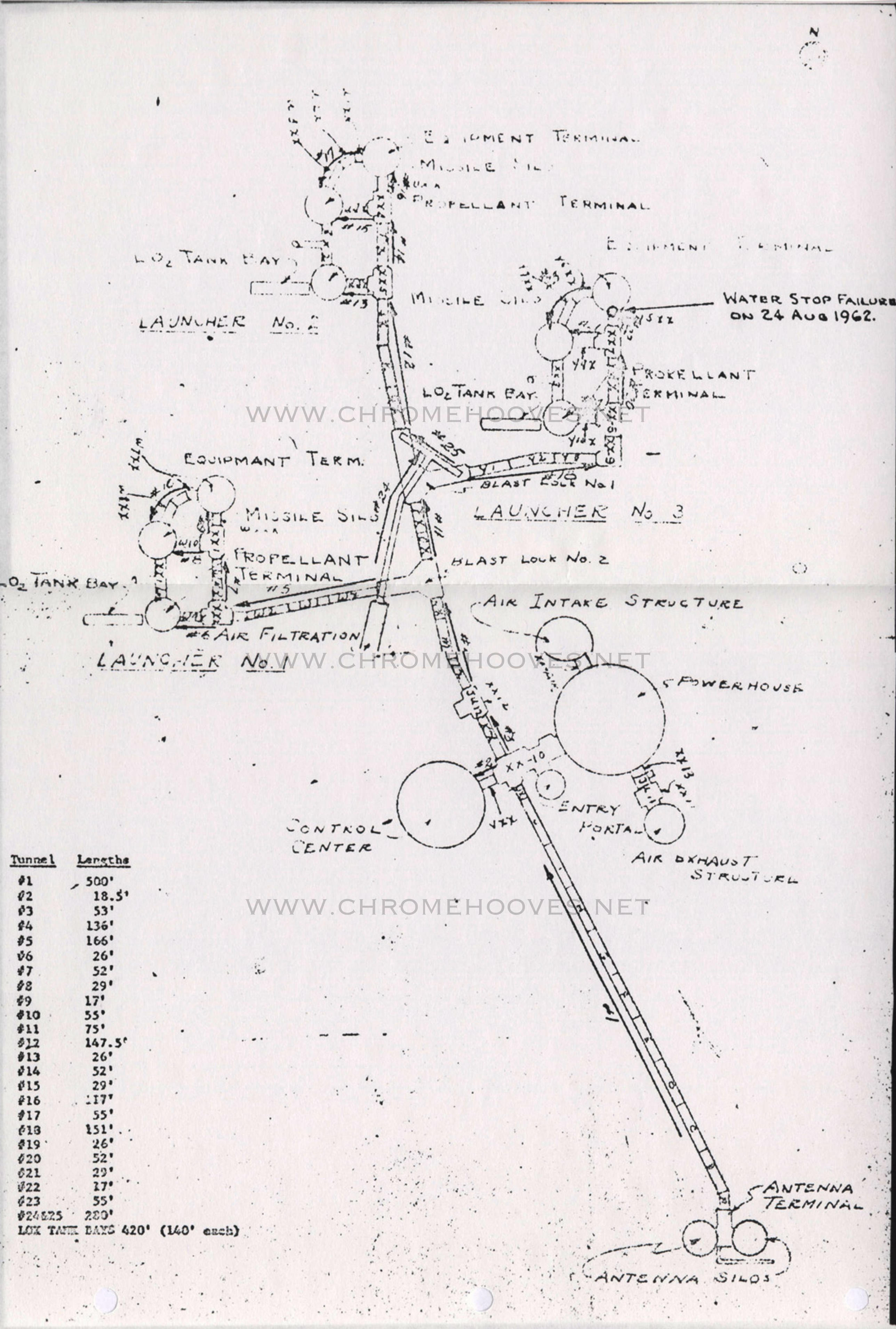


NOT TO SCALE

TYPICAL CONNECTION BETWEEN TUNNEL LINERS AND CONCRETE STRUCTURES

(TRACED FROM SEATTLE DISTRICT DRAWING, FILE NO. 700s/71-18-01)

* DETAILS OF "PAN-FIX" AND "STRAP-FIX" ADDED BY WBS.



Tunnel	Lengths
#1	500'
#2	18.5'
#3	53'
#4	136'
#5	166'
#6	26'
#7	52'
#8	29'
#9	17'
#10	55'
#11	75'
#12	147.5'
#13	26'
#14	52'
#15	29'
#16	117'
#17	55'
#18	151'
#19	26'
#20	52'
#21	29'
#22	17'
#23	55'
#24&25	280'
LOX TANK BAYS	420' (140' each)

Attendants at Conference in SATAF Headquarters

Larson AFB, 7:00-10:00 p.m., 27 August 1962

Name	Organization	Office
Brig. Gen. Kelley	BSD	Los Angeles
Col. York	SATAF	Larson AFB
Col. John L. McCoy	BSD	Norton AFB
Col. Charles A. Carrol	CEBMCO	Los Angeles
Lt. Col. Johnston	SATAF	Los Angeles
Major Looke	BSD/BSSFT	Los Angeles
Major J. D. Peters	SSND	Los Angeles
Mr. G. T. Mahoney	BSD/BSSFT	Los Angeles
Mr. Aaron Sheldon	Seattle District	Spokane
Mr. John M. Wells	Seattle District	Seattle
Mr. D. R. Moody	Seattle District	Seattle
Mr. Woodrow Glenn	Seattle District	Larson AFB
Mr. Charles G. Tiersch	BSD/BSSFT	Los Angeles
Mr. L. L. Shelden	DMJMDA	Los Angeles
Mr. Fred J. Matthies	DMJMDA	Los Angeles
Mr. Len Adams	DMJMDA	Los Angeles
Col. Robert Mitchell	BSD	Los Angeles
Mr. T. B. Goode	WES	Vicksburg

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