CONSTRUCTION HISTORY

Excavation & Backfill

General

Excavation was started in May 1959 on the first squadron and in July 1959 on the second squadron. Complexes were identified as 1-A, 1-B, 1-C for the first squadron and 2-A, 2-B, 2-C for the second squadron. The contractor tentatively established a sequence of complex completion for all work as 1-A, 1-B, 1-C, 2-A, 2-C, 2-B. This order was maintained with the exception of the interchanging of 1-B and 1-C during the concrete phase of construction. Refer to the actual typical construction progress chart for complex 1-C shown following page 61.

Open Cut

As soon as contractor survey parties established site excavation configuration from control furnished by the Corps of Engineers, heavy earth moving equipment moved in. The Prime Contractor, MK&A, handled open cut at complexes 1-A and 2-B. A sub, Hopkins Construction Company, open cut the remaining complexes.

A typical open cut operation consisted of 2-10 hour shifts using 8-10 21 to 24 yard scrapers, 4-5 push cats, with and without dozers and rippers, and one grader. In an average of six weeks, approximately 650,000 cubic yards of material per complex was excavated and stock piled near by. The three launcher areas were completed first so that shaft excavation could start as soon as possible. Excavation followed for the interconnecting tunnels, powerhouse and control center areas and the antenna silos.

The only unusual problem encountered was the uncovering of live ammunition at 1-B during stripping operations. During World War II years, the area occupied by 1-A, 1-B, 1-C, and 2-A was used by the Navy and the Army Air Force as a bombing range. Stripping operations were held up for a short time while military bomb disposal squads cleared the area.

Shaft Excavation

As soon as one launcher area was cut to depth, mining crews moved in to complete the excavation of the missile silos, equipment terminals, and propellant terminals. Normally mining operations were first undertaken at two missile silos simultaneously on a 2-10 hour shift basis.

Excavation was performed with a small crawler tractor in the bottom of the hole equipped with a front end loader and a ripper attachment. Material was ripped and scooped to one side of the shaft and picked up with a shovel with clam shell. Material was stock piled beside the hole and periodically carried away by dumpsters which roved between complexes. Most of the material could be used as backfill and the remainder was spoiled. Miners dressed the sides with jack hammers and hand tools.

At intervals from 2-7 feet, 6" H ring beams were blocked and wedged around the circumference of the shaft. 2" X 2" X 12" wire mesh was secured in place between the beams with hard wood lagging and shot with gunite to prevent sloughing of sides. Before wedging, ring beams were secured to each other with all-thread tie bolts and positioned for wedging by checking with temporarily installed plumb bobs at the shaft quarter points.

For purposes of safety, a 5' chain link fence was installed around the top of the shaft. Caged ladders were used with landings every 30 feet. A segment of the shaft was partitioned off with an I beam and lumber frame work behind which the shovel clam shell was lowered to pick up material. A signalman, with telephone hook up to the shovel operator, directed operations.

Occasionally tough shale or cemented conglomerate seams were encountered which had to be blasted. Site 2-C had some trouble with water which slowed operations to some extent and prevented adherence of gunite. These areas were heavily cribbed to prevent slacking and water was collected and pumped from the shaft.

The following table gives open cut and shafting statistics:

Structure	Open Cut Depth	Shaft Depth	Mining Diameter	# Ring Beams	Approx Sacks Gunite Cement
Missile Silo	38'	125'	45'	44	1750
Equipment Terminal	38'	48'	44'	10	580
Propellant Terminal	38'	26'	41'-6"	6	300
Antenna Silo	48'	23'	30'-6"	6	235
Powerhouse	72' (ring footing)				750 (post-stressing
Control Center	66' (ring footing)				240 (post-stressing

Bearing Tests

After the powerhouse and control center areas were open cut to depth, bearing tests were performed on the foundation material by progressively loading to 75,000 psi and recording load vs settlement for varying time periods. All tests proved foundation material adequate except that at 2-A. The condition at this complex was corrected by removing the objectionable lignite seam and backfilling with acceptable material.

Backfill

The material excavated in open cut and shaft operations was used for backfill. Densities required for compaction were 90, 95, and 100%. Open fill areas required 90%. Areas under and around structures required 95% and road base course material required 100%. Oklahoma Testing Laboratories (OTL) contracted with the Corps to do all testing for both dirt work and concrete. OTL covered all the complexes from their laboratory at Buckley Field. Procter Compaction curves were run on various types of fill material at each complex and density tests were taken when called for by the Corps of Engineers earthwork inspector.

Compaction was obtained with the use of sheeps-foot rollers, self propelled vibrating rollers (sand) and hand-operated vibratory compactors. Material was placed in approximately 6" lifts. The first area to be backfilled was around the antenna silos and the "B" tunnel leading from the antenna silos to the powerhouse area. Backfilling resumed again when concrete operations elsewhere were far enough along and was more or less continuous for the remainder of the job. 1-3 scrapers were kept busy at each complex.

Approximately three feet of sand fill was used under floor slabs and around interior structures in the powerhouse and control center. This was compacted to 95% density carrying a 3" to 6" lift.

Backfill placement required close inspection to obtain the desired compaction which was made under conditions considerably less than ideal, especially during the winter months. Bedding tunnel sections and tunnel junctions was unusually critical and required the closest of supervision. Inspector forces were spread quite thin during this particular phase, as evidenced later on when tunnel settlement became somewhat of a problem at most complexes. Maintaining and protecting backfill areas from run off was always a problem that was never completely solved. Considerable placed material had to be ripped and aerated because of rain and snow storms.

Concrete Operations

Forms

Practically all forms were prefabricated 3/4" ply wood designed and built in a central carpentry yard near MK&A headquarters at Buckley Field. Two to four sets of forms were built and trucked to the sites for use. Each panel was numbered on form erection drawings and so well were the forms engineered that very little remodeling was necessary at the site. The contractor design section engineered all scaffolding, shoring, staging and types of concrete tie rods and fasteners so that the maximum amount of material could be re-used on downstream complexes. All forms were static and were cleaned, patched and oiled after each use.

Probably the most exact forming was required on missile silo, antenna silo, and portal silo doors. These were formed in place and quite often were handled by special contractor crews going from complex to complex. Powerhouse and control center dome forms and attendant scaffolding represented the largest individual forms investment by the contractor in both time and money.

Steel Reinforcement

Meehleis Steel Co. furnished all reinforcing steel for both squadrons. A central yard was set up at the entrance to the access road to 1-B. Steel was trucked to the yard, cut to the right length, bent to the right shape, tagged in accordance with erection drawing nomenclature and trucked to the sites for use.

Re-steel shop drawings were well detailed and were used by both the ironworkers in tying and the Corps of Engineers inspector in checking size and spacing. In a few instances (cap pour of missile silo and thin floor slabs of antenna silo) re-steel was of such density, spacing could not be rigidly adhered to and each complex used acceptable innovations as they saw fit. Representatives of the designer (DMJM&A) were always available to pass on re-steel changes.

During the steel strike of 1959, #18 bars were not available. Because of this, foundations of missile silos, equipment terminals, propellant terminals, and portal silos were redesigned at some complexes substituting more mats of #11 bars. Some delays resulted.

Rigid grounding requirements called for continuous bonding of re-steel in most structures. Ironworkers and electricians bonded the re-steel by arc welding. The following table illustrates the heaviest re-steel used in each structure.

Structure	Foundation	Walls	Cap or Dome	Doors
Missile Silo	18	11	18	18
Equipment Terminal	18	6	18	-
Propellant Terminal	18	6	18	-
Antenna Silo	18	5	11	11
Portal Silo	18	6	-	11
Power House	*5	-	7(9's at apex)	
Control Center	*4	-	6(9's at apex)	
Blast Locks	11	6	11	

*See post-tensioning.

Post-tensioning

Contract drawings called for post-tensioning foundation footings of the powerhouse and control center. A sub, Preload Co., Inc., accomplished the job which was to be done after the domes were placed and after 3' of sand fill had been compacted to 95% density within the periphery of the ring footing. Eighteen gage high strength steel wire was stressed to approximately 150,000 psi and wrapped, in one operation, around the foundations with a specialized wrapping machine. Under good working conditions, one layer of wire, approximately 100 wraps, could be wound and stressed per eight hour shift. Each layer was gunnited, allowed to set up for 12 hours and the process repeated until 25 layers were stretched around the power house footing and ten layers were wrapped around the control center. The total post stressing operation took approximately six weeks at each complex and usually had to be done on a night shift so as not to interfere with access to the powerhouse and control center during the day.

Concrete Materials

Each of the six complexes required approximately 30,000 cubic yards of concrete. Strength requirements varied from 5,000 psi for missile silo doors to 2,500 psi for tunnel invert concrete. Most concrete placed called for a 28 day strength of 3,000 psi using 1½" aggregate. The following mixes were used:

Concrete, Grout and Mortar Mixes Currently Manufactured at 3 Missile Batch Plants Located at Lowry Bomb Range, Site 2B and Site 2C

		Materials to make one cu. Yd. of concrete (wts. - S.S.D.)							
Class Concrete	Mix No.*	Cement Content Pounds	Cement Content Sacks	Water Content Pounds	Water Content Gallons	Sand Pounds	#4-3/4" Aggregate	3/4" to 1½" Aggregate	A.E.A. oz.
A	1-C	564	6.00	282	33.8	1117	1046	857	9
A	2-C	588	6.25	282	33.8	1264	1740	--	9-10
C	3-C	517	5.50	290	34.8	1250	986	806	9-10
A	4-C	611	6.50	298	35.8	1209	1733	--	5-9
-	6-G	774	8.23	358	43.0	1605	1111	--	None
-	7-M	1075	11.4	491	58.9	1897	---	--	10-12
AAA	8-C	752	8.0	289	34.7	857	1095	893	8-10
AAA	9-C	799	8.5	306	36.7	997	1765	--	8-10
A	10-C	705	7.5	342	41.0	1387	1383	--	4

*Prefix C denotes concrete; G denotes grout, and M indicates mortar mix.

Aggregate and concrete sand were obtained from near Boulder, Colo., shipped to rail heads near the job sites and trucked to the batching plants for stock piling. Cement was obtained from Portland Colo. (Ideal) and shipped by rail and truck to the batching plants. "Gunite" sand was obtained from acceptable gravel pits near the sites.

Concrete Plant

Three batching plants were employed during concrete placing operations. A central dry batch plant located at the junction of the main road and the access road to 1-B furnished materials for the first squadron and 2-A of the second squadron. Capacity was about 200 yards per hour. Wet batch plants were set up at complexes 2-B and 2-C.

The dry batch plant batched quantities of 1.385 cu. yards (capacity of mixer) which were hauled to the sites in compartmented dump trucks. Batch counts were maintained at the plant and batches were accounted for at the site to reflect waste for each pour made.

Concrete Placement

Mixing was done at the complex using a two drum 34 cu. ft. paving machine. Under normal placement conditions slumps were maintained around 3" with about 4% entrained air. Concrete testing was under Government contract to Oklahoma Testing Laboratories who took slump and air tests of every pour and concrete cylinders for every 200 yds of concrete placed. Fourteen and 28 day breaks were made and in the case of door pours breaks were made for seven days and under to determine when forms could be removed. Cylinders were water cured at the sites and transported to Buckley Field laboratory for breaking.

Before concrete pours were started, Corps of Engineers inspectors checked approved contractor "lift" drawings and the re-steel drawings for proper clearance and spacing of re-steel and the correct positioning of all embedded items. Form measurements were spot checked and provisions made to have carpenters, electricians, and iron workers on the pour to check on their work as the placement was made.

Generally, a labor foreman was in charge of the placement and directed the crane operator with hand signals or telephone head set. Crane cabs were equipped with signal buzzers which were required to be sounded when the bucket was swung over the forms or lowered into the silos.

Concrete lifts were carried as near to two feet as possible and tremies were used if the concrete was dropped over five feet. Electric and air operated vibrators were used in placement.

Powerhouse Dome

The first and second dome pours caused some difficulty on the first complexes due to the length of the pour and the fact that only one rig was used which necessitated frequent moves, thus causing delays. Vibration was difficult, the weather was hot, and it was hard to keep the pour "alive". Removal of pours disclosed some "rock pockets" and "honey combing". This problem was solved at later sites by two rigs, cutting more form pour pockets, and using a richer mix with more slump.

Missile Silo Caps

Haunch areas of the missile silos had re-steel so thick it was hard to drop a vibrator through. A special 3/4" mix was designed for this condition and was used to cover the seven layers of #18 bars. The standard 1½" mix was used to top out. The biggest pour consisted of about 750 yards and resulted in a continuous operation of about 14 hours.

Pump-crete

At some sites MK&A elected to use pump-crete. This method worked well for missile silo wall pours. Set-up time was longer and placement averaged around 50 to 60 yards per hour, about the average speed using the crane and bucket.

Winter Operations

The steel strike was instrumental in causing concrete placement delays during the fall of 1959 because of the scarcity of reinforcing steel. The contractor fell behind schedule and was directed to place concrete during the winter 1959-60. Winterizing consisted of complete inclosure of wet mix plants and use of 100 HP boilers to heat the water, aggregate bins, and operating areas of the plant. The dry mix plant on the bombing range was completely inclosed and space heaters were used to heat the operating areas. At the complexes, steam boilers were used. Water up to 160°F was introduced to the mixer to obtain placing temperatures of over 50°F. Space heaters were used on the pours which were inclosed as much as possible. Considerable concrete was placed at air temperature below freezing and only on rare occasions was it necessary to remove frozen concrete.

Missile Silo Door Placement

Door placement was held up until all missile crib steel, counter weights, and other large items had been installed by AF associate contractors at all six complexes. A tight schedule was established, and work started in early February 1961 using the same roving placement crews for all complexes and three sets of forms. Doors were formed, poured in place, and opened at each complex in a period of just under 30 days. Class AAA concrete was used with a compressive strength of 5,000 psi in 28 days. Doors were "cracked" with hydraulic jacks and raised, using the AF associate contractor installed hydraulic system.

Joint Preparation, Curing and Finishing

Lift joints were either sand blasted or "green cut" with air-water jet. On the following pour, the joint was "buttered" with either a grout or 3/4" mix.

Forms were generally removed on compressive strength concrete within 12 hours. Removal of forms from domes, caps, and door pours varied from four to ten days and was monitored by job cured cylinders.

Concrete surfaces were patched as required after form removal and "sacked" if painting was to be done. Floors were hard trowel finished and the propellant terminal floating slab received a special spark proof topping which was hard troweled.

Curing was obtained by a number of methods including water, polyethylene film, wet sand, clear and pigmented curing compounds and asphaltic damp proofing. During the winter, "green" concrete in exposed places, was protected by oil fired space heaters.

Structural, Tunnel Installation, Shock Mounting

Eaton Metal Co. of Denver subcontracted the tunnel sections, tunnel junctions, and structural covers for the powerhouse air intake and exhaust structures, the launcher air filtration structure, the lox tank structure, the propellant and equipment terminal access "stacks" and the 5' diam. air tunnel. All tunnel sections and junctions were inspected at the source in Denver, water proofed and transported by truck to Buckley Field where they were out-fitted with utility piping and pipe supports and trucked to the complexes.

"B" Tunnel

The 9'6" five gage multiplate "B" tunnel was the first tunnel section to be installed and backfilled. Before backfill placement, these sections were strutted out of round about 3%. Struts were placed every 8' throughout the tunnel and left in place until the backfill was complete. Struts were removed and measurements taken periodically to check on tunnel deformation. To accomodate movement, connections were made to tunnel junctions with 12" neoprene dumbell water stops. About a foot of class C fill concrete was placed in the invert for a walking surface. At most complexes, enough tunnel settlement took place to crack the fill concrete and shear pipe bracket bolts but not enough to tear the neoprene connection.

"A" Tunnels

These tunnel sections varied from three to five gage and were the same diameter as the B tunnel, were made of multiplate and reinforced with ring beams (10" WF) and channel sections (6") every 14 feet. Since they were reinforced, struts were not used during backfill. Utility and fuel piping with supports were installed loose prior to trucking to the sites. Walking surfaces were removable checkered floor plate. After fire water piping was installed under the floor plates, the invert was filled with class C concrete to facilitate drainage. Connections to tunnel junctions and concrete structures were by neoprene water stop backed up by vermiculite fill prior to backfill. During and after backfill, settlement at some connections was severe enough to tear neoprene closures. Before complex turnover, all damaged neoprene closures were patched or replaced with rubber.

Tunnel Junctions

Tunnel junctions were basically curved channel sections bolted together and reinforced with heavy structural I beams welded together to form a yoke section. Junctions were water proofed and piped before delivery to the site. Considerable difficulty was had in fitting TJ #10 to three structures (PH, CC, & PS) and two tunnel sections, all of which were at different elevations. At most complexes, subsequent backfilling resulted in some sort of damage to this structure. Settlement at powerhouse and portal silo entrances caused unequal stresses to be set up which caused yoke beam welds to crack, neoprene closures to rip, structural floor plate members to warp, and channel section bolts to shear. This was all repaired by additional welding and new closure connections.

TJ #12 warped out of shape at some complexes and installed RP-1 piping had to be cut and refabricated; fuel pump housings cracked and had to be replaced and neoprene closure sections, between the junction and the RP-1 tank, ripped and had to be patched.

Curved channel cover sections for powerhouse air intake and exhaust structures, launcher air filtration structures, and lox bay structures were very difficult to install due mostly to the way they were anchored to the concrete slabs. Considerable field fabrication was necessary to obtain a workable fix.

Propellant terminal, equipment terminal access stacks, lox vent stacks, and the blast lock #2 escape hatch stack were corrugated liner plate and were installed as backfill progressed. The propellant terminal stack was added by modification to provide the contractor with easier access during PLS installation during the period when backfill was complete. The equipment terminal stack was used as a place of access to the complex during construction and follow-on AF I&C work. With the exception of the lox vent stack, all were backfilled with sand after the hatch covers had been installed.

The lox vent stack was lined with lox compatible polyurethane when delivered to the site. During PLS installation this lining was badly damaged and had to be patched. Finally it had to be painted (added by mod) to provide a completely sealed fire proof surface.

Lox and RP-1 fuel cribs in the missile silos were fabricated by Iteco Co. in two sections. They were to be lowered into the missile silos, attached to the walls, and then piped. Later on it was decided to pipe all cribs at the cleaning plant at Buckley Field, where better control of cleanliness could be maintained, and then install in the missile silo.

Most of the structural steel and associated concrete embedded anchors, were fabricated by Mosher Steel Co. of Texas. Their work was excellent and very little trouble was encountered in erecting steel in the various structures. Connections were made with high strength bolts which were torqued to develop the required bolt stress.

Shock Mounting

All areas of the complex were divided into shock zones A, B, and C. Equipment installed within these zones were required to be designed to withstand a dynamic (shock) loading of 50G's, 19G's, or 3G's, respectively.

A zones were areas in direct contact with the ground such as structure walls, floors, and domes. B zones were ground floor areas of the control center and powerhouse which were more or less isolated by the ring footings and sand fill. C zones were areas shock mounted by spring beams or coil springs. Mezzanine floors of the powerhouse and control center and the floors of the equipment terminal were spring beam mounted. Most equipment in the propellant terminals was mounted on a slab which floated on 105 coil springs.

Almost all early equipment submittals to the AE (DMJM&A) had to be turned down pending the completion of a satisfactory shock test. And, in order not to delay installation, a great deal of equipment was installed before it was cleared by a shock certificate. Before turnover, all equipment had been certified for the correct shock zone. In numerous instances, there were violations of "rattle space" because of space limitations on installation of equipment. There were also instances of equipment and associated piping tied to two different shock zones without flexible connections. Many of these design deficiencies were corrected by modifications. Many more will be corrected by the Air Force at a later date.

Propellant Loading System

General:

The propellant loading system consists of storage and transfer facilities for missile propellants and auxiliary fluids and gases. The propellants consist of liquid oxygen (Lox) and RP-1 fuel. Auxiliary fluids and gases are liquid nitrogen (LN_2), gaseous nitrogen (GN_2), gaseous helium (He) and compressed air. Lox is transferred to the missile by nitrogen gas pressure. GN_2 is used for lox transfer, and high and low pressure purge. LN_2 is used for further chilling of lox and helium. Helium is used aboard the missile. Compressed air is used to actuate valves.

All PLS components were required to be unusually clean and free of particles larger than 150 microns (size of a sharp pencil dot). Such importance was attached to this requirement that the Corps of Engineers contracted with United Testing Laboratories to conduct a school at Denver for the training of PLS inspectors. From October 1960 to February 1961, classes composed of civilian and military personnel from all missile construction jobs in the U.S. completed their week of instruction and returned to their jobs. Under Government contract, U.T.L. provided personnel to assist in PLS inspection. These people had had prior inspection experience with cryogenic systems, mostly with the Atlas program, and were of tremendous help. They remained on the job during PLS installation and testing.

WWW.CHROMEHOOVES.NET

Pipe Fabrication

Paul Hardeman Inc., one of the joint venture contractors, was in charge of all mechanical work which included the PLS system. Most of the cryogenic piping and fuel piping was fabricated in their plant at Stanton, Calif. and shipped to Buckley Field for cleaning. Inspection services were performed by Corps of Engineers, Los Angeles District. Type 304 stainless steel was predominantly used for cryogenic service and ranged in wall thickness from schedule 10

WWW.CHROMEHOOVES.NET

(vent pipe) to schedule 160 (high pressure GN_2 & He). RP-1 fuel pipe was schedule 40 black iron.

Cleaning

Initially PLS pipe was cleaned at the Stanton, California plant after fabrication. At the time of installation, most of this pipe was rejected as being contaminated. A cleaning plant was built, by the contractor, at Buckley Field. Fabricated pipe was checked for faulty welding, pickled in acid solution to remove mill scale, placed in a neutralizing bath to remove the acid residue, and then dried with hot nitrogen gas. The dried pipe was then inspected for contamination and rejected or accepted by a Government inspector. Accepted pipe spools were sealed with blind flanges, taped and covered with polyethylene and trucked to the complexes for installation. All acceptable spools were green tagged at the cleaning plant indicating Government inspection had been performed.

The cleaning plant was operated on 2-10 hour shifts a great deal of the time. Towards the end of the job, 1-8 hour shift could handle all the work. For a variety of reasons the plant was always involved in recleaning operations on both pipe spools and other PLS components. Pressure vessels, valves, flex hoses, U-joints, filters, pumps, etc. were standardized equipment and were to be furnished in a lox clean condition ready for installation. It is estimated approximately 25% of all PLS components required recleaning. This condition along with lack of good scheduling and expediting created considerable delays.

PLS Installation

Fuel Pipe - As soon as all tunnel sections were installed, installation of fuel piping commenced. The early stages of this work were used in establishing acceptable welding, purging, and inspection procedures for following PLS installations.

(a) Only strictly necessary field fabricating was permitted.

(b) Argon gas purge was replaced by nitrogen gas purge.

(c) Inspection techniques were developed and refined in accepting and rejecting pipe.

(d) Interferences by SATAF were stopped and SOP's were established for future surveillance.

(e) Inspection forces were greatly augmented by new hires and utilization of more contract personnel from U.T.L.

Pipe was welded and capped. Installation of flex hoses, at neoprene closure sections, and adjustment of pipe hangers was left until after testing.

Process vessels - Work started on the lox system with the installation of the cryogenic vessels and gas pressure vessels at all sites and the piping of the missile silo cribs at Buckley Field. Lox tanks and sub-coolers were furnished equipped with vacuum pumps and gages and all connections ready for installation. Prior to hook-up vacuum of less than 1000 microns were constantly maintained.

40,000 gallon RP-1 tanks and system purge bottles were installed at the time TJ #12 was put in position.

Cryogenic Pipe Installation

System piping was installed in accordance with piping sketches (spool sheets) identified with the same number as the actual spool piece. If a particular spool would not fit it was sent back to the cleaning plant to be re-fabricated and re-cleaned.

All PLS installation was witnessed by Corps of Engineers inspectors and off and on by personnel from SATAF. To keep down contamination, propellant terminals were restricted to authorized persons only. Fitters and inspectors wore white nylon coats and handled clean parts with polyethylene gloves. When possible, working areas were protected with tents. During fit up and welding, the component was purged with GN_2. PLS components were checked for damage, particle size and hydrocarbons, and proper fit up. Ultra violet lamps (black light) were used to check for hydrocarbons. If fluorescence was found or particles were observed, the component was "yellow" tagged and sent back to the cleaning plant.

Generally, installation was "pushed" in two propellant terminals at the same time. One 10 hour shift was worked employing around 30 fitters and fitter-welders. Stainless steel pipe and fuel pipe was welded with "heli-arc" to keep down pipe contamination. All welds were x-rayed on pipe designed for pressures in excess of 1,000 psi. X-raying was done at night for reasons of propriety and safety.

Pipe Supports & Anchors - Before overall PLS installation had progressed very far along, a design change appeared which altered practically every anchor and support in the system. In addition, considerably more were added. Several complexes were caught having installed most of their missile silo supports around the walls and in the cribs, and delivery had been made on most of the original supports. The situation became very confusing for the following reasons:

1. Designs were made by both A. D. Little and DMJM&A, confusing the issue as to who was responsible for what.

2. Since time was of essence, contract drawings were furnished the contractor before they were furnished the Corps of Engineers.

3. When shop drawings were finally received, many were hard to interpret, were ambiguous and conflicting. Interferences prevented many supports from being installed as designed.

4. Extra night shifts had to be employed so as not to interfere with regular pipe installation and missile silo JOD work.

5. Installed pipe had to be removed and refabricated to fit new anchors or supports.

6. Design changes were effected piece meal over a considerable length of time and current status was hard to appraise.

Over a period of months, with the help of roving personnel from ADL and DMJM&A who were empowered to make on the spot decisions, pipe supports and anchors were finally installed.

JM-91 Gaskets - Low pressure Lox service gaskets identified as JM-91 (manufactured by Johns-Manville) were initially installed in the lox system and were found to project into the flow area. This condition could not be tolerated and was corrected by enclosing the inside circumference with an aluminum grommet to prevent fraying. These revised gaskets were installed in most of the missile silo lox cribs at a comparatively early date. Several months later it was discovered the aluminum grommets were corroding due to the electrolytic action of dissimilar metals. Replacing these gaskets with ones of reduced width necessitated opening the system from one end to the other. This replacement was accomplished on several week-ends under extremely unfavorable conditions due to confined work areas.

Testing

Fuel Pipe - Testing consisted of "blow-downs" to eliminate particles larger than 150 microns and pressure testing to eliminate leaks. Blow-downs were accomplished by hooking up at one end (fuel crib) and successively blowing down sections of pipe until clean. When a section was visually determined to be clean as evidenced by inspection of the gauze test pads, flex hoses were installed and the next section of pipe was blown.

With flex hoses installed, fuel was circulated thru the system until test filters indicated a clean effluent. Leak testing was performed last by pressurizing the system to 1¼ times working pressure. All flanges and welds were "soaped" and observed in the presence of an inspector. Leaks could usually be repaired on the spot. After the system was successfully leak tested, fuel was left in the system under pressure or was drained and pressurized with dry nitrogen gas.

Cryogenic Testing - Several test crews were organized by the contractor for simultaneous, around the clock testing at several complexes. All anchors and supports had to be in place before testing could proceed.

Vacuum test - Cryogenic vessels, lox tank, lox and helium sub coolers were vacuum tested. Tanks were required to hold vacuums within a rise of 50 microns in a 24 hour period after starting with an initial vacuum of not more than 1,000 microns.

Safety valve test - All safety valves were removed from the system and bench tested to insure their operation at the required settings. With the completion of the cold flow tests, all safety valves were re-installed in the system.

Pressure and leak tests - All systems were proof pressure tested to $1\frac{1}{4}$ times working pressure and held for five minutes using GN_2. Test gases and liquids were furnished by the Government. Nitrogen re-charger trucks were furnished the contractor. LN_2 was vaporized in the recharger, filtered, and used as the test gas. During proof tests, no personnel were allowed in the area because of the very high test pressures in some cases (7500 psi on helium lines). After holding the proof pressure for five minutes the pressure was dropped to working pressure and lines and components were inspected for evidence of damage. Joints were soaped to determine gas tightness.

Blow down tests - All systems were blown down to check for particle size and hydrocarbons. Test pieces consisting of a pipe section with gauze pads and backed up by a strainer of less than 150 micron size were installed on end of line to be tested. The line was blown with GN_2 at pressures around 200 psi or greater. Gauze pads were "black lighted" and visually inspected for particles size. Blows were continued until a clean line was obtained as later verified by independent laboratory analysis.

Cold flow tests - LN_2 ($-320^{o}F$) was used to test tanks and Lox lines because LO_2 was considered too dangerous to use. Purpose of the test was to observe system components, especially expansion joints, anchors and supports, when subjected to operating temperatures. The Lox tank, Lox sub-cooler and helium sub-cooler were partially filled with LN_2, which was circulated through the system under gaseous nitrogen pressure. At the conclusion of the cold flow tests, each pipe system was purged with nitrogen gas, valved off, and left in a standby condition under about 20 psi blanket pressure.

Control system testing - Initially all PLS transfer instrumentation was individually calibrated by factory representatives at each complex. After the cold flow test was completed, each control system was loop checked. The loop check involved the successful operation of the following control components.

1. Pressure controller
2. Flow control valve
3. Valve Positioner
4. Booster
5. Solenoid valve
6. Limit switches
7. Pressure switches

All testing was witnessed by the Corps of Engineers and SATAF. Each test was signed off by the contractor, Corps of Engineers and SATAF.

Mechanical Work

Mechanical installation started in each structure as soon as the concrete operations were far enough along. Mechanical installation included the following systems:

1. Supply and Distribution systems.
   - (a) Condenser water supply and return.
   - (b) Chilled water supply and return.
   - (c) Hot water supply and return.
   - (d) Domestic water distribution.
   - (e) Demineralized water system.
   - (f) Fire water and sprinkler system.
   - (g) Diesel fuel supply and return.
   - (h) Diesel lube oil supply and return.
   - (i) Diesel exhaust system.
   - (j) Sewage ejection system.
   - (k) Waste water system.
2. Water storage system.
3. General Plumbing.
4. Ventilation system (Powerhouse and Launcher).
5. Air Conditioning system.
6. Fuel oil storage system.
7. Diesel starting air system.
8. Utility air system.
9. Filtered air system (PLS).
10. Elevators (Portal silo and equipment terminals).

11. Portal hydraulic system for doors.
12. Ethylene glycol system (antenna silo and portal silo doors)
13. Carbon dioxide fire protection system.
14. Blast valve system.
15. System instrumentation and controls.

Installation of mechanical systems generated great numbers of problems. Interferences were common wherever follow-on work by "others" was required. Many design deficiencies were uncovered especially on control systems in the powerhouse, and all blast valves. During the mechanical testing phases, representatives from Corps of Engineers, DMJM&A and SATAF held almost daily change order conferences to formulate methods of correcting operational deficiencies.

In the missile silos, interferences created the most problems. Ventilation duct work and control air tubing was installed quite early and had to be completely replaced at some complexes before turn over because of AF associate contractor damage.

Powerhouse deep-well pumps were a constant source of trouble. During the early construction phase of operations, the contractor installed his own submersible pumps. For reasons still not clear, at least one and sometimes as many as three pumps per complex burned out and had to be pulled and replaced. Later the same trouble developed with contract furnished submersible pumps. Several had to be pulled and replaced. At one complex, during pulling operations the damaged pump was dropped back into the hole. Well drilling equipment had to drill through the embankment and powerhouse dome and "fish" the pump back out of the hole.

After turnover, powerhouses and other structures were operated by the AF associate contractor (Martin Co.). Many problems developed in regard to responsibility delegation when equipment failed or operated in a faulty manner. Under the circumstances, no clear cut method usually existed for determining whether failure was responsible under the warranty clause or was due to faulty operation and maintenance, and the contractor was quite generous in assuming liability.

Testing

Testing consisted of original contract required acceptance testing and additional testing deemed necessary and added by modification and referred to as validation testing. Testing was closely monitored by Corps of Engineers, the design agency, and the SATAF and was signed off by everyone concerned. The contractor organized a roving test crew consisting of all the trade specialists. Diesel engine tests and air balancing required considerable time and were conducted on a "round the clock" basis. The air balancing test required close coordination with SATAF because of limited access to the complex during the two days of tests. Delays were frequent due to design deficiencies and incomplete installation of systems at the start of tests.

Electrical Work

During concrete operations, a crew of electricians were required to install grounding mats under the foundations of most of the structures and install grounding cable, grounding plates, junction boxes and rigid conduit in the forms prior to concrete placement. Stand-by electricians were required at night whenever any type of work was done.

The electrical subs were responsible for the procurement, installation, and testing of the following systems.

1. Grounding system.
2. Signal and alarm system.
   (a) Fire detection.
   (b) Radiation detection.
   (c) Gas detection.
   (d) Explosion detection.
3. Diesel electric generating plant.
   2400V power
   120V lighting
4. Emergency lighting.
   (a) Self contained units.
   (b) 125V battery.
5. Cable tray system.
6. Closed circuit television system.
7. Wiring of mechanical equipment of controls including PLS.
8. Temporary power during construction.

Electrical installation progressed with a minimum of confusion and interferences. Conduit runs were installed early which eliminated considerable congestion. Cable tray installation which required a long time was done before AF associate contractors moved in.

Testing

Both validation and acceptance testing was required and was usually performed in conjunction with the mechanical tests if appropriate.

SIGNIFICANT EVENTS

The first construction contract for the Lowry Titan missile program was awarded on 29 September 1958. A non-strike agreement was entered into on 9 July 1959 between Morrison-Knudsen Company, Inc. and Associates (M-K&A) and the Northeastern Colorado Building and Construction Trades Council. This agreement applied to all work performed by M-K&A for the United States Army Corps of Engineers on the Titan Missile Project near Denver, Colorado. The purpose was to establish and maintain harmonious relations between all parties to the agreement; and to avoid strikes, lockouts or delays in the prosecution of the work undertaken by M-K&A. Acceleration, buying back time in lieu of granting time extensions, began on 2 May 1960. Joint occupancy started on 1 August 1960. The heavy construction phase for the first of six complexes was completed on 4 June 1961 and for the last complex on 11 October 1961.