5. REINFORCING AND STRUCTURAL STEEL

Reinforcing Steel:

All reinforcing steel was furnished, cut, shaped, and placed by Meehleis Steel Co. of Los Angeles, California, a subcontractor of MacDonald-Scott & Associates. Bar sizes varied from #4 to #18, and quantities of steel used were far in excess of amounts normally considered adequate for reinforced concrete, due to the special design requirements of this project. Quantities (by weight) of reinforcing steel installed in the various structures is given in the following list:

STRUCTURE	RESTEEL (lbs)	TOTAL, 1 SITE (lbs)	TOTAL 3 SITES (tons)
Missile Silo	1,564,000	4,692,000	7,038.00
Equipment Term.	200,114	600,342	900.51
Propellant Term.	260,600	781,800	1,172.70
Power House	1,112,519	1,112,519	1,668.78
Control Center	241,398	241,398	362.95
Entry Portal	229,501	229,501	344.25
LOX Bay	91,197	273,591	410.38
Antenna Silo	169,957	339,914	509.87
Air Intake	642,677	642,677	964.01
Air Exhaust	375,846	375,846	563.76
Blast Lock #1	220,814	220,814	331.20
Blast Lock #2	145,918	145,918	218.85
Air Filtration	28,091	28,091	42.13
Waste Clarifier	11,613	11,613	17.40
Seal Chamber	577	2,885	4.37
Recept. Hand-Hole	194	970	1.40
Orient. Targets	1,353	2,706	4.05

STRUCTURE	RESTEEL (lbs)	TOTAL 1 SITE (lbs)	TOTAL 3 SITES (tons)
Elect. Manhole	6,857	6,857	10.28
LOX Tunnels	8,162	24,486	36.72
TOTALS	5,311,388	9,733,928	14,601.59

Installation of reinforcing steel was accomplished in a most satisfactory manner in spite of many placement problems generated by the unusual quantities of steel required in limited space, large size of steel used and the extreme accuracy required in placing the thousands of embedded items in structure walls. It was necessary to tack-weld many of these items to the re-steel to maintain proper position and to provide adequate electric grounding throughout the structure.

Steel crews were well organized, with a high percentage of experienced and well-qualified personnel operating under very competent supervision. All crews were adequately supplied with shop drawings and little difficulty was experienced on quantity, check-outs, placing, and alignment of re-steel.

A problem developed in the top pours of missile silos where considerable pulling and realignment was found necessary to obtain proper clearance of steel after placement. This situation was due in part to the extremely large amount of steel required to meet specified strength for structures at the surface.

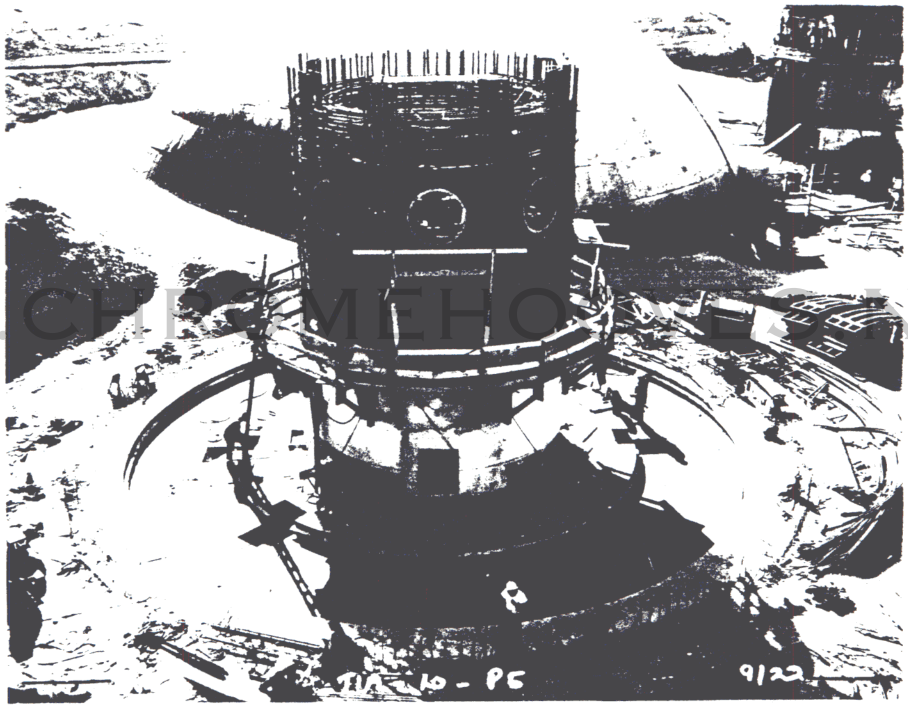
Structural Steel:

Few major difficulties were encountered in placing of structural steel but the accuracy required in placement and fabrication necessitated a high degree of vigilance on the part of inspectors to insure proper placement and assembly within tolerances required to permit installation of subsequent work. It was ascertained at an early date that the Contractor's layout did not always comply with the close tolerances required and a procedure was adopted whereby all Contractor's placing of forms, anchor bolts, templates, etc. was checked for accuracy by C of E Survey Section before pouring of concrete or final placing of steel on support members. In many instances it was found necessary to use theodolites and optical plummets to obtain an accurate check of embedded items, column bases and anchor bolts. Based on this check-out, several placement errors were determined and corrected before concrete pours were allowed to proceed. Even with this check system, some errors were not detected until steel setting operations were underway; viz: in several cases where templates were used for setting of anchor-bolt groups, templates were properly centered but rotated 90° resulting in wrong configuration of bolts for column base-plates. However, only a few such errors occurred. The most serious instance of this type occurred in the Entry Portal at Complex 1-A where three of four concrete pedestals were fractured by Contractor's personnel attempting to "beat" mislocated anchor bolts into place when setting steel. Contractor was required to rebuild this assembly.

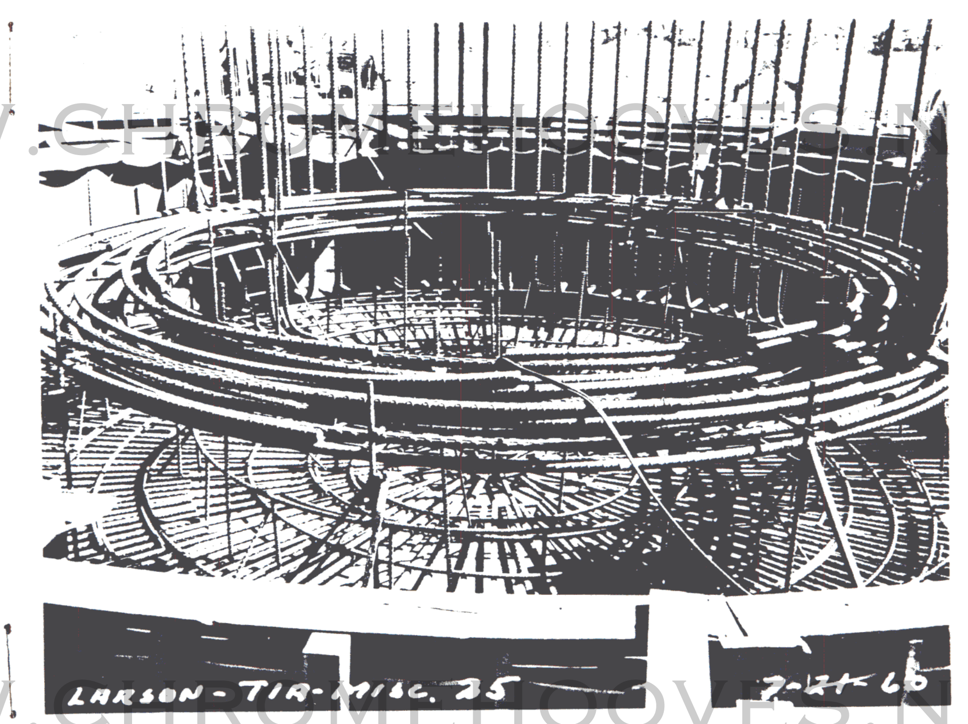
Structural steel was fabricated and supplied by Mosher Steel Co., from two shops located in Dallas and Houston, Texas. On the whole, fabrication was most excellent and dimensions well within tolerance. A few dimensional errors, corrected and reported by the on-site Contractor resulted in a "tightening up" of inspection, both by the fabricator and the Ft. Worth District, C of E, which had responsibility for source inspection.

In January 1960, the Mosher Co. called attention to the fact that specifications for spring-beams in Equipment Terminals did not call for high-strength steel. This matter was taken up with the A. E. (Ralph M. Parsons Co.)

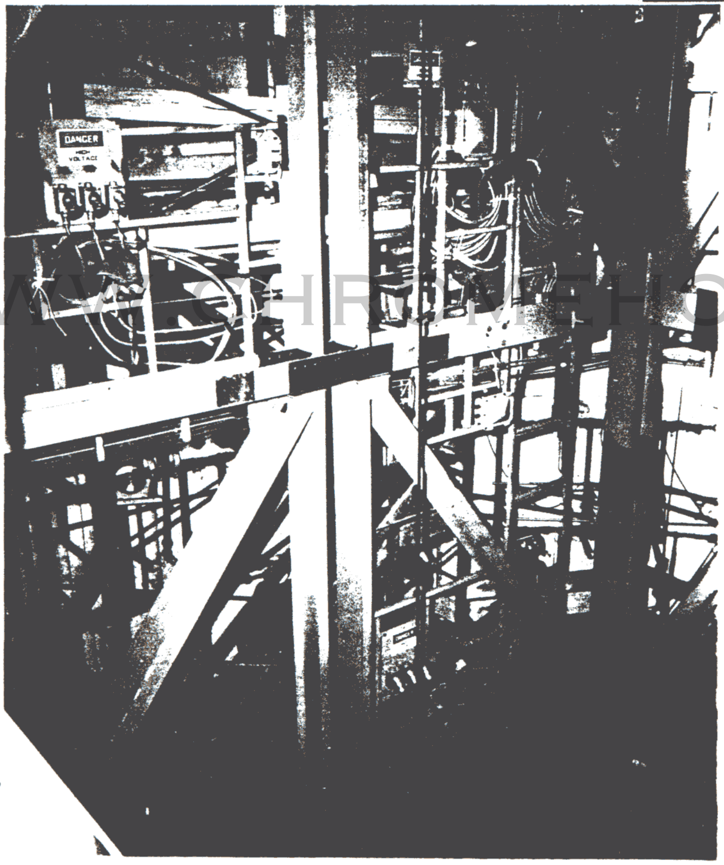
who verified that these beams should be fabricated with high-strength steel, and a Change Order was issued (C. O. No. 2) correcting this deficiency.



(Figure 14)
Reinforcing Steel in Place for Inner Wall of Air Intake Structure, Site 1-A, Sept 60. (Note density of spacing of No. 18 rebar)



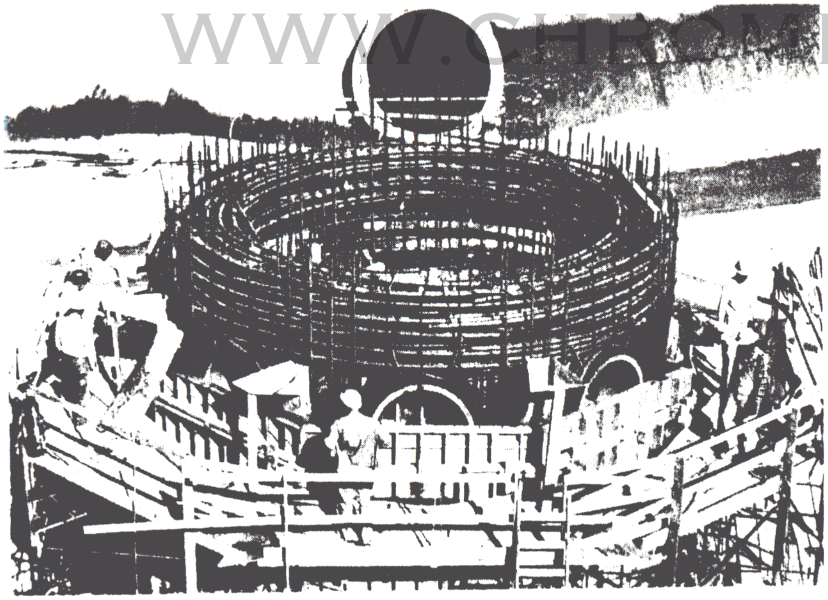
(Figure 15)
Close-Up of Pattern of No. 18 Reinforcing Steel in Air Intake Structure at Site 1-A During Placement in July 1960. (Large bars are No. 18)



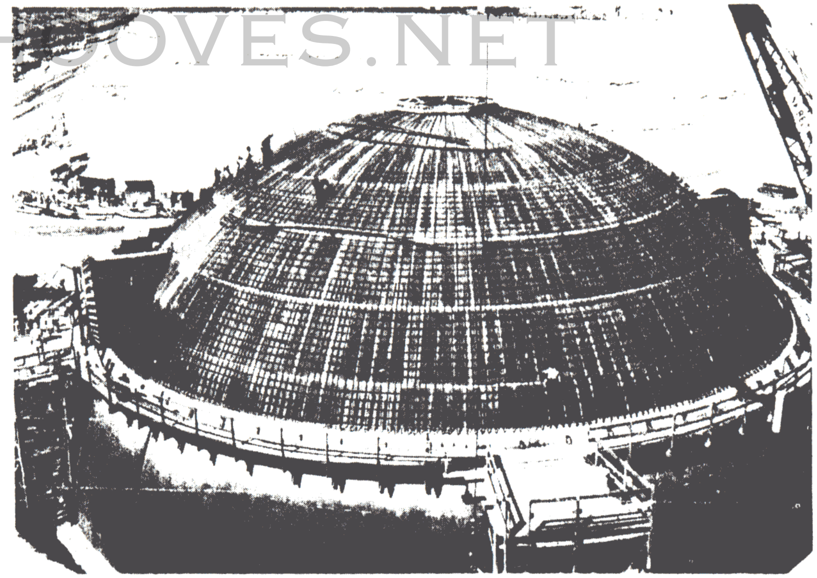
Left
Structural Steel Members and Piping and Wiring in Place at 80 foot Level in Missile Silo. (Figure 16)

Below
Placement and Pattern of Reinforcing Steel for Upper Lift of Missile Silo, Site 1-A, Aug 60. (Figure 17)

(Figure 19)



Air exhaust outlet. Note density of reinforcing steel



Powerhouse construction showing reinforcing steel over dome-shaped forms

Placing pre-fabricated terminal junction between antenna silos

Personnel tunnel from antenna silos showing terminal junction in place and typical cut sections

6. CONCRETE OPERATIONS

Materials:

The concrete subcontractor was Central Pre-Mix Concrete Co., Spokane, Washington. Aggregate was furnished by this contractor from the following sources:

a. Aggregates for Complex 1-A were furnished by Columbia Sand & Gravel Company of Moses Lake, Washington. (Haul distance 35 miles.)

b. Aggregates for Complex 1-B were furnished by Pre-Mix Concrete Inc. of Othello, Washington. (Haul distance 12 miles.)

c. Aggregates for Complex 1-C were furnished by Pre-Mix Concrete Inc. of Othello, Washington from the same pit used for Complex 1-B material. (Haul distance 28 miles.)

Aggregates were delivered by truck from these suppliers' plants to stock piles at the three complexes. Stockpiling and charging of the concrete batch plant was by means of a conveyor system. Aggregates were stockpiled in three sizes: 1-1/2" aggregate, 3/4" aggregate, and fine aggregate. Aggregate consisted of basaltic materials which are very hard and well-suited for use in high-strength concrete.

Darex air-entraining admixture was used in the concrete under this contract.

Cement for all three complexes was furnished by Lehigh Portland Cement Company of Spokane, Washington. All cement met Federal Specification SS-C-192, Type II. Cement was delivered to the railhead nearest each of the complexes. Transportation of bulk cement from railhead to storage silos at each complex was by means of a cement truck designed for this purpose. Storage in the following amounts was installed as part of the concrete batch plants at each complex: Complex 1-A - 1,000 barrels; Complex 1-B, 1,000 barrels; Complex 1-C, 1,100 barrels.

Concrete plants were set-up at each complex for batching of the various concrete mixes. The plants were of the dry batch type charging truck mixers. Batch plant models were:

a. Complexes 1-A and 1-C - Noble Mobile Type, Rated Capacity, 75 c.y. per hour.

b. Complex 1-B - Noble, Model GA-100. Rated capacity of 75 c.y. per hour.

Mixing and delivery to the concrete pours were performed in transit mix trucks. Recording of the weighed materials for concrete was by means of a Noble, Model H-E, three-pen graphic recorder. Cement and water were recorded on separate graphs. The aggregates were recorded separately on the same graph with the needle returning to zero after recording the weight of each aggregate. The concrete supplier, Central Pre-Mix Concrete Company, Spokane, Washington dry-batched to mixer trucks with water added concurrent to the charging of aggregates and cement. The concrete was mixed in the trucks rather than being pre-shrunk and wet batched. Charging cycle after weighing of materials was approximately: (1) 50% of the water; (2) aggregates and cement together with 40% of the water; and (3) remaining 10% of the water for chute clean-up.

For cold-weather placement the water for the concrete was heated to 120° - 150° F. This served to insure that the resultant concrete met the minimum temperature of 50° F. required by Paragraph TP 2-14C of the specifications. Frozen or frosty aggregate required heating.

The maximum placing temperature permitted by specifications was 85° F. Measures taken by the Contractor to maintain the concrete placing temperature below the prescribed maximum included installation of three sprinklers at each site. One was placed on the stacker conveyor to sprinkle only material delivered to each complex which was not already moist. The other sprinklers were placed on the 1-inch and 3/4 inch aggregate stock piles. The sprinklers were controlled in such a manner as to keep the exterior portions of the stock piles moist and to replace water lost through evaporation. The contractor provided insulation on the tanks with a spray on the tanks to provide a cooling effect on the water storage. Water lines were also insulated. Relatively large pours such as the Missile Silo doors (110 c.y.) were started at 0400 hours to avoid the midday heat.

Mix Designs:

Concrete mix designs were prepared by the U. S. Army Engineer Division Laboratory, Troutsdale, Oregon. Summary of concrete mix designs for Complexes 1-A, 1-B, and 1-C are as follows:

The design mixes used at Complex 1-A produced satisfactory concrete. Mixes primarily used were the 3/4 mix with 5.25 sacks of cement with a maximum 2-1/2 inch slump for the silo walls and a 1-1/2 inch aggregate mix with 5.2 sacks and a maximum 2-1/2 inches of slump being used for the foundation slabs. Third mix was a 6-1/2 sack mix with 3/4 aggregates for the dome construction and 4" slump maximum.

At complexes 1-B and 1-C, however, the control of the slumps and air was erratic. As both of these items were critical, particularly with the aggregate from the Othello pit, the contractor was instructed on 6 June 1960 to reuse the mixes as follows:

a. Continue with number 10533, which was a 1-1/2 inch aggregate with 5.2 sacks cement and with a maximum of 2-1/2 inch slump for foundation slabs and 2 inch slump for floor slabs. This latter requirement was in accordance with the specifications.

b. Use mix No. 10547, a 3/4 inch mix, but increase the cement content to 5.5 sacks with a 3 inch maximum slump.

c. For the Class "C" concrete to use mix No. 10547, with a 3/4 inch aggregate, 5 sacks of cement and 3-1/2 inch maximum slump, but include pozzolith as an admixture.

d. For the domes of the Control Center and Powerhouses; to use mix No. 10549 but with 6-1/2 sacks of cement and 3/4 inch aggregate with a maximum of 4 inch slump.

Quantity Placed:

Listed below are the quantities by class of concrete placed at Complex 1-A, 1-B, and 1-C:

	1-A	1-B	1-C
Class "AAA"	533	324	2,499
"AA"	143	201	47
"A"	32,398	30,865	28,235
"C"	1,521	4,592	7,741
Grout	1,219	552½	3,181
Totals	35,824	36,534½	41,703

Approximately two-thirds of the grout used at Complex 1-A was placed in the overbreak. The 30,865 c.y. of Class "A" used at Complex 1-B includes some "AA" and "AAA" concrete. The 324 c.y. represents the concrete placed in the missile silo doors and is additional to the 30,865 c.y. An additional 474 sacks of cement was used for grout to stabilize tunnel settlement at Complex 1-B.

Breakdown of grout usage at Complex 1-C is as follows:

2,912 c.y.	Pumped grout placed with Class "C" concrete (overbreak)
138 c.y.	Placed with Class "C" concrete
105 c.y.	Placed with Class "A" concrete
26 c.y.	Placed with Class "AAA" concrete

Forms:

The shape of concrete structures required considerable ingenuity in construction of forms. The domes of the Control Centers and Powerhouses utilized moulded plywood forms which required a considerable amount of shoring to insure stability during pours. Each lift was formed throughout an entire circle. Slip-forms utilized at some other Titan I sites were not used at Larson. Most forms were used first at Complex 1-A then shifted to 1-B and 1-C for subsequent use.

Cylindrical structures such as Missile Silos, Antenna Silos, Propellant Terminals, etc., utilized moulded plywood forms. More intricate forming was required for the upper lift in the Missile Silos, Antenna Silos, and Entry Portals where a flare to a greater diameter was required. Carpenters engaged in more intricate phases of forming were shifted from Complex 1-A to 1-B to 1-C when possible, to utilize experience gained. However Union restrictions made such shifting difficult.

Many concrete lifts utilized templates furnished by associate contractors to insure proper fit of installed equipment. Some such templates were left in place, others were removed after pours and returned to the associate contractors for their disposition.

Missile Silo Doors:

Missile door pours were performed ahead of schedule to permit accomplishment of associated tasks. Five thousand pound Triple "A" concrete was used for these pours. The possibility of using High Early Strength was explored but was rejected due to great heat of hydration which would have been developed in the 5 foot thick slab.

Complex 1-A Concrete Batch Plant and Aggregate Stock Pile - Feb 60 (Figure 18)

Complex 1-A view of Top of Missile Silo (Center) after Stripping Forms for Concrete Pour II, Pour 12 Will Cover Exposed Reinforcing Steel - Aug 61. (Figure 19)

7. CONCRETE PLACEMENT HISTORY

The following is a summary of the concrete placement history at each complex:

Complex 1-A

Concrete placement operations started 22 February 1960 with the first-third of the Powerhouse footing pour. Winter operations were in order. Water was heated for mixing to keep placement temperature within specifications. The Laboratory Section took concrete samples and made test cylinders on all concrete placements. All aggregates were controlled from point of source for gradation. Aggregates at this complex were of very good quality.

Concreting operations were well supervised and the crews involved were experienced personnel. The efficiency of the crews and adequate supervision was evidenced by the fact that very little honeycombed concrete was encountered. The only honeycomb evidenced occurred in areas where the reinforcement steel pattern was extremely difficult. In areas of difficult access due to the reinforcement steel pattern 3/4" maximum aggregate was used to minimize honeycomb.

The snake type vibrator was used almost exclusively as there were no pours massive enough to use other types such as a post vibrator. Due to the design of the reinforcement steel, a snake vibrator was about all that would fit between bars. Considerable difficulty was encountered on placement of concrete around openings in the structures where added reinforcement was used and it was difficult even with a 3/4" maximum aggregate mix. The bulk of concrete operations was during the period 22 February 1960 through 28 July 1961. A small amount of concrete such as pedestals and fire walls was placed through October 1961. Operations continued throughout the winter of 1960. During this period the contractor heated aggregate with steam from a steam jenny and utilized gas pressure heaters to heat the water. Little lost time was experienced due to mechanical equipment freezing as the plant itself was winterized. All exposed placements were covered and heated inside to keep from freezing. Electric light bulbs (1,000 watt) or Herman Nelson heaters were utilized. No frozen concrete was experienced at this complex.

The majority of the concrete was handled with cranes and buckets, bottom dump and side dump. The side dump buckets were especially useful for dumping into wall port holes. Cranes and buckets were used exclusively in the Missile Silos. For floor, pedestals, etc., inside structures, a storage hopper was set up outside the structure and buckets dumped into the hopper. The concrete was then drawn from the hopper into "Georgia Buggies" and wheeled manually to the point of placement on wood panel runways.

The basic mix used was the 3/4" maximum aggregate, 5.25 bags/c.y. The 1-1/2" maximum aggregate mix was used only in placements that were not congested with resteel and embedded items. Specifications on slump were strictly enforced. There were times due to plant malfunction that a batch or two were out of specifications--usually too wet. These were wasted.

Concrete was transported by transit mix trucks of Central Pre-Mix Co. of Spokane, Washington. During winter operations the truck drums were flushed with hot water before loading on the first batch. The temperature of the mixing water was observed closely to insure that it did not get too hot to avoid a "flash set". Little delay, if any, was experienced on transportation of concrete.

An approved grout mix was used on all air and water washed or sandblasted construction joints. The grout was mixed to a consistency that it could be easily broomed into semi-inaccessible spots. The approved grout mix used contained 9.25 bags of cement/c.y.

In all, the concrete operations at Complex 1-A were well managed due to good supervision and experienced crews.

Complex 1-B: Concrete placement operations started 10 March 1960 at Equipment Terminal No. 3. The concrete plant erected on site was a Model CA-100 manufactured by the Noble Company. The plant was semi-automatically operated and had a rated capacity of 75 c.y. per hour. A system of conveyor belts recovered the aggregates from a reclaiming tunnel and filled the plant hoppers. Storage capacity of the hoppers was approximately 150 tons of combined aggregate sizes. The plant was winterized by inclosing the aggregate bins and provisions were made to produce concrete in cold weather by heating the water and the aggregates. Very little difficulty was experienced during plant operations. The aggregate sizes produced at the source for concrete on this complex were #4 3/4" and 1-1/2" maximum size and sand. Gradation of the materials varied only when the fines of the aggregates hung up in the bins. This was corrected by cleaning bins and refilling with proper size aggregates.

Four basic mixes for concrete were used: Class "A" for 3,000#/28 day (4.75 sk/cy); Class "AA" for 3,000#/28 day (5.0 sk/c.y.); Class "AAA" for 5,000#/28 day (6.25 sk/c.y.); and Class "C" for 2,000#/28 day (sk/cy). Approximately 90% of the concrete placed at this complex was Class "A". Concrete with higher w/c ratio than the Class "A" was used for special pours such as silo doors which was a 5,000 Class "AAA" requirement. Grout used for bonding concrete at construction joints was 7 sk/cy.

Wood and steel forms were used. In general, the forms had been prefabricated and used on pours prior to delivery at this complex. The forms required rework before use. The Contractor maintained a form yard and built approximately 30% of the forms used on site. The form fabrication on site consisted mainly of straight forms and forms for miscellaneous structures.

Concrete operations were completed in August 1961. The concrete was placed using cranes and bail operated concrete buckets. The cranes had sufficient boom length and capacity to deposit concrete in forms in close proximity to final position. Concrete for floor slabs in the structures was discharged into a hopper; loaded into concrete buggies and transported over a system of ramps and runways to final position. Both of these conventional methods were satisfactory. The quality and effectiveness of the concrete crews was above average and at the peak of concreting operations their work was excellent. A revised mix design which allowed placement of concrete with higher slump from the basic design was used to insure good placement and sound concrete. This revised design was requested by the Contractor who assumed the cost of the additional cement. The revised mix design was used around blockouts and through heavily reinforced steel sections, reducing the Contractor's concrete placement costs.

Two types of finish for concrete slabs were specified for the complexes. The major finished areas were steel troweled and drainage slabs were given a tight wood float finish. Tolerances were maintained through tight inspection with the use of straight edges.

The interval between form stripping and the rod hole patching was slight. The number of finishers employed by the contractor was generally adequate and of experienced quality.

Two methods of cure were used:

a. The exterior and interior walls were sprayed with Hunt's Process (white) immediately after the forms were removed.

b. Water was used for the curing medium on slabs, construction joints, and level areas. These areas were wet down, covered with burlap and burlap was maintained in a wet condition for the duration of the curing process.

Construction joints were prepared for receiving the next lift of concrete by two standard methods:

a. Air water cutting was used to expose the aggregates on a major portion of the pours. Periodic inspections by the Corps inspection personnel during this work insured satisfactory work.

b. In locations where the use of water was not feasible or possible, wet sand blasting was used.

The contractor's schedule of operations included concrete placement during the winter months. Preliminary precautions consisting of the installation of a boiler for hot water to the batching plant and preheating the forms and resteel were undertaken. The contractor draped tarpaulins over forms and wood framework and installed heaters. Forms were left in place to provide additional insulation for the concrete.

Concrete placement in the Missile Silos at one time deviated from the standard use of cranes transporting two cubic yard concrete buckets from the transit mix truck to the forms.

The Contractor field fabricated an air operated concrete placing machine. The machine consisted of a beam extended over the entire silo, fixed at one end and equipped with wheels at the other end. A circumferential pad of concrete was placed for the wheel traffic of the machine. A one cubic yard hopper to which several sections of tremie pipe were attached was suspended from the beam. The operator was seated in an enclosure on the beam and using a phone system, was directed where to position the machine. The concrete was delivered to the hopper and released through the tremie pipe by an air actuated valve operated at the pour. The machine was named the "Moose" and was used only a short period of time as its use was not economical.

Complex 1-C: Concrete placement operations started 25 March 1960 with the first-third of the Control Center footing pour. The concrete plant and appurtenances were located on leased, privately owned property adjacent to and south of the complex. The concrete plant was the same type as that used at Complex 1-A and had a capacity in excess of 75 c.y. per hour. The cement was delivered via rail to Beverly, Washington, about 10 miles away, and then trucked to the batch plant.

Some difficulty was experienced with aggregate gradation. Aggregate size would alternate from too coarse to too fine. This was found to be due to stockpile segregation at the source and then loading haul trucks from the side of the stockpile. This was avoided by altering methods of stockpiling and loading out so as to compensate for the tendency for segregation. It was also found that keeping the stockpiles at the batch plant full resulted in more uniform gradation. On occasions it was necessary to draw out and waste aggregate found to be outside the specified gradation.

The maintenance of the proper slump was at times a problem. During hot, dry, windy weather the aggregate dried out beyond the saturdated surface and became quite warm. This fostered excessive loss of slump between the batch plant and the point of placement and induced premature initial set in the concrete. This was remedied by spraying the aggregate going back into the stockpiles and again going into the batch plant hoppers. During cold weather, it was necessary to heat the mixing water and to inclose and heat the stockpiles.

Concrete forms not fabricated on the job were occasionally in poor condition from previous use and required considerable reconditioning to make them useable. Delay was sometimes experienced in waiting for forms to be passed down from the previous complex.

The handling of the concrete in the forms was good. However, the methods of transporting the concrete between the mixer trucks and the forms varied from good to poor. Before the job had progressed very far the rectangular buckets were scrapped and elephant trunks with a steel funnel on top, equal to the diameter of the bucket, were in common use.

Curing was the same as at the other complexes, with the following exceptions. Due to waterproofing requirements at this complex, the use of membrane curing compound (Hunt's Process) was limited. The waterproofing membrane would not adhere to a surface after membrane curing had been used. Therefore, those surfaces to receive waterproofing were water cured. Water curing was accomplished by burlap covering and/or sprinkling with water by means of a sprinkler or garden type soaker. Curing water caused complications as it was not minimized. The result was waste water which required pumping out of structures and excavated areas. In general, the waste water was not initially pumped far enough away from the working area to prevent it from seeping back into the same area. This greatly increased the overall workload of disposing of waste water.

During the coldest months, it was necessary to heat the aggregate in the stockpiles. This was done by inclosing the stockpiles and circulating heated air through the aggregate reclaiming tunnel. In extremely cold weather the water heaters were the limiting factor on the rate of concrete placement.

The requirement for total waterproofing at this complex engendered several problems pertinent to concrete. In the silos below the "S" line, it was necessary to place Class "C" concrete between the rock and the neat line of the structural concrete. A leveling slab under the foundation of all concrete structures and under all Tunnel Junctions, LOX Tunnels, LOX Bays, and the Antenna Terminal was also required by the waterproofing requirement. The concrete surface had to be devoid of all sharp projections and edges which would puncture or shear the waterproofing and had to provide a surface to which the waterproofing would adhere. This included the embedment of wood nailing strips. At points where the waterproofing transferred from one surface to another, it was necessary to do this by means of a pitch pocket. The location of the pitch pockets in the concrete was at times very difficult from both the design and physical accessibility standpoints.

Due to the tunnel settlement and compaction problems experienced at Complexes 1-A and 1-B, the Contractor elected to use a lean mix concrete under the tunnels in lieu of the specified soil material. The use of this concrete was the most expedient method of bedding the tunnel liners. In general, the rock excavation was carried to the minimum, therefore a relatively small amount of lean concrete was required to fill the void between the tunnel liner and the adjacent rock. This method also simplified the aligning and grading of the tunnel liners. In the Launcher Areas the excavation was not accomplished with a great amount of precision; therefore, the rock under the Utility Tunnels and Personnel tunnels connecting the Tunnel Junctions and the concrete structures was in most cases over 24" below the bottom of the tunnel liner. Here the Contractor constructed concrete piers under the liners. These piers supported the liners on grade while backfilling was accomplished.

Concrete placement was completed September 1961 with the exception of small surface structures and tunnel bulkhead pours.

DATES OF CONCRETE PLACEMENT - SITE 1-A

Structure	Start	Finish
MS No. 1	15 March 1960	24 July 1961
MS No. 2	11 March 1960	19 July 1961
MS No. 3	18 March 1960	28 July 1961
ET No. 1	14 March 1960	27 Dec 1960
ET No. 2	11 March 1960	29 Dec 1960
ET No. 3	16 March 1960	29 Dec 1960
PT No. 1	21 March 1960	6 Feb 1961
PT No. 2	23 March 1960	20 Jan 1961
PT No. 3	10 March 1960	20 Jan 1961
PH	22 Feb. 1960	7 Jan 1961
CC	9 March 1960	11 Nov. 1960
AS (West)	8 April 1960	19 Jan 1961
AS (East)	8 April 1960	3 Feb 1961
AE	13 June 1960	9 Nov 1961
AF	12 July 1960	29 July 1960
AI	19 July 1960	3 Mar 1961
EP	13 July 1960	28 July 1961
BL-1	28 Sept 1960	4 Nov 1960
BL-2	13 Oct 1960	11 Nov 1960
Tunnel Conc.	6 Oct 1960	23 Feb 1961

The following tabulation gives a breakdown by structure for the quantity and class of concrete used at Complex 1-B:

Structure	"A"	"AA"	"AAA"	"C"	Grout
M.S. #1	3609	48	104	1135	86
M.S. #2	3678	54	108	825	75
M.S. #3	3652	54	112	896	60
E. T. #1	1152	--	--	251	27½
E. T. #2	1099	--	--	291	27
E. T. #3	1123	--	--	323	18
P. T. #1	915	--	--	164	21
P. T. #2	978	--	--	44	25
P. T. #3	1107½	--	--	109	14
Air Filt.	242	--	--	66	7
B. L. #1	926	--	--	--	10½
B. L. #2	618	--	--	--	7
A. E.	701	--	--	--	12½
A. I.	1685½	--	--	--	23
A.S. #1&2	1515	--	--	103½	36½
C. C.	2309	--	--	55½	24½
E. P.	818	--	--	--	16
P. H.	4376	--	--	59	62
Misc & TU's	362	45	--	270	--
TOTALS	30865	201	324	4592	552½

CONCRETE PLACEMENT
Complex 1-C

Structure	CLASS "C"		CLASS "A"	
	Start	Finish	Start	Finish
M.S. #1	10 May 60	12 July 60	23 Aug 60	7 Sep 61
M.S. #2	13 May 60	30 June 60	27 July 60	11 Sep 61
M.S. #3	24 May 60	14 July 60	2 Sep 60	13 Sep 61
E.T. #1	29 Apr 60	23 June 60	26 July 60	6 Dec. 61
E.T. #2	19 May 60	15 June 60	4 Aug 60	20 Dec 60
E.T. #3	1 June 60	21 June 60	9 Aug 60	30 Dec 60
P.T. #1	27 Apr 60	24 June 60	19 July 60	5 May 61
P.T. #2	11 May 60	1 July 60	2 Aug 60	8 Feb 61
P.T. #3	25 May 60	10 June 60	25 July 60	30 Jan 61
P.H.	13 Apr 60	7 June 60	23 June 60	24 Jan 61
A.E.	12 May 60	12 June 60	4 Aug 60	25 Jan 61
A.I.	14 June 60	14 June 60	8 Aug 60	11 Apr 61
E.P.	12 Nov 60	30 Nov 60	14 Dec 60	15 Sep 61
C.C.	25 Mar 60	20 May 60	4 June 60	23 Dec 60
A.S. East	10 May 60	31 May 60	17 June 60	6 Apr 61
A.S. West	17 May 60	31 May 60	22 June 60	14 Apr 61
A.T.	31 Aug 60	31 Aug 60	None	None
B.L. #2	18 Nov 60	18 Nov 60	4 Jan 61	26 Jan 61
B.L. #1	21 Nov 60	28 Nov.60	17 Jan 61	15 Feb 61
Air Filt.	15 June 60	28 June 60	20 July 60	10 Aug 60

8. BACKFILL OPERATIONS

Complex 1-A:

Backfilling operations at Complex 1-A started on the type "B" tunnels, AS-TJ-10, on 6 June 1960, under a subcontract to Murphy Brothers Co., Spokane, Washington. Backfilling started under Antenna Terminal Junction, 11 August 1960, and around Antenna Silos on 22 August 1960. Lean concrete was placed under the Antenna Junction to insure full bearing because the required compaction of dirt could not be obtained due to inaccessibility with proper tools to obtain compaction. It was found at the start of backfilling operations, from observation and laboratory tests that it was necessary to sample often, due to the changing moisture content caused by variation in the soils. It also was determined that some caliche had to be present to obtain specified compaction with the proper amount of rolling and added moisture. The Contractor worked to obtain this goal which resulted in considerable blending of silt and caliche. The water was added by water truck sprinkling and at times in confined areas by a series of garden hoses. In most cases on the backfilling operations, the amount of water added was critical due to the sharp peak of the optimum moisture curve and the Contractor, aware of this, leaned toward the dry side to attain specified compaction. The general rule used was that if a handful of the wetted material was picked up and squeezed and formed a ball that did not disintegrate that the lift was ready for rolling and in most cases met compaction requirements.

Rolling of the lifts of material was done with tractors, sheepsfoot rollers, loaded end-dump Euclids, and the loaded scrapers themselves. Around the circular structures, small paving rollers completed the job effectively because they could make the short radius turn.

On the backfill around the tunnels, the bulk of the material under the tunnels was compacted with pneumatic tampers as was the material around the fuel tanks and RP-1 tanks and water storage tanks. In many cases the Contractor elected to mix some pit-run gravel with the material at hand in order to be sure to get the required compaction around tunnels and on the sides. The Contractor had considerable difficulty on the first tunnel (TJ-1 to BL-2). His material was on the silty side and would laminate and "hump" with continued attempts to compact it. It was from this operation he learned that added caliche or gravel would facilitate his compaction. No difficulty was encountered after that.

On the stock piles the Contractor installed a sprinkling system made up of aluminum irrigation pipe and nozzles to pre-wet the material. This eliminated much wetting-down of material at the site of placement but was of no value in freezing weather. In freezing weather the material was carefully selected from the stockpiles after a frozen crust was removed. When the fill was not being worked, it was covered with a blanket of very dry material to prevent freezing then removed when ready to place material. Occasionally a large rock or two was deposited in a lift but these were removed.

One bad feature on the backfill presented itself when settlement up to 3" occurred in the tunnels at the blast lock entrances where the neoprene expansion joints connected the tunnel to the blast locks. Investigation showed inadequate compaction in these areas. Since the area under the expansion joint had to be trenched below the flow line grade to permit installation of the neoprene seal, it made difficult backfilling and the Contractor did not obtain required density in these areas, which were later grouted from the inside with a lean P. C. mix.

Backfill operations resumed on a small scale by hand 23 January 1961 around the fuel tanks. The Contractor blended in some gravel with the existing material to insure good compaction. All this type backfill and compaction was done with pneumatic tampers and Jackson vibrators. Considerable hand work was necessary in the tank areas before any machine work could be done. After this was accomplished a pattern of laying material and rolling was set up and maintained. Most of the compacting was done by loaded scrapers and loaded end-dump Euclids.

It was in this area where most of the difficulty was encountered with silt. Since the Contractor was approaching the bottom of the stockpiles the material became more silty since it was the first and top material taken out. More of the laboratory compaction tests were failing than passing for awhile and in many cases the material had to be removed. The optimum moisture content was so fine that it made the application of the required water very touchy. By better blending through use of a disc for better distribution of the water throughout the material, this problem was overcome but required constant surveillance. Small rolling equipment was used to compact around structures with small radii. An average of 3 scrapers was used to haul and backfill with a D-6 dozer smoothing out lifts. The Contractor worked two 10-hour shifts, 5 days a week and overall had a planned and well-supervised operation. The main backfill was completed 17 June 1961. Some extra backfill was stockpiled to take care of low spots on the grade and for the final lift around the entry portal. The roads were cut in from 20 March to latter part of May 1961.

Complex 1-B:

The material excavated contained an abnormally large quantity of silt, highly altered vesicular basalt, volcanic ash with lesser amounts of caliche, calcium oxide, ferrous oxide and opalite.

During the excavation phase, the material suitable for backfill was sorted and stockpiled separately. Three separate stockpiles, with varying gradations, were located on site. The material unsuitable for backfill was wasted in an area designated for waste. A portion of the smaller-sized rock was segregated and stockpiled separately from the main waste material. The material in the stockpiles was not sufficient to complete backfill requirements and permission was given to the Contractor to borrow sufficient material to complete the work.

An area immediately west of the west security fence line was designated by the Contracting Officer as a borrow area for silty material for use next to structures. Rock not exceeding 6" maximum size was used from excess waste stockpile for backfill of remaining open areas.

Backfill Placement:

Backfill and roadway embankment was subcontracted to Murphy Brothers Construction Company of Spokane, Washington. Backfill operations at Complex 1-B began in June 1960. The material used in the preliminary stages of backfill was secured from the stockpiles on-site.

The Contractor used conventional methods for backfill compaction. In open areas, the backfill was placed in specific lifts and compaction was achieved with the use of a sheepsfoot roller. A loaded rubber-tired Euclid truck was used to supplement the sheepsfoot roller when placing operations were such that additional rolling equipment was needed. Water was added by sprinkler truck.

In limited access areas it was necessary to use hand tools to obtain proper densities. The backfill material was placed in a pile and laborers spread, wet down using garden hoses, and compacted the material. Compactors utilized included Barco and pneumatic types.

Backfill under the tunnel sections at the neoprene joint connection was extremely difficult and it was not possible to secure density samples. Examination and tests made later through inspection holes cut in the tunnel inverts proved the lack of effective compactive effort on the part of the Contractor. Remedial action was taken in areas from Tunnel Junction No. 10 to Launcher Area No. 1 and in areas to Launcher Area No. 2. The Contractor elected to place concrete beneath the ring beams of the tunnels using low strength (2/sk cement mix) concrete. This action on the part of the Contractor minimized the access problem.

The drainage features of the area and the type of backfill material used were such that the puddling method of backfill was permitted in the area between the Antenna Terminal and Tunnel Junction No. 10.

Due to the varying characteristics of the backfill material it was necessary to set up a field laboratory to control and correlate operations to insure specified degrees of compaction for the various areas throughout the complex. Due to this variation several control curves had to be used. The laboratory set up these control curves for the various stockpiles and made continuous tests of stockpiled and backfilled material.

There was a considerable lapse of time between the excavation and backfill phases of the contract. Moisture content of the backfill material was a critical item. To maintain the moisture in the stockpiles a sprinkler system--irigation pipe with nozzle sprays--was installed. This system maintained the moisture uniformly and in the proper range. The blending of materials in the stockpiles to facilitate compaction was accomplished under the control of the field laboratory.

As backfill operations continued throughout the winter, additional controls were necessary to prevent frozen material from being incorporated into the fill areas. It was necessary to maintain either a continuous operation to prevent the exposed material from freezing or to place a protective covering of loose material over filled areas. The loose material was removed prior to placing additional backfill material. Since two 10-hour shifts were in force, the loose material was used only during periods of one-shift operation.

Complex 1-C:

Backfill operations at Complex 1-C were initiated by Murphy Brothers Construction Company in August 1960.

The sub-surface geology at Complex 1-C differed from that of the other two complexes. Four types of materials were excavated. The top soil consisting chiefly of silty sand had an average depth of approximately 4-1/2 feet. Next was a layer of very hard caliche averaging about 17 feet in thickness. Below the caliche was a layer of diced and weathered basalt approximately 23 feet thick. At an average depth of 44-1/2 feet hard, dense columnar basalt was encountered. The remainder of excavation was in this material. These variations in sub-surface materials greatly influenced the Contractor's excavation and backfill operations. From the beginning it was obvious that there was a shortage of material which could later be placed economically as backfill.

The excavated materials were segregated and stockpiled in three areas. The sandy topsoil and most of the caliche were economical backfill materials. The basalt rock was fractured and broken during excavation into pieces much larger, in general, that could be incorporated into the backfill. The cost of crushing the basalt to produce backfill material would have been exorbitant. It was, however, feasible to recover small-sized rock from the stockpile. This could be done by passing the stockpiled materials over a grizzly having the rails spaced 6" apart. At the request of the Contractor, Change Order No. 124 (Modification No. 119) was issued authorizing the use of rock 6-inches and smaller for backfilling all tunnels from a point 4 feet above the liner and all access ramps from their then present grades. Only the north end of the rock in the spoil area was found to contain enough 6" minus material to be worth processing. After this was exhausted and all other usable material on site was depleted, the Contractor requested and was given authority to use material from two off-site locations. This material had the same general characteristics as the fine-grained material at the complex--a silty sand and/or sandy silt and hard caliche. It is estimated that between 50,000 and 75,000 cubic yards of the off-site material was hauled-in and that approximately an equal amount of excavated basalt remains in the spoil area.

At the beginning of backfill operations, it was evident that a maximum effort was required by both the Contractor and inspector personnel to insure acceptable backfill--especially around the tunnels. With the exception of the "B" type tunnel, all tunnels and tunnel junctions were placed on lean concrete slabs or piers which are founded either on rock or thoroughly compacted (95% or more density) backfill which is founded on rock. The "B" type tunnel--which extends from T. J. No. 10 to the Antenna Terminal--is founded on compacted backfill with the exception of 200± feet from T. J. 10 towards the Antenna Terminal which was placed on a concrete slab.

Inspection of compaction was expedited by the initiation of inspection methods for fast checks. The time required to determine the density of a compacted area by standard density tests was in excess of one hour. A density sample could not be taken if compacting equipment was operating in the vicinity and then the results were not known for some 60 minutes later. It was found that density could be estimated by puncturing areas of known densities (densities which had been determined by the standard method) and to compare results with results of probing in newly-placed lifts. By this method an inspector could soon learn to estimate the density within less than 10% of the compaction required. He could probe a large area in a few minutes. If an area was found to be unacceptable by probing, one or more standard density tests would be made immediately and rejection or acceptance would be made in accordance with the results of the standard tests. The probe also unmasked areas in which the lifts were excessive and where a second lift had been placed over an unacceptable lift immediately below. Probing provided additional control and the same number of standard density tests were still performed.

Compaction was carefully controlled. A field laboratory was responsible for determination of densities. To obtain acceptable compaction, it was necessary to exercise tight control over the moisture content of the fine-grained backfill material. Mostly by trial and error, it was learned that the most satisfactory place to add water was in the stockpile. The excavation from stockpile and spreading in the area to be backfilled induced beneficial blending and allowed the greatest latitude for compensating for material which was too dry or too wet. Some hand sprinkling in places was necessary. This was especially true if there was much of a time lapse between lifts. More than 2100 standard density tests were made at Complex 1-C.