DESIGN, INSTALLATION AND TESTING
OF THE
KLXSTRON GALLERY COOLING TOWER WATER LINES

Report To: STANFORD LINEAR ACCELERATOR CENTER - ABA NO. 104
STANFORD UNIVERSITY SUBCONTRACT S-136
UNDER AEC CONTRACT AT(04-3)-400

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September, 1965
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DESIGN, INSTALLATION AND TESTING
OF THE
KLYSTRON GALLERY COOLING TOWER WATER LINES

INTRODUCTION

This report presents the results of an investigation and analysis of the Klystron Gallery Cooling Tower Water (CTW) System requested by SLAC Plant Engineering memo of August 18, 1965.

The installation contractor, C. R. Fedrick, encountered considerable difficulty in completing the required hydrostatic testing of the lines from Sectors 16 through 30. A total of 45 breaks in the lines occurred during acceptance testing of these sectors. Relatively few breaks or leaks occurred during acceptance testing of the CTW lines serving Sectors 1 through 15.

The text presents a summary of the development of design criteria and final contract drawings and specifications; a review of installation procedures during construction; a review of construction and acceptance testing problems; and an analysis of these problems and recommendation for future action. The Appendices include a tabulation of the location of all breaks that occurred in Sectors 16 through 30, the geographical distribution of the breaks, and copies of data pertinent to seismic resistance of the lines and to the construction procedures.

BASIS FOR DESIGN

The criteria for the design and construction of the Cooling Tower Water system was developed jointly by SLAC and ABA engineers as a result of many meetings and engineering studies. Meetings were held on a semi-monthly basis for nearly a year with all SLAC user groups represented. The general parameters followed were: a) that the system be reliable; b) that the cooling capacity be adequate for SLAC's Stage I needs; c) that the pipe lines be sized for Stage II requirements; d) that the final system be the most economical consistent with the above criteria; and e) that the installation of the system be coordinated with the construction of the Accelerator Housing, Klystron Gallery and Cooling Towers, and with SLAC's Accelerator installation program.
The economics of the various piping materials, types of cooling tower equipment and pumps were evaluated in detail. The following design criteria was adopted by all concerned:

**TABLE I - CTW DESIGN CRITERIA**

<table>
<thead>
<tr>
<th></th>
<th>Stage I</th>
<th>Stage II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Each Tower</td>
</tr>
<tr>
<td>Cooling Capacity</td>
<td>22 megawatts</td>
<td>11 megawatts</td>
</tr>
<tr>
<td>Wet Bulb Design</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>$68^\circ$F</td>
<td>$68^\circ$F</td>
</tr>
<tr>
<td>Design Approach</td>
<td>$7^\circ$F</td>
<td>$7^\circ$F</td>
</tr>
<tr>
<td>Water Temperature Range</td>
<td>$20^\circ$F</td>
<td>$20^\circ$F</td>
</tr>
<tr>
<td>Cooling Water Flow,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Over Tower, Max.</td>
<td>10,000 gpm</td>
<td>5,000 gpm</td>
</tr>
</tbody>
</table>

The design differential pressure available at each sector is 18 psi for both Stage I and Stage II.

The adopted design utilized cooling towers located adjacent to Stations 25+00 and 75+00, with each cooling tower providing cooling for one-half of the equipment in the Accelerator Housing and Klystron Gallery. The two towers and associated piping are not connected and hence operate as two separate systems.

**SELECTION OF MATERIAL AND LINE SIZE**

After adoption of the criteria described above, comparative costs and material characteristics for various pipe materials were considered. Required line sizes and system working pressures for both Stage I and Stage II were determined. As the lines were to be large enough to service Stage II needs, they were designed on the basis of Stage II flow quantities and operating pressures.

**Comparative Costs**

As reliability and economy were primary considerations in the design of the system, various types of steel and asbestos-cement pipes were evaluated. Table II presents a cost comparison of the materials considered.

**TABLE II - ESTIMATED COST OF PIPE PER LINEAL FOOT**

<table>
<thead>
<tr>
<th>PIPE SIZE</th>
<th>24&quot;</th>
<th>16&quot;</th>
<th>14&quot;</th>
<th>12&quot;</th>
<th>10&quot;</th>
<th>8&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. TRANSLITE (asbestos-cement)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CL,200</td>
<td>$20.83</td>
<td>$8.97</td>
<td>$7.18</td>
<td>$5.74</td>
<td>$4.61</td>
<td>$3.91</td>
</tr>
<tr>
<td>CL,150</td>
<td>15.84</td>
<td>7.43</td>
<td>6.20</td>
<td>4.93</td>
<td>4.00</td>
<td>3.27</td>
</tr>
<tr>
<td>CL,100</td>
<td>11.80</td>
<td>6.36</td>
<td>5.23</td>
<td>4.40</td>
<td>3.58</td>
<td>3.02</td>
</tr>
<tr>
<td>2. STEEL PIPE (coated and wrapped)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>27.98</td>
<td>19.24</td>
<td>17.11</td>
<td>15.07</td>
<td>11.43</td>
<td>10.35</td>
</tr>
<tr>
<td>3. SPIRAL WELD (cement lined and coated)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>17.75</td>
<td>12.19</td>
<td>11.17</td>
<td>10.00</td>
<td>8.92</td>
<td>6.69</td>
</tr>
</tbody>
</table>

*PIECE COSTS ARE COMPARABLE AND INCLUDE MATERIAL AND FIT-UP ONLY.
COST OF VALVES AND FITTINGS ARE APPROXIMATELY THE SAME FOR ALL THREE PIPE MATERIALS.
Material Characteristics

Asbestos-cement is a widely used material for piping systems. It has been in use for a great many years, and where properly installed, has practically unlimited life and very low maintenance. It is generally lower in cost than other pipe materials giving comparable service. It is inert to soil chemical effects. The fact that it is not affected by electrical ground current is of particular value in this application since metallic pipe has failed here on the site in several instances in less than two years because of such corrosion. The probability of serious corrosion in wrapped and coated steel pipe is considerably less than for unwrapped pipe. However, corrosion is accelerated at any "holidays" in the coatings or wrappings. Such "holidays" or pinholes do sometimes occur despite the best construction practices, inspection and testing. The principal limitation of asbestos-cement pipe is that it is somewhat brittle and should not be subjected to high shock or crushing loads.

A careful survey was made of industry practices and experience with asbestos-cement pipe installations. Johns-Manville Co., the principal manufacturer of asbestos-cement pipe, estimates that 85% of all buried pipe 10" and larger in cooling tower water service, now being installed in the United States, is asbestos-cement. Aerojet-General, (one of the parent companies of ABA) has extensive piping systems of all types which are required to have top reliability. Asbestos-cement pipe has been used whenever possible in these systems and has proven very successful. Also, 98% of the pipe footage of domestic water systems operated by Pacific Gas and Electric Co. is asbestos-cement pipe.

Of the types of pipe listed in Table II, ABA did not recommend use of steel pipe because of the excessive cost. If steel pipe were to be used, ABA recommended that the pipe be cement lined and coated. The cost analysis indicated that such pipe would cost $99,100 more than Class 100 asbestos-cement pipe. However, both types of pipe plus cast iron were included in the final specifications to avoid charges of discrimination.

Asbestos-cement pipe has an excellent record with regard to resisting breakage during earthquakes. For example, in the Inyokern, California earthquake which occurred in 1946, no leaks were reported in asbestos-cement piping systems, although systems using other materials suffered extensive damage. Other earthquake areas report similar experience. The relatively short lengths (about 13 feet) and flexible joints of asbestos-cement pipe give a piping system that reacts somewhat like a string of beads to the rolling earth waves. The flexible couplings will take a mis-alignment of up to 5 degrees (about one foot per 13 foot length) before damage occurs. In addition, the crushing strength of the pipe
required to withstand imposed vehicle loads is adequate to resist lateral loading that may occur during a seismic disturbance. The letters included in Appendix A of this report indicate the experience of installations with large amounts of buried asbestos-cement pipe subjected to earthquakes.

Selection of Class 100 Asbestos-Cement Pipe

Initially, Class 150 pipe was recommended and was used in the design basis for the Title I Report on the CTW system (ABA-58, dated January 28, 1963). During Title II design, ABA was requested to re-review the proposed system for further budget economies. After carefully analyzing the operating pressures, the predicted relatively light vehicle loading, and the cost savings of about $21,000 to be realized by Class 100 pipe versus Class 150, ABA was directed to use Class 100 pipe. It should be noted that Class 100 pipe is entirely adequate for the required operating pressures; however, the factor of safety is reduced from that furnished by Class 150 pipe. Another factor considered was that the vehicular traffic along the Klystron Gallery would be relatively light both in numbers and weights of vehicles. This is important as failures that occur during operation of asbestos-cement piping systems are generally caused by the excessive weight of vehicular traffic. The pipe is guaranteed by the manufacturer to withstand crushing loads of 4000 psf for 12-inch pipe, 4400 psf for 14-inch pipe, and 4800 psf for 16-inch pipe. In addition, each length of pipe is internally pressure tested to 350 psig at the factory.

Line Sizes and Pressure

Line sizes were determined by a careful evaluation of head loss in the pipe versus required pumping for both Stage I and Stage II operations. A detailed study was made involving some 51 different sizing configurations, comparative installed costs, and comparative operating costs over the first 10 years of operation including five years of Stage II operation. In addition, the minimum flow rate required for Stage I operations was considered, as very low flow rates would tend to allow sludge accumulation in the lines.

Pumps serving Sectors 1 through 15 and Sectors 16 through 30 will operate initially at 40 psi head. At this pressure, each pump will deliver the design quantity of 2500 gpm as shown in the attached pump curve, Appendix B. For Stage II conditions, the water quantity handled per pump will remain constant, but more pumps will be added so as to double or triple the flow in the lines. This will increase the pressure drop in the lines and the supply pressure will correspondingly increase. The pressure drop through the cooling towers and heat exchangers will remain the same, since the additional towers and exchangers will
be installed in parallel. The Stage I pressure drop in the lines was calculated to be 6 psi. The Stage II pressure drop on the basis of 15,000 gpm per tower would be 46 psi, an increase of 40 psi. The comparison of pressure loss as calculated on the basis of 5000, 10,000 and 15,000 gpm per tower is as follows:

**TABLE III - COMPARATIVE OPERATING PRESSURES IN PSI**

<table>
<thead>
<tr>
<th>Supply Line Pressure</th>
<th>Stage I 5000 gpm/tower</th>
<th>Stage II 10,000 gpm/tower</th>
<th>Stage II 15,000 gpm/tower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Headers and Branch</td>
<td>6.5 max.</td>
<td>24.0 max.</td>
<td>46.0 max.</td>
</tr>
<tr>
<td>Tower Supply and Return Piping</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Tower Internal Loss Including Static Head</td>
<td>9.5</td>
<td>9.5</td>
<td>9.5</td>
</tr>
<tr>
<td>Heat Exchangers &amp; SLAC Piping</td>
<td>18.0</td>
<td>18.0</td>
<td>18.0</td>
</tr>
<tr>
<td><strong>Supply Line Pressure (MAX.)</strong></td>
<td>39.0</td>
<td>57.0</td>
<td>79.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Return Line Pressure</th>
<th>Stage I 5000 gpm/tower</th>
<th>Stage II 10,000 gpm/tower</th>
<th>Stage II 15,000 gpm/tower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Header</td>
<td>2.8 max.</td>
<td>11.2 max.</td>
<td>26.0 max.</td>
</tr>
<tr>
<td>Tower Return Piping Header</td>
<td>2.2</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Tower Internal Loss</td>
<td>9.5</td>
<td>9.5</td>
<td>9.5</td>
</tr>
<tr>
<td><strong>Return Line Pressure (MAX.)</strong></td>
<td>14.5</td>
<td>22.9</td>
<td>37.7</td>
</tr>
</tbody>
</table>

The maximum pressure the Stage I pumps are capable of attaining is 57 psi, at shutoff condition. The working pressure at Stage II will be 79 psig at the pump discharge. The pressure in the piping system gradually decreases in the direction of flow to about 12 psig at the return connection to the cooling tower.

If in the future, the working pressure in the system is increased so that it approaches the design pressure of the piping and so that the shutoff head of the pumps exceeds the design working pressure of the pipe, an automatic pressure relief bypass should be installed at the pumps. This will be required only at flow rates above 15,000 gpm per tower which is well above presently foreseeable cooling requirements of the Accelerator.

The design of the system minimizes water hammer. Damage from water hammer is caused by rapid changes in water velocity and is usually caused by quick-closing valves. The main valves in the CTW system are gear operated and require more than one full minute to close. Closing the return line valve will cause a rise in pressure in the return line of about 5 psi. Closing the supply line valve will create a reflected pressure wave. This will cause a very small pressure increase in the supply line. Rapid closing of a heat exchanger supply valve at the end of the line would give the highest pressure rise. However, even at maximum flow, the eight-inch valve would have to close in less than one second for the total pressure to exceed the design working pressure of the pipe at that point. This would be difficult to do manually, and is very unlikely to occur.
CONSTRUCTION DRAWINGS AND SPECIFICATIONS

Installation Instructions and Details

To ensure that the final system as installed would perform satisfactorily, certain installation requirements and instructions were written in the contract specifications or were shown on the drawings. For example, to ensure proper bearing and support for each section of pipe, the specifications required:

"The bottom of trenches shall be accurately graded to provide uniform bearing and support for each section of the pipe on undisturbed soil at every point along its entire length and for a width equal to at least 1/2 the pipe diameter, except for the portions of the pipe sections where hand excavation shall be used to provide for pipe bell, proper sealing of joints and as hereinafter specified. No point bearing on pipe sections will be permitted. Bell holes and joint depressions shall be prepared after the trench bottom has been brought down to grade." (Emphasis added for this report.)

"Unless otherwise approved by the Manager, preparation, handling, and installation shall be in accordance with the manufacturer's specifications, instructions and technical data particular to the materials or products specified."

In addition, typical details were shown on the drawings for concrete thrust blocks for anchoring the water piping and for lateral connections. All laterals from the CTW piping were specified to be steel, coated and wrapped below grade to protect against corrosion.

Test Requirements

It is normal to test piping systems at 150 percent of the line working pressure. The industry-wide acceptance of pipe line testing at such pressure is indicative of its adequacy. It has been found that leaks rarely develop in the systems so tested. In this case, it was decided to test at 150 percent of the rated pressure of the pipe since extra assurance of system reliability was desirable. The resulting required test pressure was 385% of Stage I maximum working pressure and 190% of maximum Stage II working pressure. The fact that the CTW lines were specified to be tested at a substantially higher pressure than the commonly accepted standard gave added assurance that leaks in the line would not develop after start of operation.

The specifications required that the piping system hold a pressure of 150 psig for one hour with minor seepage permitted according to the following formula:

\[ L = \frac{ND\sqrt{P}}{1,850} \]

Where:  
\[ L = \text{allowable leakage rate, in gallons per hour;} \]  
\[ N = \text{number of joints in the test section;} \]  
\[ D = \text{nominal diameter of pipe, in inches;} \]  
\[ P = \text{average test pressure, in psi gage; and} \]  
\[ ND = \text{represents the summation of the (number x size) of all individual size of lines and number of joints under test.} \]
HISTORY OF INSTALLATION

All construction for the Accelerator-Klystron Gallery complex was carefully planned to allow installation and testing of Accelerator equipment at the earliest possible dates. The construction schedule for underground piping and utilities was therefore closely tied to the Accelerator Housing and Klystron Gallery construction. As the working areas along the Accelerator were quite restricted, the Klystron Gallery and Utilities contractors could not work in the same sectors at the same time but had to work in sequence. Once SLAC equipment installation was initiated, it was necessary that access be maintained to the Klystron Gallery for SLAC contractors. In addition, the CTW lines and the 12.47 kv underground distribution duct construction were also closely coordinated. With many inter-dependent contracts, some delays and reshuffling of construction sequence were inevitable.

As noted previously in this report, few problems were encountered during construction of the CTW lines serving Sectors 1 through 15. Most of the problems occurred in the lines serving Sectors 16 through 30. The discussion following is therefore concerned primarily with these sectors.

Sectors 1 through 15

The original utilities contract schedule required that installation of the CTW lines follow completion of the Klystron Gallery. After the contracts were awarded, it became apparent from observing the contractors' methods of construction that less interference between the two contracts would occur if most of the piping on both sides of the Gallery could be installed prior to construction of the Klystron Gallery. Therefore, meetings between these contractors, ABA and representatives of SLAC Plant Engineering were held to reschedule the work of the Klystron Gallery Utilities contract, ABA 600-Y-1. By this rescheduling, the installation of the CTW lines and construction of the Klystron Gallery were carefully coordinated between the two contractors up through Sector 4. Thereafter, the CTW lines were installed ahead of Gallery construction through Sector 9. The advantage to SLAC was that open trench work would be minimized adjacent to the completed sectors of the Klystron Gallery. Therefore, interference to SLAC contractors installing Klystron Gallery equipment would be materially reduced.

In order to provide SLAC with cooling water for testing Accelerator equipment, the CTW lines from Cooling Tower 1201, serving Sectors 1 through 9, were installed first during the period June 19 through August 24, 1964. Some difficulties were experienced with respect to the fit-up of asbestos-cement pipe to cast iron
fittings. The events and conditions associated with the correction of these deficiencies are reviewed in a letter to D. Browne, Jr. from H. B. Kiker dated December 4, 1964; see Appendix C. SLAC beneficial occupancy of these lines was effected August 25, 1964. Some minor leaks developed in this line but were found to be caused by incomplete seating of the rubber gasket at several connecting collars. These were repaired and final acceptance of this portion of the work occurred on September 17, 1964. No leaks have been reported since that time.

The CTW lines for Sectors 13 through 15 were installed in the trench and backfilled during September and October 1964. The lines for Sectors 10 through 12 were not placed and backfilled until April 1965 due initially to conflict with the Klystron Gallery construction and subsequently to wet winter weather. Final trench backfill compaction and acceptance testing of the pipe for Sectors 10 through 15 were completed on June 17, 1965. The area was paved shortly thereafter.

**Sectors 16 through 30**

The CTW pipe serving Sectors 16 through 30 was installed in the trenches during September, October and November 1964. The construction did not follow a sector by sector basis but was scheduled to minimize interference with the Klystron Gallery and State Highway Bridge construction. Compacted backfill was placed around the pipe at the time of installation but final compaction to specified density was not completed in these sectors due to wet conditions. Daily precipitation reports show approximately 1 inch of rain for October, 5 inches of rain for November, approximately 10 inches during December and approximately 5½ inches during the month of January, 1965.

Final trench backfill compaction for these Sectors could not be started until late May 1965. The pipes were filled with water at line pressure (80 psig) on about June 8, 1965. Leaks due to split pipe and/or broken collars occurred as pressure was increased toward the specified test pressure. Each broken pipe was replaced in full sections, about 12½ feet in length. Broken collars which comprise approximately one-half of the breaks were also replaced. Appendix D presents a summary of the location and type of the breaks, pipe size, and test pressure at which the break occurred. Appendix E locates the breaks graphically. Of necessity, the trench backfill was disturbed during the repair of each break. Although the initial re-compaction of backfill for most of these areas did not meet specification, the contractor decided to pressure test the piping prior to final re-compaction. A successful pressure test was attained on August 25, 1965.
The contractor agreed to re-test the lines after final acceptance of the backfill. Re-testing of the pipe after re-compaction disclosed two additional breaks in the line. After these breaks were repaired, testing was resumed, a few leaks occurred and were repaired, and final specified pressures together with the completed backfill, were attained on September 8, 1965.

QUALITY CONTROL AND INSPECTION

The contract specifications provide for assurance of the quality of the manufactured pipe by reference to ASTM Standards. Installation of the pipe was required to be in accordance with certain stipulations and with manufacturers' instructions. ASTM Standard #C-296-63T provides that each piece of pipe and coupling shall be tested for hydrostatic strength and flexural strength. The class of pipe and manufacturers' name are stamped on each piece of material after such factory testing. All material received on the job was observed to be properly stamped.

The compacted fill material in which the cooling tower water lines are trenched is composed of evenly graded fines. This material lends itself exceptionally well to the forming of an evenly graded trench bottom. Therefore, the specifications provided for installation of the pipe on a graded trench bottom. Bell holes or depressed areas were provided for clearance under the couplings. Careful inspection was made to assure that the possibility of couplings resting on the original trench bottom did not occur. This method of placement within the trench is in accordance with manufacturers' instructions. The method used for assembly of the pipe was the bar and wood block method which is considered to be a conservative method for installation of asbestos-cement pipe. Appendix F shows pictorially the installation method followed. Other methods such as the swinging-in method are considered to be faster but the possibility of damaging pipe ends is greater.

The handling of the pipe during unloading and distribution was observed to follow recommended practices. Pipe was properly lowered into the trench; unusual or rough treatment of the pipe on the bank or in the trench was never observed. Lubrication of pipe ends and the installation of rubber rings was carefully done and in full accordance with the manufacturers' instructions. To make certain that the rubber rings were properly located, their position was frequently checked with a feeler gauge. The feeler gauge does not reveal if the rubber ring is completely sealed, however, pressure testing of the line does reveal any such defects.
Backfill was placed around the pipe and to approximately 6" to 8" above the pipe at the time of installation for Sectors 16 through 30. The backfill material was imported blue shale-like material, sand equivalent of 25 or greater in accordance with Cal. 217-E test method. This portion of the backfill was compacted to 90% relative compaction in accordance with specification. Native material was placed over the 90% compacted imported material. The compaction specified was 95%. An attempt was made to attain specified compaction using a pneumatic hammer. It should be noted that the method used to compact the backfill and the type of material (on-site native material or imported backfill) are the contractor's prerogative although ABA verbally recommended that the contractor use imported backfill material and a lighter compactor. The operating pressure of the contractor's equipment varied from 100 psi to 150 psi resulting in compactive force on the backfill material of 14,000 to 21,000 lbs. per square foot. Compaction tests on the backfill indicated that specified compaction had not been attained. Further effort to attain compaction was deferred until completion of the Klystron Gallery and installation of cross connections. By agreement with ABA (see R. L. Hawkins memorandum to Files, dated August 5, 1964, Appendix G) the contractor agreed to leave the trench backfilled sufficiently to avoid settlement. It was understood and planned that he would return and complete the compaction of the backfill after the Klystron Gallery contract was completed and cross connections from the cooling tower water main to the Klystron Gallery were in place.

It should be noted that though the specifications requested that pressure testing of the line be accomplished prior to completion of backfill, this sequence of operations was impractical in this case. This type of testing requires that the pipe be covered between the joints with sufficient material to hold the pipe in place during the application of hydrostatic pressure within the pipe. Since this would require that the trench remain open for a considerable period, it would thus defeat the purpose of getting the installation of the pipe accomplished ahead of the Klystron Gallery. Also, this required the placement of loose material over the pipe which would have to be evenly spread and compacted at a later time. The contractor elected to place compacted backfill around the pipe and over it to a depth of 6" to 8" plus partially compacted native material backfill to the surface prior to testing. This procedure was field approved with the understanding that removal of backfill material for the correction of leaks was at the sole cost to the contractor.
Since specified compaction of 95% had not been attained by the initial compactive effort during installation of the pipe for Sectors 16 through 30, the trench backfill was again compacted with a pneumatic hammer. This occurred in the early part of July and prior to pressure testing. This compactive effort appeared to be effective. Compaction tests were generally acceptable.

ACCEPTANCE TESTING

As previously reported, the pressure testing of the CTW lines serving Sectors 1 through 9 encountered no unusual circumstances other than the conditions associated with the fit-up of asbestos-cement pipe to cast iron fittings and minor leakage at a few collars. Once these problems were solved, the test pressure came up to a successful and acceptable condition in late August 1964. Through a one year operation, there appears to be no other deficiencies. Also, that portion of the lines serving Sectors 10 through 15 has experienced no difficulty in operations.

Most of the problems occurred in the lines adjacent to Sectors 17 through 30. It is of interest to note in Appendix E that over half of the breaks involved broken collars. As the collars are relatively light, they can be handled easily by one man. As a consequence, minor cracking, not readily discernible to the naked eye, can occur due to dropping or rough handling. Such damage is disclosed only upon pressure test of the line.

Research has shown that when an excessive external load is applied to rigid conduits such as asbestos-cement pipe, failure is by rupture of the pipe walls. Tests by the American Railway Engineering Association show that vertical fill loads are transmitted directly to rigid type conduit because it is more rigid than the adjacent soil. When excessive loads are applied, the conduit tends to fail with longitudinal cracks at the top and bottom on the pipe interior and at the sides on the pipe exterior. It should be noted that in the present installation the material in which the pipe was laid had been compacted to 95% of maximum density. As such, the supporting soil was quite rigid and hence provided excellent support for the piping.

Of the pipe breaks, 18 were in the return line which is closest to the surface and seven were in the supply line which is about five feet below the surface. A careful inspection of each broken collar and pipe section did not disclose a definite correlation between events that occurred during construction and the location and type of breaks. Some of the cracks which appeared as a result of the pressure test were hairline in nature and hardly discernible to the naked eye. This indicates that even slight damage to the pipe structure is
exaggerated under the specified test conditions and shows up as a pipe failure. In some instances, it appears that compactive equipment might have been the cause; in others, heavy vehicles passing over the pipes during wet weather may have caused damage. Some of the collar breaks were undoubtedly caused by minor damage that occurred during shipment and handling, as numerous collars were rejected prior to placement because of cracks or other observable defects.

Laboratory tests were made of sections of broken pipe removed from Sectors 17 through 30. Pittsburgh Testing Laboratory conducted Hydrostatic Proof Tests, Crushing Tests and Uncombined Calcium-Hydroxide Tests in accordance with the test methods for testing asbestos-cement pipe, ASTM #C-500-63T. In addition, measurements of inside diameters and wall thicknesses were made. The results are included in Appendix H. Except for the results of a crushing test on one piece of pipe, the results comply with requirements of ASTM #C-296-63T.

It is of interest to note that for all practical purposes, the CTW system serving Sectors 15 through 30 has been pressure tested a total of 17 times at 150% or greater of maximum expected Stage II operating pressure. The future reliability of the system should thus be assured.

FUTURE CRUSHING LOADS

As soon as possible after successful tests were completed, the overlying areas were paved. The paving and aggregate sub-base helps distribute surface loads and will keep water from permeating the underlying soil and thus keep the earth cover effective. The level surface also minimizes vehicle wheel shock loads. The successful tests after completion of the compaction of the soil over the pipe should assure a tight system that will remain tight.
CONCLUSIONS AND RECOMMENDATIONS

This report has reviewed the engineering development of the CTW system, the contract specifications, installation procedures, quality control and inspection procedures, acceptance testing and problems associated therewith, and the results of an investigation into the reasons for the problems that occurred. The following conclusions appear in order:

1. The construction packages and schedules were planned to provide SLAC with useable facilities at the earliest possible date. For all intents and purposes, this was accomplished.

2. Considering the number of construction contracts involved, the restricted working areas, the required sequencing of construction effort and the inclement weather that occurred during eight months or more of the construction time, the problems encountered were not too unusual.

3. The materials specified and installed have:
   a. An exceptionally good service record of low maintenance because of resistance to corrosion and deterioration, uniformly good hydraulic characteristics (no scale deposits or pitting) and minimum leakage.
   b. An excellent history of minimum damage from seismic disturbances.

4. The line sizes specified and installed are proper for the intended service including the proposed Stage II operations.

5. The installed system cost approximately $100,000 less than an equivalent steel pipe system.

6. The acceptance test pressures were greater than those normally specified so as to provide more assurance of continued system reliability. Pressure testing of CTW piping systems has proven to be a reliable method of ensuring system integrity.

7. The stable foundation material supporting the CTW piping combined with the well compacted backfill and the asphalt cement paving and compacted aggregate sub-base will, for all practical purposes, eliminate differential movement of the piping due to settlement or vehicular traffic.

8. The class of pipe installed is proper for the intended service, particularly in view of the predicted vehicular traffic and loading.

9. The large number of breaks and/or leaks that occurred during testing of the piping for Sectors 16 through 30 were probably due to a combination of factors:
   a. Over half of the breaks involved broken collars. Many of these could have been caused by handling damage incurred prior to installation.
   b. Heavy construction vehicles operating in the area during wet and muddy weather may have caused some of the breaks.
   c. The tamping equipment used by the contractor could have caused some of the damage.
d. Some of the sealing gaskets were not completely seated during initial installation, and
e. The mere fact that the piping system lay uncompleted for a period of eight months or more made the piping susceptible to damage from various sources.

10. The CTW piping system has now been tested to specified standards, the pipe trenches are properly compacted and the overlying areas are paved or will be in the next few days. The piping for Sectors 16 through 30 has been tested 17 times at pressures exceeding 150% of maximum predicted Stage II operating pressure. In addition, the CTW system for Sectors 1 through 9 has provided trouble-free service for over one year. The system should therefore provide reliable trouble-free service for many years.

As a result of the foregoing review, it is recommended that:

1. Heavy vehicles that might operate along the south side of the Klystron Gallery be restricted to low speeds.

2. If operating conditions require flows exceeding 15,000 gpm per tower, a bypass relief should be installed at the pumps to limit maximum system pressure to slightly above the line operating pressure.
APPENDICES
APPENDIX A

Letters Describing Earthquake Resistance of Asbestos-Cement Pipe:

Inyokern, California Earthquake, 1946
Tehachapi (Kern County), California Earthquake, 1952
Arvin (Kern County), California Earthquake, 1952
Anchorage, Alaska Earthquake, 1964
APPENDIX B

Operating Pressures of Cooling Tower Water Pumps
APPENDIX C

Installation and Testing of Cooling Tower Systems - Sector 4
APPENDIX D

Summary of Pipe Leaks - Sectors 16 through 30
APPENDIX E

Location and Nature of Pipe Breaks - Sectors 16 through 30
APPENDIX F

Assembly of Transite Pressure Pipe

(Excerpt from Johns-Manville Instruction Guide)
APPENDIX G

Installation Schedule and Procedure - Sectors 13-16

(Backfilling of Trench)
APPENDIX H

Test Results of Class 100 Asbestos-Cement Pipe:

Crushing Strength

Internal Pressure (Hydrostatic) Test

Uncombined Calcium Hydroxide Test