ORIGINAL RESEARCH IN CONNECTION WITH THE COLORADO RIVER AQUEDUCT

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In planning and executing a project such as the Colorado River Aqueduct, great care must be taken to muster all available facts and theories to the end that construction may be carried out in an expeditious and economical manner. All sources of accumulated information must be carefully explored. Books must be studied, plans and specifications for similar undertakings assembled and examined; statistics on rainfall, river discharge, earthquake, and other natural phenomena must be collected, compared, and analyzed; vital statistics must be analyzed, populations and commercial demands predicted, building materials must be sought and judged; manufacturers, merchants, builders, and workers must be consulted; and so on, through an endless list. This constitutes the first and usually the primary research activity of such a project, covering that part of the definition of the term which is designated as a "careful searching out."

Because man's collection of engineering data is incomplete, this search for known facts never yields information entirely adequate for the work to be done. There are inevitable gaps which must be bridged by "assumptions," or improved by a program of experimentation planned to reveal facts previously unknown or imperfectly understood. Such experimentation constitutes that phase of research designated as "experimentation and study directed toward the discovery of new facts or theories."

There is no distinct line of demarcation between these two types of research. The transition from pure book research, at one extreme, to pure experimental research at the other, is gradual. Also, there is much laboratory work that is for the purpose of testing for conformity with known laws and which, accordingly, is not original research. Here, again, the divsion between routine and research is not clearly drawn.

Original experimentation usually requires money, time, and ingenuity. Frequently, one or all three of these are lacking and the engineer must resort to approximations, using his best judgement and precedent as guides. There is always a tendency, under pressure for immediate action, to follow some established "rule of thumb," to save the time required to ascertain the facts, particularly in small matters where a large "factor of ignorance" can be provided at small cost. And it must be admitted that many engineers are bewildered by the thought of research.

As a project increases in magnitude, the need for original research and the opportunity for carrying it out increase. However, the practicing engineer is always under the handicap of having to show that money and effort invested in research will yield dividends on the work in hand, and usually experimentation can be carried only to the point required for this purpose. Increasing the store of human knowledge seldom can be advanced as an argument for increased appropriations.

Because of its magnitude and the special conditions involved, the Colorado River Aqueduct offered considerable opportunity for research, and a great deal of original work was done. Although directed primarily toward the "practical" purpose of solving immediate problems, important contributions to the store of engineering knowledge were made.

It would be impossible to list or describe all these accomplishments. Experimentation with a new type of mucking machine, a canal paver, or an "air washer" for sand, is just as truly research as is the study of more specifically scientific subjects. A large amount of such experimentation was carried on, and notable advances in the art of building were made. Passing by these very important achievements and ignoring an important mass of indivdually small investigations, a brief discussion will be presented of each of the following four principal research projects:

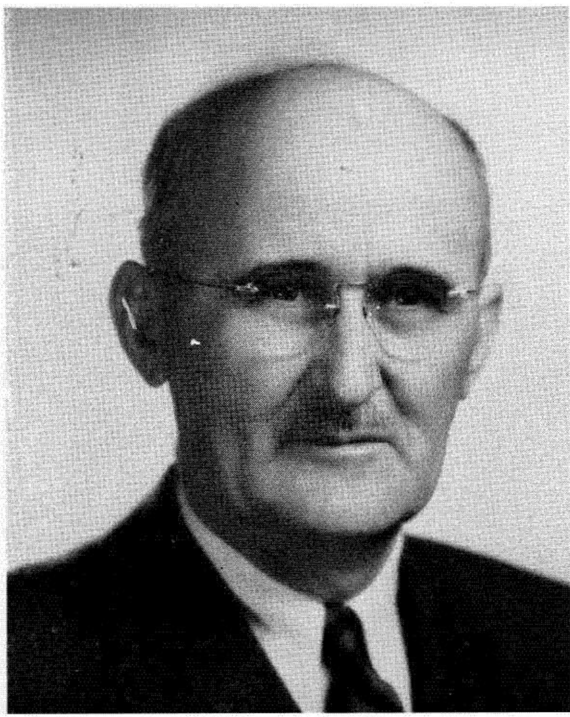
1. Cement composition and concrete manufacture.
2. Curing of concrete under desert conditions.
3. Investigation of pump charactersitics.
4. Study of water softening processes.

CEMENT COMPOSITION AND CONCRETE MANUFACTURE

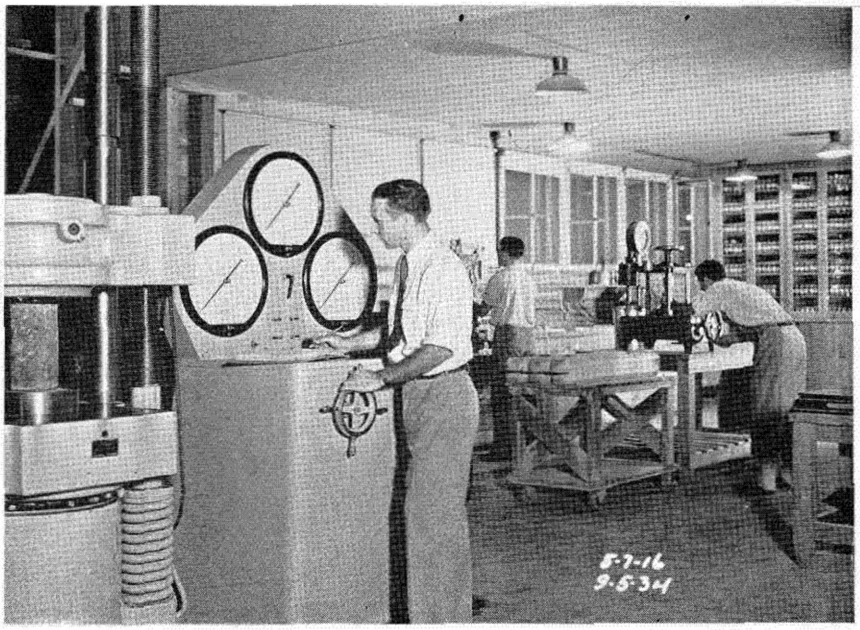
The aqueduct system, as planned, was to contain some five million cubic yards of concrete, requiring for its manufacture seven or eight million barrels of portland cement. This concrete was not to be concentrated in a single mass as in Boulder or Grand Coulee Dams, but was to be spread out in a long thin line across the desert. It needed to be enduring and water-tight to an unusual degree in spite of unfavorable manufacturing and curing conditions.

Concrete aggregates of usual types, i.e., well-worn river gravels, were available at the two ends of the line. At intermediate points, only the partially rounded products of local disintegration were available. It was important that these local materials be tested and used if possible.

Water for curing concrete was scarce. Temperature changes were excessive. It was essential that curing methods, and the cement itself, be adapted to desert conditions.



JULIAN F. HINDS



A view of some of the equipment included in the cement testing laboratory maintained by the Metropolitan Water District in Banning during the aqueduct construction period.

Accordingly, an extensive research program was inaugurated. A laboratory, unsually complete for a construction project, was set up at Banning, California. Cements from local mills were studied, also the materials available at these mills for the manufacture of cement. It was decided to investigate the possibility of utilizing a specially designed cement.

There is always grave danger in using an entirely new product on a project of great magnitude. Some unsuspected latent defect may cause disaster. Recognizing this, it was decided to work strictly within the limits of precedent. Standard specifications of the day for cement permitted great latitude in all variables. They were purposely designed to secure a generally passable product with materials from any section of the country, processed in a wide variety of plants. Although carrying the sanction of governmental and scientific organizations, specifications were largely influenced by manufacturing expediency. It was evident that by restricting tolerances designed to aid far-flung small manufacturers, a distinct improvement could be made with little if any increase in cost.

A series of special cement clinkers were made, covering permissible ranges in composition. These clinkers were ground to several specifications for fineness. Briquets, cylinders, bars, and slabs were made from the resulting cements, and tested for soundness, strength, hardness, density, resistance to alkali, expansion, contraction, resistance to freezing and thawing, curing qualities etc. All of the usual standard tests were made, and many more. Full-sized slabs were cast and cured in the desert, under actual field conditions.

Hundreds of 12-inch by 36-inch by 6-inch slabs were used in special weathering tests. Groups of 50 of these slabs were set up to constitute the walls of an accelerated weathering chamber, and the inside faces (the tops of the slabs as cast) were subjected to upwards of 100 cycles of the following treatment each 24 to 36 hours: Wet heat to 179° F., wet cold to 28° F.; dry heat to 175° F., and dry cold to 26° F. One group of 50 was water-cured in the laboratory at approximately 70° F. for 60 days, and dried for 30 days, before the accelerated weathering. Another group was composed of slabs cast outdoors near the laboratory, 20 in the form of walls (formed slabs cast on end) and 30 on subgrade; all exposed for seven months before the accelerated weathering. A third group was made up mostly from slabs which had been exposed one year in desert locations and included a few one-year laboratory control slabs.

These slab tests were made in addition to many hundreds of more conventional tests, and to other special tests for resistance to alkali action and weatherings.

The ultimate result was special "modified portland cement", promising superior performance under the anticipated conditions. The excellence of the resulting concrete structures amply justifies the test program.

Some of the primary conclusions reached are as follows:

1. Notably beneficial results were produced by limiting some of the theoretical compounds, notably C_3S and C_3A.

2. Pozzuolanic admixtures clearly were not indicated for exposed work in thin sections, as such admixtures accelerated drying, increased shrinkage, and reduced flexural strength. (This conclusion has no relation to the use of pozzuolan cements in more massive structures, and for more favorable curing conditions.)

3. Within the limits of commercial feasibility, fine grinding improved strength, resistance to abrasion, impermeability, workability in placing, and did not materially affect shrinkage.

4. The amount of mixing water per cubic yard of concrete (not per sack of cement) was the principal factor in volume change, particularly shrinkage in drying.

5. Resistance of concrete to disintegration by sodium sulphate in ground waters is most successfully obtained by use of cements with a special chemical composition. A special cement for this purpose was designed and used.

CURING OF CONCRETE UNDER DESERT CONDITIONS

Adequate water curing of concrete was difficult to attain because of extreme aridity and scarcity of water supply. Attention was turned to surface sealing materials, commonly known as curing compounds. There were many of these on the market. As little was known of the actual effectiveness of these materials under desert conditions, a system of testing was devised. Standard 6-inch by 12-inch concrete test cylinders were coated with the various preparations and exposed under actual field conditions. These specimens were carefully weighed from time to time, to determine water loss. They finally were broken for strength comparison with standard moist-cured cylinders. Also, curing tests were carried out on slabs poured and cured under field conditions.

Proprietary compounds, usually composed of asphalt, were found to be ineffectual in a single coat. Two coats gave better results but still did not fully meet the requirements. It was decided to test coal tar, which up to that time was not being offered for that purpose. The results were gratifying. Two coats of coal tar cut-back, the first applied to a freshly finished or freshly drenched concrete surface, gave strength superior to those obtained from standard laboratory water curing.

It is not to be inferred that products other than coal tar should never be used. In fact, the District has made frequent use of commercial products, particularly some of the "clear" coatings, in moderately exposed locations. However, coal tar is much more effective under extreme conditions than any other materials tried.

Coal tar, or any other black coating, has the objection of excessive absorption of solar heat, thus increasing the curing heat of the concrete and subsequent shrinkage. This led to a search for a cheap, light colored material. None was found which approached the curing effectiveness of coal tar. The idea of whitewashing the coal tar was tried. At first the tar ran through the whitewash, but after some experimentation, a formula was found which produced a two-coat job of surprising whiteness and permanence. Some of these coatings exposed to the weather for two or three years are still white.

It was found by test that maximum curing temperatures were 20 to 30 degrees less under whitewashed surfaces than under black surfaces.

The use of whitewash to control temperatures in all kinds of black pipes, during curing and shipping, has spread rapidly and is now in more or less general use throughout the country.

INVESTIGATION OF PUMP CHARACTERISTICS

The location finally selected for the Colorado River Aqueduct required a total lift of 1617 feet for a maximum flow of 1600 cubic feet per second. This lift was divided among five pumping plants with lifts ranging from 146 to 444 feet. General consideration of the practical size of pumps and motors that could be manufactured without departing too radically from established practice, and whose electrical characteristics would fit in best with the District's transmission system, resulted in the selection of 200 cubic feet per second as the nominal capacity of each pumping unit. The initial installation was three such units in each of the five pumping plants, with provision for additional units as the demand increases, up to the ultimate capacity of 1600 cubic feet per second.

No pump manufacturers in the United States had built pumps of the capacity and head required for the aqueduct plants, and there was consequently a great diversity in their recommendations as to the speed, type, head per stage, and inlet pressures. In view of the large power consumption involved and the saving in equipment and building costs possible with the use of higher speed, single stage pumps, it was decided to make a thorough experimental investigation into the efficiencies obtainable with different types of pumps. To this end the District made arrangements to construct a pump testing laboratory at the California Institute of Technology. The principal problems investigated in the laboratory were:

1. Whether the pumps should be the single suction or double suction type. This question materially affected the design and cost of the pumping stations.

2. The maximum practical head per stage for the higher head pumps. The Eagle Mountain and Hayfield stations required lifts in excess of 440 feet, and pump manufacturers were unanimous in recommending two stage pumps for this lift, which would have consisted of two separate pumping units in series. This problem affected materially the cost of the pumps and motors, as well as the size of the pump buildings, the control apparatus, and the arrangement of the water passages to and from the pumps.

3. The proper selection of rotative speed for the lifts at the various stations. The higher the speed the less cost of both pump and motor, but the greater the danger from cavitation and other possible operating difficulties. The question of speed is also closely tied to the proper location of the pump with reference to the inlet water level. The higher speeds require a deeper submergence below the inlet water level.

4. Investigation of the pump control valves and the behavior of the combination of pump and valves in the event of power failure or other emergency shut-downs.

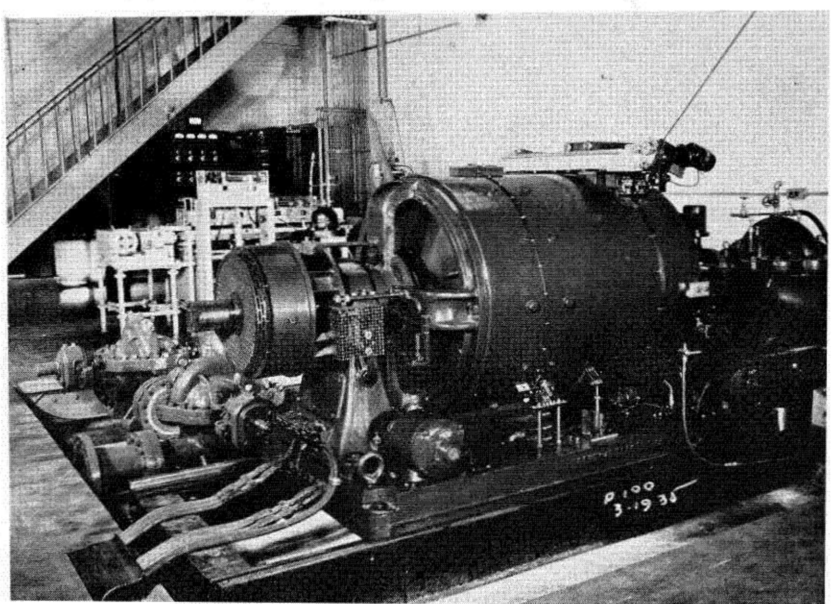
Prior to issuing specifications for aqueduct pumps, models of both single and double suction pumps specially constructed for the laboratory were purchased and completely tested. These pumps covered the entire range of heads and speeds recommended by the manufacturers and necessary for the pumping heads at the various plants. In addition to tests of the actual pumping perfomance, investigations were made with special apparatus of the distribution of pressures inside the pump cases. The results of this first series of tests showed that single suction single stage pumps would give satisfactory efficiencies at the higher heads required at Eagle Mountain and Hayfield, and that rotative speeds considerably higher than those originally recommended by the manufacturers were perfectly safe to use with a reasonable amount of submergence below inlet water level.

The investigation of internal pressures showed that with pumps of this size under certain operating conditions, there are very large unbalanced forces on the pump shafts so that in the final specifications much larger shafts were called for than contemplated in preliminary designs.

Each bidder submitted with his proposal a model pump which was tested at the laboratory to determine whether the guaranteed characteristics could be met. The successful bidders were required to construct somewhat larger models which were also completely tested in the laboratory, and the results made available to the manufacturers for their guidance in improving the performance and efficiency in the final design.

Other work done in the laboratory on both the preliminary and final pump models, was the investigation of pump performance under abnormal conditions of reverse flow which might be encountered during power outages. Direct and reverse flows through various types of shut-off valves were also investigated

Dynamometer and test pump used in experiments conducted at the California Institute of Technology in determining the type of pumps to be installed in the five pumping plants on the Colorado River Aqueduct.



and used in the selection of pump control valves, and the timing of valve operation.

As a measure of the value of this investigation by the District, a comparison has been made of the difference in costs for Eagle Mountain and Hayfield stations; first, using pumps of the heads and stages originally recommended by the leading pump manufacturers and which without laboratory research would undoubtedly have been used as a basis for the purchase of the pumping apparatus; and second, the cost of these stations using the single stage, higher speed pumps which the laboratory research demonstrated to be safe and satisfactory for these two plants.

Including the differences in building costs, pump and motor costs, cost of control valves and control switchboards, the saving due to the single stage, higher speed pumps for the initial installation of three pumps in each plant amounts to more than $900,000.

The total cost to the District of the construction of the pump testing laboratory and its operation for all of the tests required by the District, including consultants' fees, was $144,000.

Thus in the saving made possible on the initial installation alone, the research program was amply justified. As to the actual results in improved efficiencies, there is no such definite yardstick of measurement. Prior to the first pump tests, the maximum efficiencies that the manufacturers in general were willing to guarantee was 88 per cent. During the progress of the investigations, certain of the test pumps under favorable conditions showed efficiencies as high as 92½ per cent. The actual field acceptance tests of the completed pumps showed an average at all plants at 90½ per cent. This is a considerable increase over the 88 per cent originally estimated, and undoubtedly is due in large part to the research investigations.

STUDY OF WATER SOFTENING PROCESS

Colorado River water in its natural state is heavily laden with silt but is otherwise free from pollution. The silt is completely removed by sedimentation in the Boulder Canyon and Parker storage basins. The resulting water is clear but is charged to an undesirable extent with those dissolved solids which cause the quality known as hardness. This hard water is entirely satisfactory for drinking but is less desirable than soft water in the bathroom, laundry, and for industrial uses. Consequently, it is planned to remove a portion of the hardness.

Because of the large amount of water to be handled and the relative expense of the operation, it was considered desirable to thoroughly investigate available softening processes and their applicability to Colorado River water before attempting to design a plant.

Advantage was taken of the very complete small plant which was being operated by the U. S. Bureau of Reclamation at Boulder City, Nevada. The Bureau made all the facilities of this plant available for whatever type of test the District wished to carry out. Because the normal supply of the city could not be interfered with, auxiliary tanks and special equipment were required for many of the tests. The investigations covered the following primary points:

1. The feasibility of the reclamation of lime from the sludge produced during the water softening process;

2. The efficiency of various "sludge blanket" types of mixing and settling basins;

3. A comparison of the commercial zeolites available, and the conditions affecting their efficiency of operation; and

4. The use of barium compounds as softening agents instead of the usual chemicals.

LIME RECLAMATION

One of the principal chemicals used in the softening process is lime. Preliminary quotations indicated delivered costs of $9.00 to $10.00 per ton. The lime added as calcium hydroxide does not remain in the water but combines with calcium bicarbonate already present (one of the elements of hardness) and precipitates as calcium carbonate. Thus, for every pound of lime added to the water, approximately two pounds come out. This precipitate usually is wasted as a sludge. Attempts to reclaim the lime by calcining the sludge generally have been unsuccessful because of the incidental precipitation of other substances, particularly magnesium, which dilute the lime.

By careful study, a system of operation was devised by which a practically pure calcium carbonate could be precipitated. The composition of Colorado River water is favorable for this operation. Also, it was found practical to burn this sludge, producing lime at a fraction of commercial cost.

SLUDGE SETTLING BASINS

A large part of the expense of a water softening plant goes into the construction of settling basins, in which the precipitated solids are permitted to settle out. Notable success has been had in recent years with so-called "precipitators", in which the dosed and flocculated water is caused to bubble up through a blanket of previously deposited sludge. This process seems to speed up the chemical action and remove much of the precipitate by filter action, thus appreciably reducing the space required both for mixing and for sedimentation.

Although apparently efficient for many conditions, this type of clarifier was not found suitable for the District's plant.

COMPARISON OF ZEOLITES

Colorado River water is to be softened by the lime-zeolite process. The zeolite will be of the synthetic or manufactured type, with the exception of two companies, the manufacture of synthetic gel-type zeolite in this country has been developed only recently. As a result, very little reliable information was available on the performance of the various makes of zeolite produced. More or less extravagant claims were made by the various companies as to the excellence of their products. Careful investigation showed little difference in the operating characteristics of several of the leading brands. On the basis of these investigations, the strong arguments put forth by the old-line companies about the poor quality or lack of background of the newcomers could be given proper weight in evaluating bids. As a result, the District purchased 27,000 cubic feet of zeolite at less than $4.00 per cubic foot, instead of about $12.00 which was the price previously quoted for such material.

STUDY OF BARIUM COMPOUNDS

Water is usually softened either by the lime-zeolite process or by the excess lime-soda ash process. In these processes, the lime that combines with the calcium bicarbonate in the water

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AQUEDUCT RESEARCH

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effects a straight subtraction, i.e., it actually reduces the mineral content of the water. This is a desirable procedure; also, lime is cheaper than the other softening agents. However, certain hardness-forming compounds cannot be removed by lime but require the use of zeolite or soda ash. These agencies soften by base-exchange, i.e., they remove the hardness compound but leave another in its place.

Theoretically, barium acts on other hardness compounds in much the same way that lime acts on calcium bicarbonate, and effects a straight subtraction. Because of its cost, its suitability for large-scale water softening never has been developed. Large deposits of this mineral are available within reasonable distance of Los Angeles and it was thought possible that its use might be justified. However, a series of tests indicated that much development work will be required before large-scale use of barium for water softening is practical, if indeed it ever is.

All of the investigations described were carried out under the direction of F. E. Weymouth, General Manager and Chief Engineer of the Metropolitan Water District of Southern California.

L. H. Tuthill, Testing Engineer, was in charge of cement, concrete, and curing compounds studies, working with Professor Raymond E. Davis, of the University of California, as a consultant.

The pump tests were carried out by J. M. Gaylord, Chief Electrical Engineer, and R. M. Peabody, Mechanical Engineer, in collaboration with Professors Theodor von Karman and Robert L. Daugherty of the California Institute of Technology. Dr. W. F. Durand was consultant.

The water softening experiments were carried out by W. W. Aultman, '27, Engineer, with the assistance of Messrs. Charles P. Hoover and James M. Montgomery, consultants.

AIR TRANSPORT PROSPECTS

(Continued from page 5)

such occurrences are eliminated. It is encouraging that the means of achieving almost 100 per cent schedule completion are at hand. It will probably take a number of years of peace time development to realize this goal, but the post-war decade will certainly see the airlines moving at any time when ground transportation is moving, and at times when trains and busses are stalled.

The year 1940 saw passenger air traffic up 64 per cent over 1939. Nearly a million more revenue passengers were carried, one-third more miles were flown, and a third more express was carried. Likewise, 1939 had seen similar gains over 1938. This phenomenal growth took place in a period when the attention of research and development groups was diverted to military needs, and therefore gives only a hint of what may be expected from the post-war era.

The air transport industry is hardly out of the adolescent stage. It will attain maturity when it realizes economy, safety and reliability that are the equal of any other means of transportation. These assets are now coming within reach. Speed, air travel's basic inherent advantage, is an ace in an off suit. Only when the trumps have been led will its real value become apparent.

ALUMNI SEMINAR

(Continued from page 15)

Naval Base on Terminal Island" by Professor F. J. Converse, and on "Earthquake Forces in Terms of Design Factors" by Professor R. R. Martel.

Electrical Engineering — meeting presided over by Professor Royal W. Sorensen; discussions by Wendel Morgan '33 on the stability limits of a transmission line, and on "Dynamic Mechanical and Electrical Measurements by Means of a Recording Oscillograph" by George W. Downs.

Geology — discussion led by Professor Ian Campbell with reviews of current research projects; talks by Professor Horace J. Fraser on "The Effect of the National Defense Program on the Mining Industry," by Professor J. P. Buwalda on "Engineering Geology," by Clay T. Smith '38 on "The Chromite Deposits of the Western States, and by Professor Robert M. Kleinpell and Willis Popenoe, Ph.D. '36, on the progress of petroleum exploration in the Philippine Islands.

Humanities — Inspection of the art treasures of the Huntington Library as a sequel to the earlier lecture by Professor Macarthur.

Industrial Relations — meeting led by Professor Robert D. Gray; talks by representative personnel directors in California industries, including Cassius Belden of the Union Oil Company and Robert C. Storment of Lockheed Aircraft Corporation, on the subject of "Validity of Testing Techniques in Personnel Work."

Mechanical Engineering — meeting presided over by Professor Robert I. Daugherty; talks on "Vibration Damping in Metals" by Donald Hudson '38, "Methods and Results of Refrigeration of Quick-Frozen Foods" by Regis Gubser '27, and "Problems in Mounting of the 200-Inch Telescope" by Mark Serrurier '26.

Physics — seminar led by Professor Earnest C. Watson; lectures by Dr. Maurice F. Hasler '29, Ph.D. '33, on "Spectographic Analysis of Materials," and by Professor William V. Houston on "The Electron Microscope."

SUNDAY PROGRAM

Address, "Propoganda Three Centuries Ago and Today," by Kermit Roosevelt, Jr., dealing with the techniques and comparative effectiveness of propaganda today and in the time of Cromwell.

Address, "Some Problems in Modern Astronomy," by Dr. John A. Anderson, covering some of the major problems in astronomy and astrophysics which are currently being pursued by local and other scientists.

Address, "The Economic Consequences to America of a Totalitarian Victory," by Dr. Edwin F. Gay, Institute Associate in Economic History and former Dean of the Harvard Graduate School of Business Administration — a description of the government-controlled barter system employed by Germany in international trade, and an analysis of the problems that may be in store for us.

Address, "Synthetic Gasoline, Rubbers, Resins, and Plastics," by Professor Howard J. Lucas — discussion of polymerization reactions and their relation to modern industrial development and the national defense program.