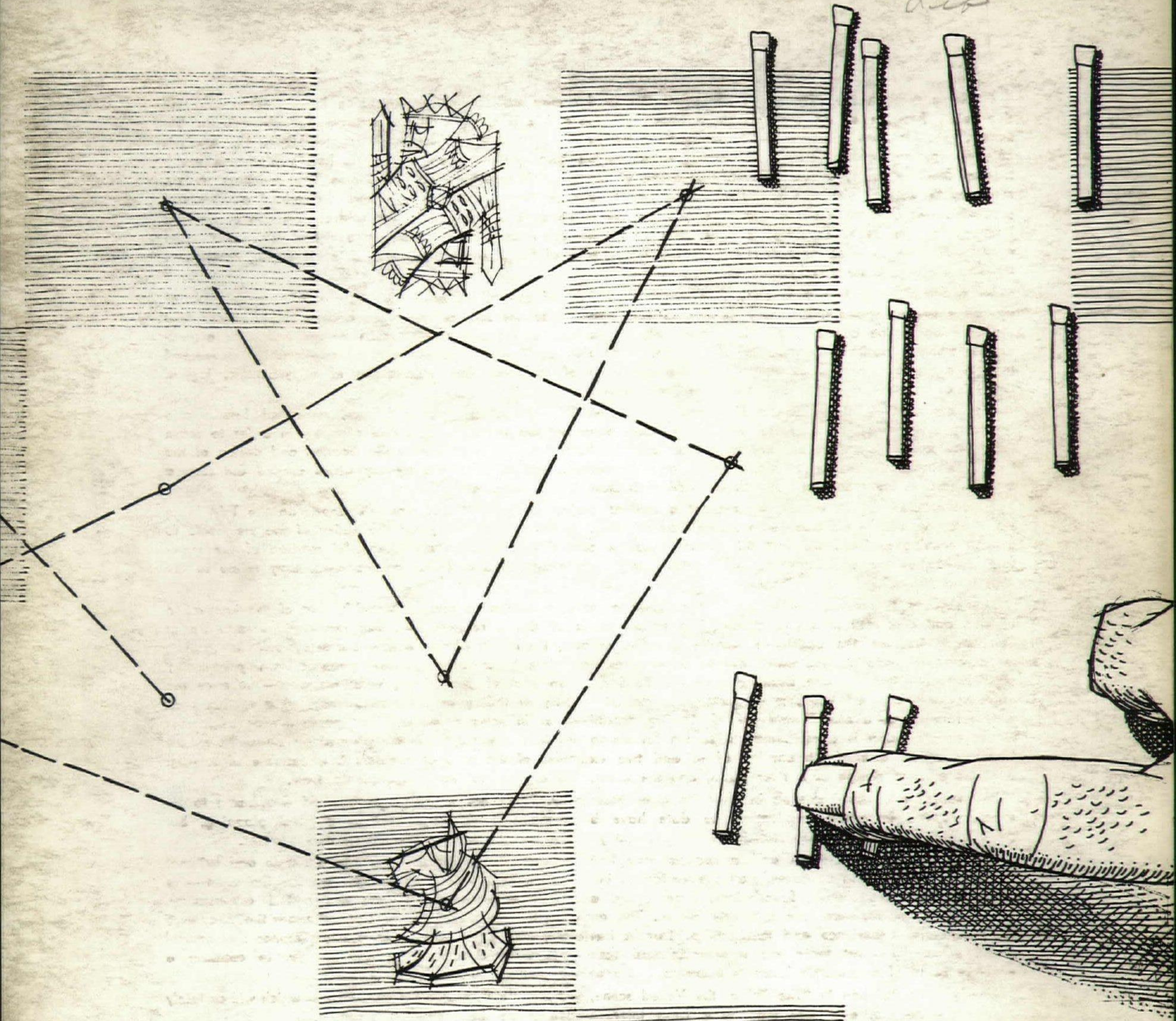

STUDENT PUBLICATIONS
THE SCHOOL OF DESIGN

NORTH CAROLINA STATE COLLEGE
RALEIGH, N. C. VOLUME 7 NO. 2

Glancing through the contents of this issue, the reader may wonder if this magazine has forsaken in some degree its function as an architectural publication. One article is concerned with a theory of bureaucratic behavior, another with a discussion of bridges of various lengths, a third with a new approach to the analysis of painting, and yet another with mathematical models and systems analysis. This is hardly standard architectural fare. In reply, it can be said that many of the most important problems facing the architect, if we mean by "architect" one who would alter and add to our physical evironment, are hardly standard architectural problems. The day when the definition of architecture could be limited to the design and construction of isolated buildings or groups of buildings is long since past. The consequences of action in our complex world have become far too ramified to safely neglect the major part of them. As Kennedy puts it in his paper, component thinking must give way to systems thinking.

As the architect is forced to expand his traditional field of action, he becomes aware that past methods of operation are inadequate. Not only do the possible combinations of physical materials become so numerous that the selection of the best is nearly impossible, but the actions and reactions of human beings and their organizations become positive elements in the design. A careful study of the organizational relationships developed in such a planning project as the TVA, and a discussion of some of the potentialities of a systematic, logical analysis of complex problems, does not seem out of place.

We look at the finished results of a project such as TVA—the dams, power houses, replanted forests—and are very much impressed. But to understand more than just the visual surface, and certainly in order to learn for future action, we must ask not only what are the limitations which determine the location and design of the dams, but what were the political, social and bureacratic limitations of the agency which carried out such a scheme. This is the theme of Selznick in "TVA and Democratic Planning".

As an adjunct to this article, we present a student project for a system of worker's resorts on the TVA lakes which was entered in the Sao Paulo competition of 1955. While it is generally not the policy of the magazine to publish specific projects, we feel this demonstrates a careful consideration and successful solution of the manifold aspects of the problem—those of function, materials, construction and the landscape—as they relate to the TVA area.

Kennedy, in "Mathematical Models", is tackling a problem similar to that of Selznick, that of the interaction of men and men and men and machines in certain types of simple relationships. The relationships must be at first simple because the attempt is not to describe verbally the results of past action, but to construct a symbolic model of these relationships which will be capable of predicting their consequences given certain preliminary conditions. Mathematics can never answer the hard question—that of determining what we want—but once the objectives are decided upon, mathematics has the potentiality of telling us the consequences of a certain plan with reference to a complicated set of limiting conditions, or in some cases, the best possible plan to follow. Linear programming is a mathematical device for doing just this. We present in the way of an appendix to the Kennedy article a brief explanation of it, and two examples of the type of problem it is capable of solving: one, the efficient design of a river basin, and the other, the analysis of an indeterminate truss.

The use of mathematical tools in planning is in its infancy. There are many difficulties and drawbacks to be overcome. The important applications to date have been made outside the field of physical planning, but there is little doubt that these techniques will eventually prove invaluable to the architect and planner.

Torroja's article on bridges and aqueducts may have special interest for designers. In a simple and brilliant manner, Torroja carries us through all the variations in the form and nature of bridges as the limitations—the span, live and dead loads, foundations, topography, and materials—change. Bridges are naked constructions whose functional problems are relatively simple. The designer, therefore, has very precise limitations that challenge his knowledge, experience and imagination. Torroja has done, with the benefit of his long experience and careful study, essentially what these recent mathematical techniques were developed to do: namely, to consider a problem in all of its possible forms in order to arrive at the best possible solution.

Finally, Fritz Bultman in "The Thing, the Veiled scene, and the Wall", presents three concepts which will certainly stimulate discussion, and may lead to a fresh interpretation of the many styles of painting.

THE EDITORS

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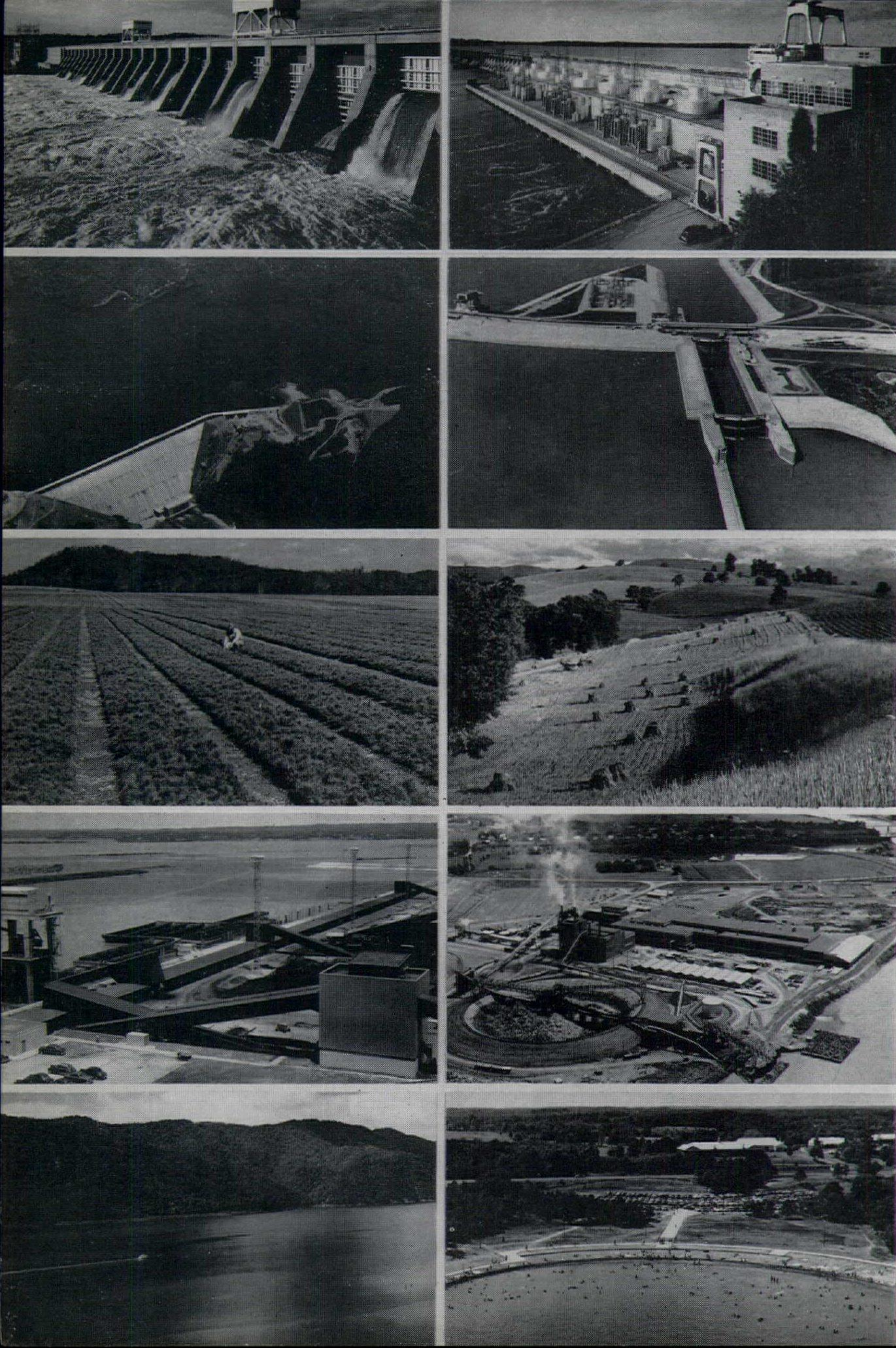


TVA

and

DEMOCRATIC

PLANNING

Philip Selznick

Reprinted from Mr. Selznick's book *TVA and Grass Roots*, published by the University of California Press, Berkeley, California.

The photographs illustrate the various functions of TVA: power, flood control, navigation, land development, industry, recreation.

"In this country we are very vain of our political institutions, which are singular in this, that they sprung, within the memory of living men, from the character and condition of the people, which they still express with sufficient fidelity . . ."

EMERSON

Whatever the ultimate outcome, it is evident that modern society has already moved rather far into the age of control. It is an age marked by widening efforts to master a refractory industrial system. That a technique for control will emerge, that there is and will be planning, is hardly in question. What is more doubtful is the character and direction of the new instruments of intervention and constraint. For these have been born of social crisis, set out piecemeal as circumstances have demanded; they have not come to us as part of a broad and conscious vision. As a consequence, the foundations of a clear-cut choice between totalitarian and democratic planning have not been adequately laid; nor has the distinction been altogether clear between planning directed toward some acceptable version of the common good and planning for the effective maintenance of existing and emerging centers of privilege and power.

Democracy has to do with means, with instruments, with tools which define the relation between authority and the individual. In our time, new and inescapable tasks demand a choice among available means within the framework of increased governmental control. It is therefore especially important to examine those organizations which are proposed as contributions to the technique of democratic planning. An example of such a proposed contribution is the Tennessee Valley Authority.

On June 25, 1942, *The Times* (London) published a brief review of TVA under the heading "The Technique of Democratic Planning." *The Times* correspondent reported that he was impressed by the physical accomplishments of dam and power plant construction, but what interested him most was "the technique which the TVA had adopted with the deliberate aim of reconciling overall planning with the values of democracy." Here *The Times* reflected what many feel to be the enduring significance of this much discussed government agency. The theme of democracy in government administration was also prominent in a widely distributed book, *TVA: Democracy on the March,* written by David E. Lilienthal, and in numerous speeches and pamphlets emanating from the Authority. In addition, much of the comment friendly to the agency has stressed its contribution to a new synthesis, one which would unite positive government—the welfare or service state—with a rigorous adherence to the principles of democracy.

What is this organization which is thought to embody an ideal so eagerly sought? What is the nature of this democratic technique? What are its implications and consequences? What will a close and critical study of the organization in action tell us about these problems? These questions have yet to be satisfactorily answered. To seek a partial answer, a study was undertaken, during 1942-1943, with attention focused primarly upon the Authority's "democratic" or "grass roots" method. This inquiry was based upon the assumption that no prior personal commitment to the TVA as a political symbol ought to interfere with a realistic examination. It was an inquiry which did not hesitate to seek out informal and unofficial sources in information. And it began with certain ideas about the nature of the administrative process which seem helpful in uncovering the underlying forces shaping leadership and policy.

The Origin and Program of the TVA

The TVA Act as finally approved was a major victory for those who favored the principle of government operation. The Muscle Shoals investment was to remain in public ownership, and this initial project was to be provided with new goals and to be vastly extended. A great public power project was envisioned, mobilizing the "by-product" of dams built for the purpose of flood control and navigation improvement on the Tennessee River and its tributaries. Control and operation of the nitrate properties, to be used for fertilizer production, was also authorized, although this aspect was subordinated in importance to electricity. These major powers—authority to construct dams, deepen the river channel, produce and distribute electricity and fertilizer—were delegated by Congress to a corporation administered by a three-man board of directors.

If this had been all, the project would still have represented an important extension of government activity and responsibility. But what began as, and what was generally understood to be, primarily the solution of a problem of fertilizer and power emerged as an institution of far broader meaning. A new regional concept—the river basin as an integral unit—was given effect, so that a government agency was created which had a special responsibility, neither national nor state-wide in scope. This offered a new dimension for the consideration of the role of government in the evolving federal system. At the same time, the very form of the agency established under the Act was a new departure. There was created a relatively autonomous public corporation free in important aspects from the normal financial and administrative controls exercised over federal organs. Further, and in one sense most important, a broad vision of regional resource development—in a word, planning, informed the conception, if not the actual powers, of the new organization.

The Message of the President requesting the TVA legislation did much to outline that perception: "It is clear," wrote Mr. Roosevelt, "that the Muscle Shoals development is but a small part of the potential public usefulness of the entire Tennessee River. Such use, if envisioned in its entirety, transcends mere power development: it enters the wide fields of flood control, soil erosion, afforestation, elimination from agricultural use of marginal lands, and distribution and diversification of industry. In short, this power development of war days leads logically to national planning for a complete river watershed involving many States and the future lives and welfare of millions. It touches and gives life to all forms of human concerns." To carry out this conception, the President recommended "legislation to create a Tennessee Valley Authority—a corporation clothed with the power of government but possessed of the flexibility and initiative of private enterprise. It should be charged with the broadest duty of planning for the proper use, conservation, and development of the natural resources of the Tennessee River drainage basin and its adjoining territory for the general and economic welfare of the Nation."

This special regional focus and broad scope of the project have given it a character which reflects one of the major motifs of our time: the need for some sort of integral planning, especially in key problem areas. It is that character which has been caught up as a model for similar projects in other areas. For the uniqueness of TVA is not that it is a government-owned power business or conservation agency, but that it was given some responsibility for the unified development of the resources of a region.

Yet it must be said that although the agency and its program have symbolized concentrated effort and planning, the TVA has had little direct authority to engage in large-scale regional planning. The powers delegated to it were for the most part specific in nature, related to the primary problems of flood control, navigation, fertilizer, and power. In addition, authority to conduct studies and demonstrations of a limited nature, but directed toward general welfare objectives, was delegated to the President and by him to the Authority. This became the basis for some general surveys and demonstration work in forestry, local industrial development, community planning and for work with cooperatives.

More important, however, is that the Act permitted such discretion in the execution of the primary purposes as would invite those in charge to recognize the social consequences of specific activities—such as the effect upon farm populations and urban communities of the creation of large reservoirs—and to assume responsibility for them. This assumption of responsibility invests the administration with an important planning function, though it is indirect and remains modifiable as circumstances may demand. In addition, there remained administrative freedom to devise methods of dealing with local people and institutions which would reflect the democratic process at work. Perhaps of equal importance is that the idea of planning associated with TVA accords this agency a central status in the consideration of the problems and the future of the Tennessee Valley region.

In the light of this weak delegation of broad planning powers, and the tendency of Congress to restrict developmental functions, it is probable that the significance of TVA in relation to democratic planning comes primarily from the infusion of specific tasks with a sense of social responsibility. In the purchase of lands, in the distribution of fertilizer and power, in personnel policy—in those functions which are a necessary part of the execution of its major and clearly delegated responsibilities—the TVA has normally taken account of the people of the area, with a view to adjusting immediate urgencies to long-term social policy. This, of course, is not the same as devising and executing a frontal plan for the reconstruction of the economy or institutions of an area. And yet, whichever view is emphasized—whether one conceives of TVA's limited regional planning as a portent of fuller ventures along that line, or whether one thinks of planning as simply an adjunct of specific responsibilities—we have something to learn from a study of the organization itself and of the methods developed in the execution of its tasks.

The Importance of Method in a Democracy

"Organization" and "method" are key words. Wherever we turn in considering the implications of a program for democracy these terms are inevitably involved. No democratic program can be unconcerned about the objectives of a course of action, especially as they affect popular welfare. But the crucial question for democracy is not what to strive for, but by what means to strive. And the question of means is one of what to do now and what to do next—and these are basic questions in politics.

If the problem of means is vital, it is also the most readily forgotten. "Results," "achievement," and "success" are heady words. They induce submission and consent, thus summoning rewards for diligence and labor—and they also enfeeble the intellect. For the results which most readily capture the imagination are external, colorful, concrete. They are the stated goals of action. Their achievement lends reality, wholesomeness, and stature to the enterprise as a whole.

But methods are more elusive. They have a corollary and incidental status. A viable enterprise is sustained in the public eye by its goals, not its methods. Means are variable and expedient; their history is forgotten or excused. Here again the concrete and colorful win easiest attention. Where incorrect methods leave a visible residue—a rubbled city or wasted countryside—then methods may gain notice. But those means which have long-run implications for cultural values, such as democracy, are readily and extensively ignored.

When we speak of methods, we speak in the same breath of instruments. Policies, decisions as to "how to proceed" require execution. Execution in turn implies a technology. We are familiar with the kind of technology which includes machines and tools of all sorts, handled and manipulated in more or less obvious ways. We are even reasonably familiar with the technology of economic and military organization, geared to the achievement of technical objectives, qualified and informed by the criteria of efficiency. But when we move into that area of technology which is related to the creation, defense, or reintegration of values, such as democracy, we find ourselves less assured. Yet the significance of this noneconomic technology, under the conditions of mass society and cultural disintegration, is of primary importance for whatever we may wish to do about that vague but demanding reality which we call our "way of life." Propaganda agencies, mass parties, unions, educational systems, churches, and governmental structures have a common aspect in that, more or less directly, they work upon and seriously affect the evolving values, the spirit, of contemporary society. Furthermore, there is a growing tendency for this effect to be conscious, to become an ordered technology available to those who have a stake in changing sentiment or social policy.

One of the pervasive obstacles to the understanding and even the inspection of this technology, is ideology or official doctrine. By the very nature of their function, all those forces which are concerned about the evolution of value-impregnated methods, or public opinion itself, have a formal program, a set of ideas for public consumption. These ideas provide a view of the stated goals of the various organizations—political or industrial democracy, or decentralization, or the like—as well as of the methods which are deemed crucial for the achievement of these goals. It is naturally considered desirable for the attention of observers to be directed toward these avowed ideas, so that they may receive a view of the enterprise consistent with the conception of its leadership. All this in the often sincere conviction that precisely this view is in accord with the realities of the situation, and best conveys the meaning and significance of the project under inspection.

However much we may be impressed by what a group says about its methods or its work, there is adequate justification for uneasiness and doubt. This doubt has its source in our general understanding of the persistent tendency for words to outrun deeds, for official statement and doctrine to raise a halo over the events and activities themselves. That this is a natural disposition among responsible men is well understood, and a gap of some sort between the idea and the act is normally expected. But what is less well understood, or at least less generally applied to objects of public esteem, is the tendency for ideas to reflect something more than enthusiasm or more or less pardonable pride. The functions of a doctrine may be more subtle and more significant, related to the urgent needs of leadership and to the security of the organization itself. Such functions, when relevant, cast a deeper shadow and indicate the need for more searching questions.

Though official statements and theories are important, an undue concentration upon what men say diverts attention from what they do. This is especially true with respect to the methods utilized in the execution of a program, for these are particularly difficult to view realistically. It is often sufficiently troublesome to attain a clear picture of the formal, stated methods in use, without pressing inquiry as to the less obvious but vital informal behavior and its significance for evolving structures and values that we must move if this kind of inquiry is to realize its possibilities.

In searching out organizational behavior and problems as keys to understanding the implications of TVA for democratic planning, we are entering a field of inquiry which probes at the heart of the democratic dilemma. If democracy as a method of social action has any single problem, it is that of enforcing the responsibility of leadership or bureaucracy. A faith in majorities does not eliminate the necessity for governance by individuals and small groups. Wherever there is organization, whether formally democratic or not, there is a split between the leader and the led, between the agent and the initiator. The phenomenon of abdication to bureaucratic directorates in corporations, in trade unions, in parties, and in cooperatives is so widespread that it indicates a fundamental weakness of democracy. For this trend has the consequence of thrusting issues theoretically decided by a polity into the field of bureaucratic decision.

The Problem of Bureaucratic Organization

The term "bureaucracy" has an invidious connotation, signifying arbitrary power, impersonality, red tape. But if we recognize that all administrative officials are bureaucrats, the bishop no less than the tax collector, then we may be able to understand the general nature of the problem, separating it from the personal qualities or motives of the individuals involved. Officials, like other individuals, must take heed of the conditions of their existence. Those conditions are, for officials, organizational: in attempting to exercise some control over their own work and future, they are offered the opportunity of manipulating personnel, funds, and symbols. Among the many varied consequences of this manipulation, the phenomena of inefficiency and arbitrariness are ultimately among the least significant. The difference between officials and ordinary members of an organized group is that the former have a special access to and power over the machinery of the organization; while those outside the bureaucratic ranks lack that access and power.

If we are to comprehend these bureaucratic machines, which must play an indispensable role in any planning venture, it is essential to think of an organization as a dynamic conditioning field which effectively shapes the behavior of those who are attempting to remain at the helm. We can best understand the behavior of officials when we are able to trace that behavior to the needs and structure of the organization as a living institution.

The important point about organizations is that, though they are tools, each nevertheless has a life of its own. Though formally subordinated to some outside authority, they universally resist complete control. The use of organizational instrumentalities is always to some degree precarious, for it is virtually impossible to enforce automatic response to the desires or commands of those who must employ them. This general recalcitrance is recognized by all who participate in the organizational process. It is this recalcitrance, with its corollary instability, which is in large measure responsible for the enormous amount of continuous attention which organizational machinery requires. There are good reasons, readily grasped, for this phenomenon.

The internal life of any organization tends to become, but never achieves, a closed system. There are certain needs generated by organization itself which command the attention and energies of leading participants. The moment an organization is begun, problems arise from the need for some continuity of policy and leadership, for a homogeneous outlook, for the achievement of continuous consent and participation on the part of the ranks. These and other needs create an intricate system of relationships and activities, formal and informal, which have primarily an internal relevance. Thus leadership is necessarily turned in upon itself. But at the same time, no organization subsists in a vacuum. Large or small, it must pay some heed to the consequences of its own activities (and even existence) for other groups and forces in the community. These forces will insist upon an accounting, and may in self defense demand a share in the determination of policy. Because of this outside pressure from many varied sources, the attention of any bureaucracy must be turned outward, in defending the organization against possible encroachment or attack.

These general considerations, which have been stated here in a summary way, should lead to a more discerning study of any administrative agency. They direct us: (1) to seek the underlying implications of the official doctrine of the agency, if it has one; (2) to avoid restriction to the formal structure of the organization, as that may be outlined in statutes, administrative directives, and organization charts; and (3) to observe the interaction of the agency with other institutions in its area of operation. Throughout, a search for the internally relevant in organizational behavior, especially that which is related to self-defensive needs, is a primary tool of such analysis.

It will probably bear emphasis that the significance of TVA for democratic planning lies not so much in its program, or in its accomplishments, as in its methods and in its nature as an organization. Even though its planning powers are limited, the TVA does represent an experiment, an adventure in executing broad social responsibilities for the development of a unified area. Furthermore, its type of organization is proffered as a model for governmental planning in other areas. This point has been clearly recognized with TVA itself:

"Few of the activities of TVA are unique as public responsibilities. The Government of the United States has been constructing waterways and building works for flood control for more than a century. State and Federal agencies have engaged in technical research, and surveys of mineral and forestry resources have been carried on with public funds for many years. The TVA is not the first instance in which the Federal Government has sold electric power. Aid to, and stimulation of business opportunities in industrial development, employment, farming, and other fields has become a familiar role of Government, State and National.

It is in the integration and the correlation on a regional basis of these various activities under a single, unified management that the Tennessee Valley Authority represents a pioneer undertaking of government. For the first time a President and Congress created an agency which was directed to view the problems of a region as a whole."[1] If the power granted to the Authority was not sufficient fully to execute that broad responsibility, still the vision has remained. It is the conception of an administrative instrument created to fulfill necessary planning functions within the framework of democratic values.

If TVA as instrument is the focus of attention, and if we are prepared to think of the Authority as a living social organization, we may expect that in one way or another the Authority will have been caught up in and shaped by its institutional environment. This expectation becomes especially relevant as we note (1) the TVA's official avowal of a special democratic relation to certain local institutions "close to the people," a doctrine which will be discussed in detail below; and (2) that TVA did not arise out of the expressed desires of the local area, and consequently was faced with a special problem of adjustment. Each of these points lends weight to the anticipation that in the Authority's relation to its own grass-roots we may find significant material of general interest to those who wish to learn the lessons of the TVA experience.

Theory of Bureaucratic Behavior

Given such an anticipation, the problem for this inquiry became one of finding a significant vantage point from which to examine this grass-roots relationship. The question thus posed required some sort of theory, a set of ideas which could point a way to the most vital aspects of the situation. The theory which seemed to make sense in the light of a general understanding of the materials was so formulated as to bring together in a single over-all analysis: (1) the avowed contribution of TVA to democratic planning, through a grass-roots method of executing its responsibilities; (2) the self-defensive behavior of the organization as it faced the need to adjust itself to the institutions of its area of operation; (3) the consequences for policy and action which must follow upon any attempt to adjust an organization to local centers of interest and power. Put in a few words, this involved the hypothesis that the Authority's grass-roots policy as doctrine and as action must be understood as related to the need of the organization to come to terms with certain local and national interests; and that in actual practice this procedure resulted in commitments which had restrictive consequences for the policy and behavior of the Authority itself.

In order to handle this problem most effectively, it has been found necessary to intro-

[1] "The Widening of Economic Opportunity through TVA," pamphlet adapted from an address by David E. Lilienthal, Director, TVA, at Columbia University, New York, N. Y., January, 1940 (Washington: Government Printing Office, 1940), p. 15.

duce a concept which, while not new, is somewhat unfamiliar. This is the idea of "cooptation" [2]—often the realistic core of avowedly democratic procedures. To risk a definition: "cooptation is the process of absorbing new elements into the leadership or policy-determining structure of an organization as a means of averting threats to its stability or existence." With the help of this concept, we are enabled more closely and more rigorously to specify the relation between TVA and some important local institutions and thus uncover an important aspect of the real meaning and significance of the Authority's grass-roots policy. At the same time, it is clear that the idea of cooptation plunges us into the field of bureaucratic behavior as that is related to such democratic ideals as "local participation."

Cooptation tells us something about the process by which an institutional environment impinges itself upon an organization and effects changes in its leadership, structure, or policy. Cooptation may be formal or informal, depending upon the specific problem to be solved.

Formal cooptation. When there is a need for the organization to publicy absorb new elements, we speak of formal cooptation. This involves the establishment of openly avowed and formally ordered relationships. Appointments to official posts are made, contracts are signed, new organizations are established—all signifying participation in the process of decision and administration. There are two general conditions which lead an organization to resort to formal cooptation, though they are closely related:

1. When the legitimacy of the authority of a governing group or agency is called into question. Every group or organization which attempts to exercise control must also attempt to win the consent of the governed. Coercion may be utilized at strategic points, but it is not effective as an enduring instrument. One means of winning consent is to coopt into the leadership or organization elements which in some way reflect the sentiment or possess the confidence of the relevant public or mass and which will lend respectability or legitimacy to the organs of control and thus reestablish the stability of formal authority. This device is widely used, and in many different contexts. It is met in colonial countries, where the organs of alien control reaffirm their legitimacy by coopting native leaders into the colonial administration. We find it in the phenomenon of "crisis-patriotism" wherein normally disfranchised groups are temporarily given representation in the councils of government in order to win their solidarity in a time of national stress. Cooptation has been considered by the United States Army in its study of proposals to give enlisted personnel representation in the courts-martial machinery—a clearly adaptive response to stresses made explicit during World War II. The "unity" parties of totalitarian states are another

[2] With some modifications, the following statement of the concept of cooptation is a repetition of that presented in the author's "Foundations of the Theory of Organization," AMERICAN SOCIOLOGICAL REVIEW, XIII, I (February, 1948), pp. 33-35. For further discussion of cooptation see below, pp. 259-261.

form of cooptation; company unions or some employee representation plans in industry are still another. In each of these examples, the response of formal authority (private or public, in a large organization or a small one) is an attempt to correct a state of imbalance by formal measures. It will be noted, moreover, that what is shared is the responsibility for power rather than power itself.

2. When the need to invite participation is essentially administrative, that is, when the requirements of ordering the activities of a large organization or state make it advisable to establish the forms of self-government. The problem here is not one of decentralizing decision but rather of establishing orderly and reliable mechanisms for reaching a client public or citizenry. This is the "constructive" function of trade unions in great industries where the unions become effective instruments for the elimination of absenteeism or the attainment of other efficiency objectives. This is the function of self-government committees in housing projects or concentration camps, as they become reliable channels for the transmission of managerial directives. Usually, such devices also function to share responsibility and thus to bolster the legitimacy of established authority. Thus any given act of formal cooptation will tend to fulfill both the political function of defending legitimacy and the administrative function of establishing reliable channels for communication and direction.

In general, the use of formal cooptation by a leadership does not envision the transfer of actual power. The forms of participation are emphasized, but action is channeled so as to fulfill the administrative functions while preserving the locus of significant decision in the hands of the initiating group. The concept of formal cooptation applies primarily in the analysis of TVA's relation to the voluntary associations established to gain local participation in the administration of the Authority's programs.

Informal cooptation. Cooptation may be, however, a response to the pressure of specific centers of power within the community. This is not primarily a matter of the sense of legitimacy or of a general and diffuse lack of confidence. Legitimacy and confidence may be well established with relation to the general public, yet organized forces which are able to threaten the formal authority may effectively shape its structure and policy. The organization faced with its institutional environment, or the leadership faced with its ranks, must take into account these outside elements. They may be brought into the leadership or policy-determining structure, may be given a place as a recognition of and concession to the resources they can independently command. The representation of interests through administrative constituencies is a typical example of this process. Or, within an organization, individuals upon whom the group is dependent for funds or other resources may insist upon and receive a share in the determination of policy. This type of cooptation is typically expressed in informal terms, for the problem is not one of responding to a state of imbalance with respect to the "people as a whole" but rather one of meeting the pressure of specific individuals or interest groups which are in a position to enforce demands. The latter are interested in the substance of power and not necessarily in its forms. Moreover, an open acknowledgment of capitulation to specific interests may itself undermine the sense of legitimacy of the formal authority within the community. Consequently, there is a positive pressure to refrain from explicit recognition of the relationship established. This concept applies in analyzing the underlying meaning of certain formal methods of cooperation initiated in line with the TVA's grass-roots policy.

Cooptation reflects a state of tension between formal authority and social power. This authority is always embodied in a particular structure and leadership, but social power itself has to do with subjective and objective factors which control the loyalties and potential manipulability of the community. Where the formal authority or leadership reflects real social power, its stability is assured. On the other hand, when it becomes divorced from the sources of social power its continued existence is threatened. This threat may arise from the sheer alienation of sentiment or because other leaderships control the sources of social power. Where a leadership has been accustomed to the assumption that its constituents respond to it as individuals, there may be a rude awakening when organization of those constituents creates nuclei of strength which are able to effectively demand a sharing of power.

The significance of cooptation for organizational analysis is not simply that there is a change in, or a broadening of leadership, and that this is an adaptive response, but also *that this change is consequential for the character and role of the organization or governing body*. Cooptation results in some constriction of the field of choice available to the organization or leadership in question. The character of the coopted elements will necessarily shape the modes of action available to the group which has won adaptation at the price of commitment to outside elements. In other words, if it is true that the TVA has, whether as a defensive or as an idealistic measure, absorbed local elements into its policy-determining structure, we should expect to find that this process has had an effect upon the evolving character of the Authority itself. From the viewpoint of the initiators of the project, and of its public supporters, the force and direction of this effect may be completely unanticipated.

The important consideration is that the TVA's choice of the methods could not be expected to be free of the normal dilemmas of action. If the sentiment of the people (or its organized expression) is conservative, democratic forms may require a blunting of social purpose. A perception of the details of this tendency is all important for the attempt to bind together planning and democracy. Planning is always positive—for the fulfillment of some program—but democracy may negate its execution. This dilemma requires an understanding of the possible unanticipated consequences which may ensue when positive social policy is coupled with a commitment to democratic procedure.

A Student Planning Project

A WORKERS' RESORT IN THE TENNESSEE VALLEY REGION

In the spring of 1955 a group of students in the third and fourth year classes of the School of Design undertook a major planning project which involved the design of vacation facilities for 3000 workers. The project was prepared for submission in an international competition for schools of architecture sponsored by the Sao Paulo (Brazil) Museum of Modern Art.

The scope of the problem was so broad that it was felt that a major institution, governmental or industrial, capable of large scale planning would be required to undertake such a project. The Tennessee Valley Authority, the government agency dedicated to the integrated regional development of the Tennessee Valley, was given immediate consideration. After a careful study of facilities for transportation and communication, the geographic relation to the bulk of the nation's laboring population, and recreation and resort potential, the Tennessee Valley region was selected as the ideal site for developing a resort system for the working man.

A motor tour of the region was arranged, and the project group visited a number of dam sites. Members of the TVA Planning Department met with the group in conference and offered helpful advice, information, and aid in securing maps and photographs.

The completed project was presented on 6 panels, each approximately 4' by 4' in dimension. Photographs, photostats, and maps (all in black and white) were utilized in the presentation.

The project was developed by the following: James S. Tuley, Roger Montgomery, Robert B. Tucker, Edison J. Willis, Jr., Bertram Ellentuck, Edwin F. Harris, Jr., and Robert P. Burns, Jr., students; and Horacio Caminos, supervisor.

1 Statement, Photographs, National and Regional Maps

2 Resort Developments at Four Dam Sites

3 Complete Development Watts Bar Site, Program

Working man's need for vacation facilities is so great it can be met only by a PLANNING APPROACH. Planning demands an integrated regional system of resorts. An institution of great size must undertake such a program.

TVA--the TENNESSEE VALLEY AUTHORITY--is an institution of regional scale capable of providing this resort system. It is a government corporation charged with developing the potentialities of the Tennessee River Valley, a watershed region located centrally to more than one-half of the population of the United States.

> "From a valley whose land was barren and scarred with erosion, whose river used its great stores of energy only for destruction, (the TVA) created fertile farms, modern productive industries based on the tremendous electric energy of a harnessed river, and a thriving commerce, utilizing the vast manmade waterways that serve them also as fisheries and playgrounds."
> David Lilienthal, DEMOCRACY ON THE MARCH

TVA has transformed by man's labor a great region into A NEW ENVIRONMENT, MAN-MADE AND NATURAL AT ONCE. Here is projected a resort system for this new environment.

The resort system is a GENERAL SOLUTION TO MANY SITUATIONS. Five sites have been developed, each for 3000 vacationists; one site is presented in greater detail.

The resort architecture is an integral part of the regional planning concept--A COMMON STRUCTURAL SYSTEM, of local materials, that may be applied at any site in the region.

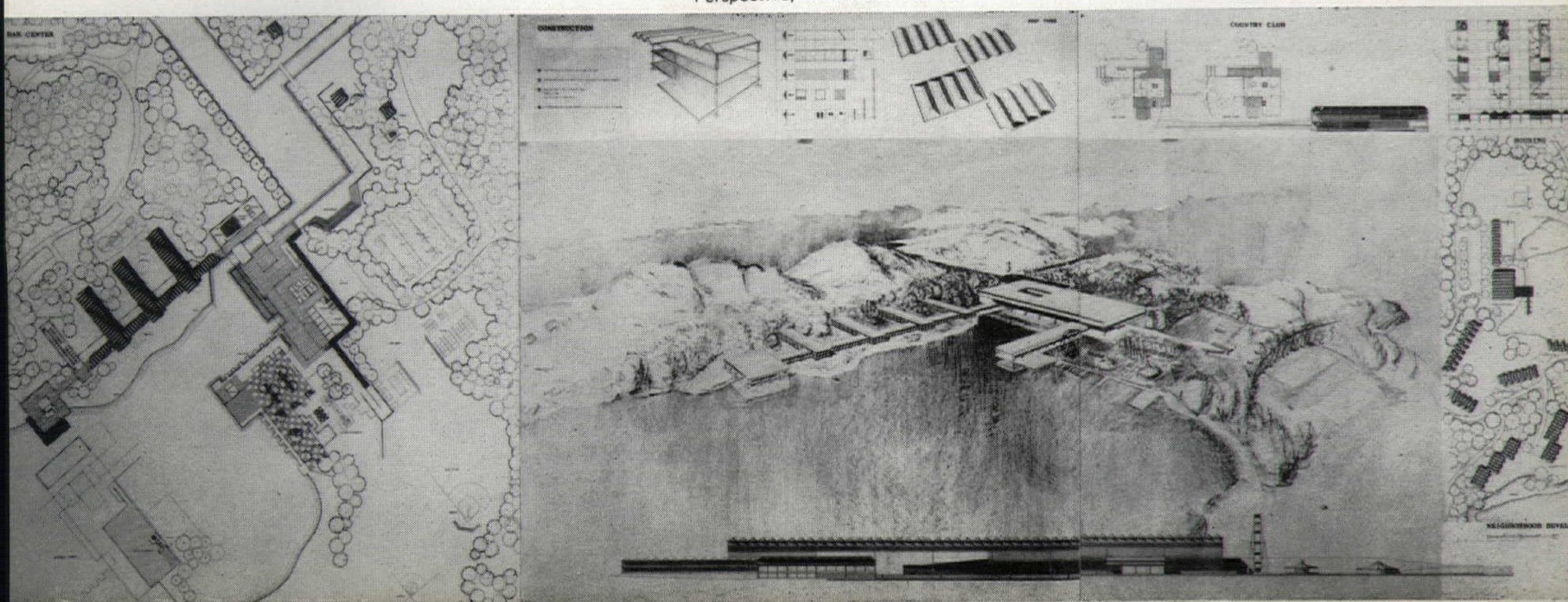
STATEMENT OF PURPOSE

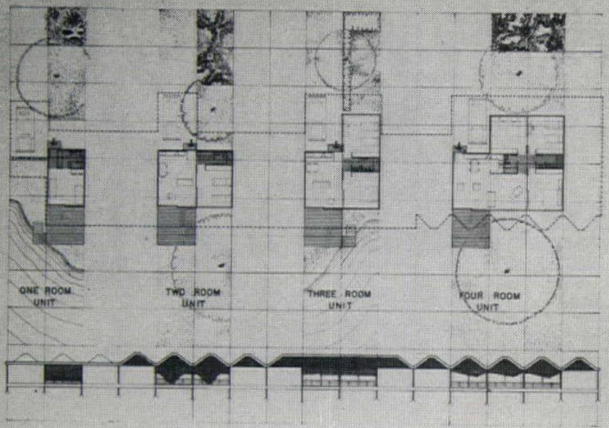
WATTS BAR RESORT 3,000 people — Hotel for 400 — 5 neighborhood developments for 480 each with neighborhood center, main center, country club, demonstration farm, administration, accommodations for staff personnel, day camps for children.

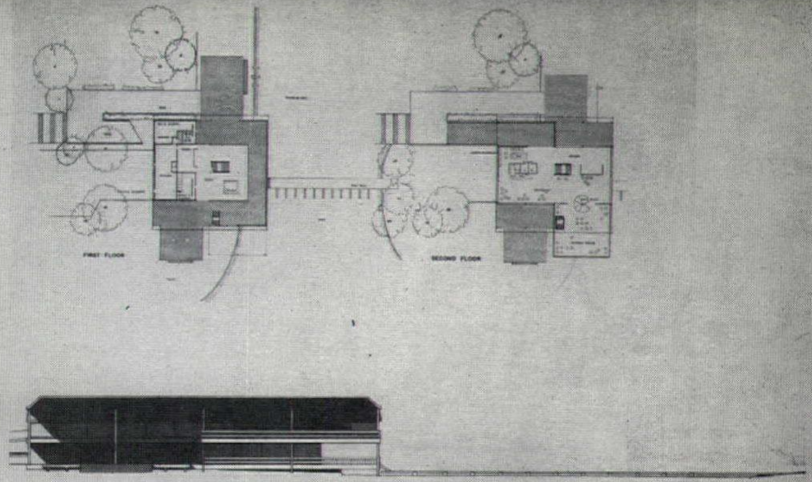
4 Watts Bar Center Plan

5 Constructional Details, Perspective, Watts Bar Center

6 Neighborhood Development, Country Club, Housing





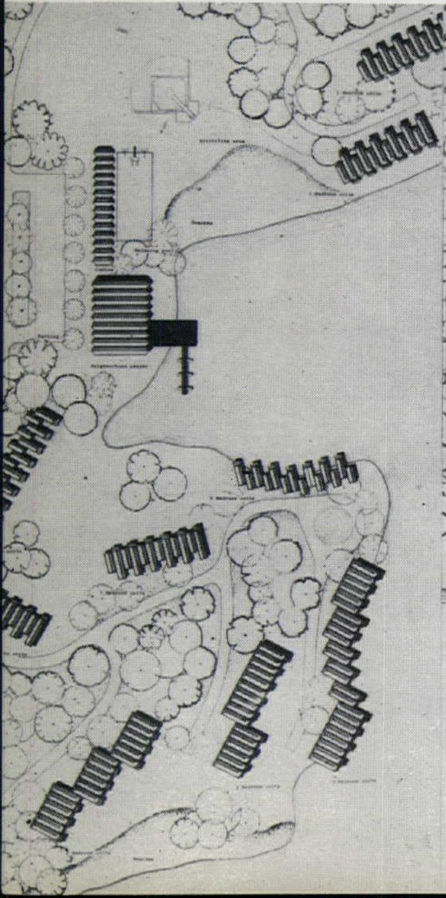


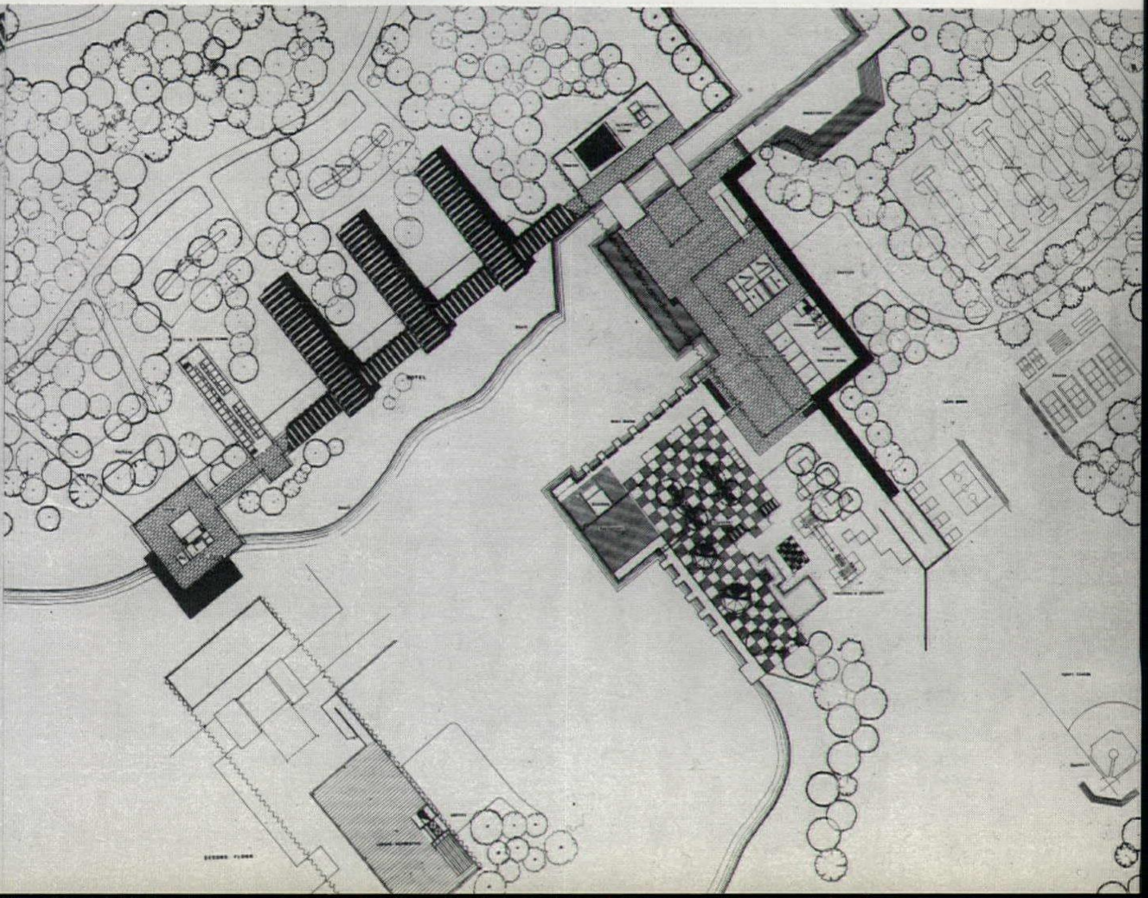
HOUSING Typical floor plans and elevations of housing units to be used throughout entire resort system.

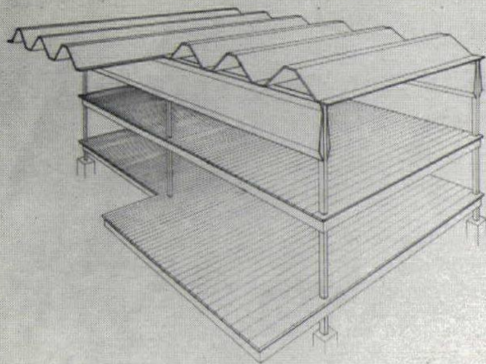
COUNTRY CLUB A typical building design. Facilities provided: Golf course and driving range, indoor and outdoor games, swimming, boat docks, night club—dining, dancing, bar.

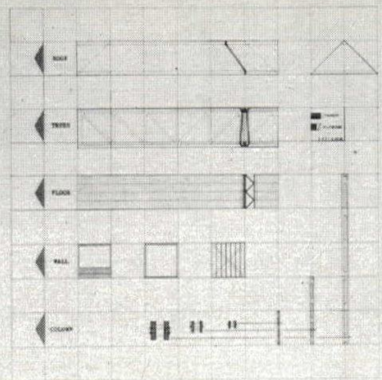
NEIGHBORHOOD 480 people. 20 1-room units, 20 2-room units, 45 3-room units, 25 4-room units, center with dining room, lounge, craft shop, gamefields, pool, and docks.

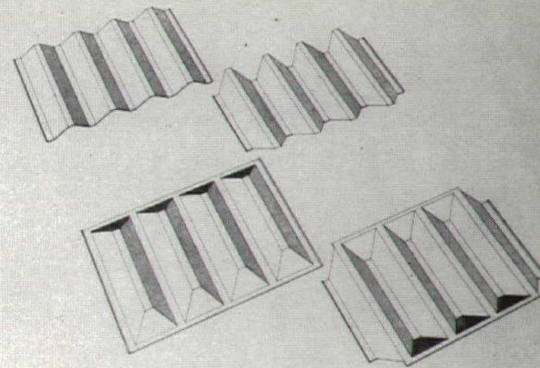
WATTS BAR CENTER Recreation: Children's playgrounds, carnival, athletic fields, swimming, boating, dancing, ping pong, bowling, billiards.
Dining: Restaurant, cafeteria, snack bar.
Shops and food store.
Cultural: Theater, museum, library, chapels, amphitheater.
Hotel for 400.





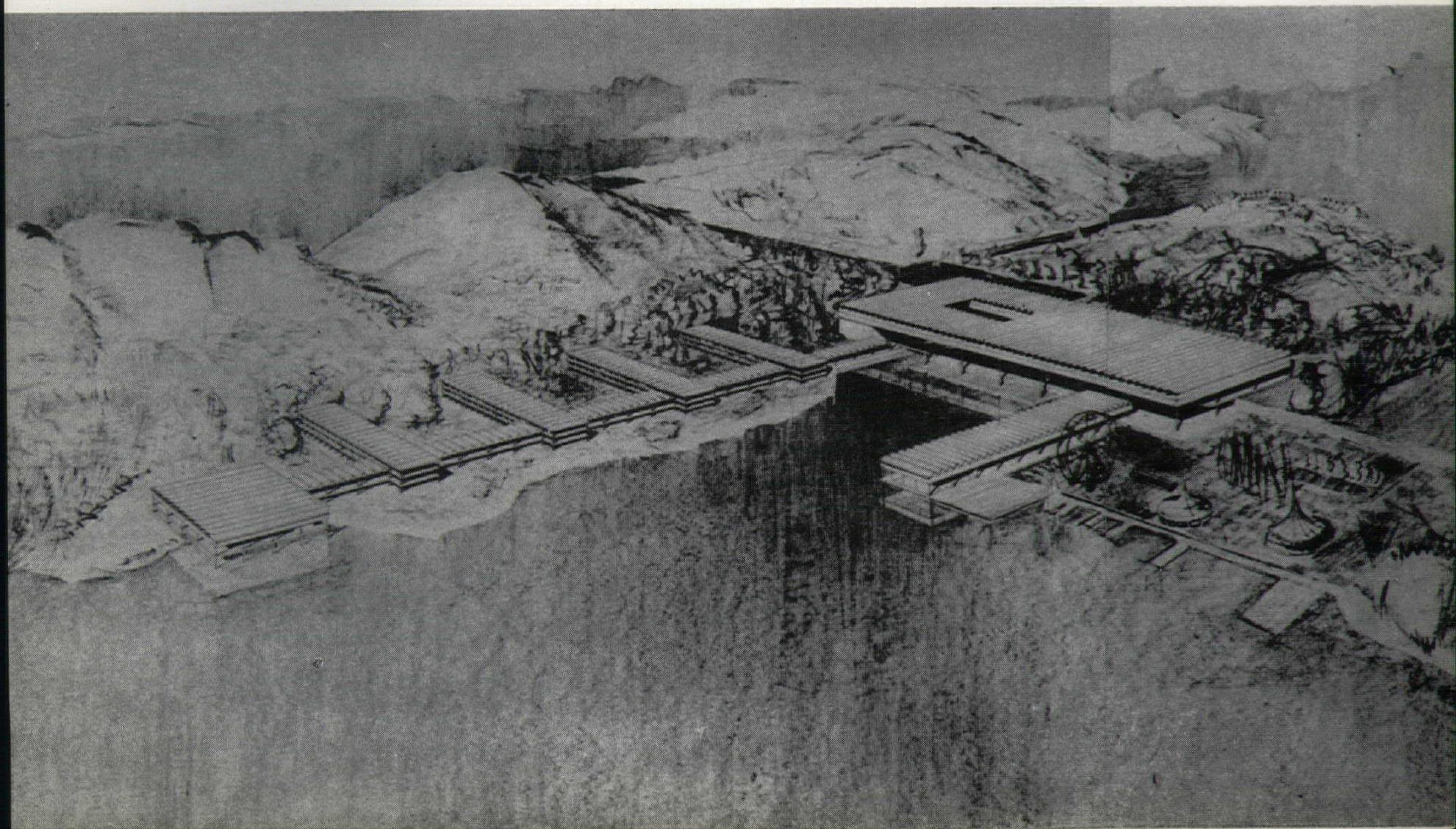






CONSTRUCTION The constructional system is based on the mass production of simple elements from readily available regional materials which could be easily assembled on the job. Formed plywood elements would constitute structural roofs and walls of all buildings. A 14' bay was adopted, to which a great variety of roof types and plans could be adapted.

WATTS BAR CENTER PERSPECTIVE



THE USES AND LIMITATIONS OF MATHEMATICAL MODELS, GAME THEORY AND SYSTEMS ANALYSIS IN PLANNING AND PROBLEM SOLUTION*

John L. Kennedy

The following address was delivered at the Sixth Annual Conference on Current Trends in Psychology, University of Pittsburgh, Feb. 15, 1952. It was prepared in association with the RAND Corporation, Santa Monica, California.

I. INTRODUCTION

Before launching into the formidable array of subject matter contained in the title of this paper, let me say, by way of introduction (and perhaps of apology) that, for the past year, I have been straying from my natural habitat, the fields of human engineering and physiological psychology, into close daily association with a group of mathematicians, philosophers, physicists, engineers, social scientists and psychologists. The common problem of these specialists may be stated as follows: How can we deal with the complexity of real human affairs? What methods, preferably scientific and objective, can be utilized or developed for predicting the behavior of complex, interacting systems? This is the problem referred to in the title of the present paper.

The word "systems" will appear rather frequently from now on. Webster says that a system is "an assemblage of objects united by some form of regular interaction or interdependence; an organic or organized whole". Webster is here defining what we should recognize as a simple system since the key word in this definition is "regular". We wish to deal with more complex systems, such as assemblages of machines, assemblages of men and machines, assemblages of men and the ultimate complex system, individual human behavior, where the interactions between parts, although well-recognized, are anything but "regular". If this is too strong a statement I think most of us would agree that much of the regularity remains to be discovered.

Why study systems rather than components? Because the important questions we are asked to solve today are primarily questions involving complex interactions. In real life, we are forced to solve "staff" problems as well as "line" problems. We are forced to plan and thus to predict in order to adapt successfully to the emergencies of life.

It has been pointed out many times that the scientist, when he is faced with complex systems, usually begins on his problem of prediction and control by breaking the system up into components of a convenient size and degree of complexity. He studies the components intensively and, many times, is piously content to leave the problem of interaction of components to some future time or to solution by wisdom. I am particularly sensitive to this criticism in relation to the field of human engineering, where, it seems to me, com-

* The preparation of this paper was greatly assisted by discussions with Allen Newell, W. C. Biel and R. L. Chapman. They should, however, be relieved of responsibility for my interpretations of their thoughts.

ponent thinking has dominated the efforts to establish it as a substantial scientific contribution to the real world of human affairs. I am reinforced in this conviction by the work we did at Tufts College in preparing the "Handbook of Human Engineering Data for Design Engineers" (4). The Handbook answers many component questions having to do with the parts of the human and his environment, but it is woefully weak in answering systems questions. Perhaps this is another way of saying that there is no central theoretical framework on which the data are hung—there was no mathematical model for spelling out the complex interactions everyone sees from common observation of individuals and groups.

Let us try out some systems questions on the human engineer to make the point possibly a little clearer. The aircraft designer wants to know, for example, the relation between the size of the dial of a particular aircraft instrument and the performance of the pilot-aircraft combination in executing a standard military mission. He is not much interested in learning that speed and accuracy of dial reading improve as dial size is increased because the performance criteria are *specific* to the component. He wants to be told that either this instrument component is critical to *system* performance so that he should maximize its space, or that its particular size within wide tolerances is not critical to the successful performance of the military task for which the plane is designed. Then he can go ahead with confidence in working out the optimal dial sizes in accordance with overall space limitations of the instrument panel in a reasonable way. Actually, the human engineer makes that latter kind of recommendation, but it should be emphasized, he does most of it by using common sense, intuition or wisdom, and not with the data from his science.

Component thinking may be illustrated in another more particularly human case. The National Research Council's Committee on Aviation Psychology (7) investigated the contribution of the Pilot's visual acuity to the task of learning to fly an aircraft. "Normal" visual acuity, as measured by the Snellen Chart, has for years been required of all aviation cadets. The Committee's studies demonstrated, however, that within a range of tolerance, visual acuity of trainees did not significantly affect training time or terminal skills.

Component thinking vs. systems thinking appears most clearly in psychology in the choice of the criterion measure for evaluating performance. At the risk of appearing to pour salt on old wounds of some of my colleagues on the program, we may cite as an example of component thinking, the choice of school grades as a criterion measure for determining the effectiveness of selection tests. Our real interest is prediction of success on the job even though it may be argued that success in school is a necessary antecedent to job success. It is possible that we are too frightened of negative results and this fright drives us to carve our systems up. Negation of an hypothesis about the relative importance of a component in a system has equal stature with affirmation. Thus, it probably saved the Western Electric Co. in the famous Hawthorne study a considerable amount of money to discover that illumination level of the work space was not a very important determiner of productivity.

You have recognized by this time, I am sure, that it is difficult to draw a line between components and systems. "Big fleas have little fleas", big systems have little systems and so on, ad infinitum. In the real world, a system is defined by the questions the scientist or expert is asked to solve or asks himself. A component solution is one that may be perfectly valid, but it does not answer the question. I shall argue then, that to deal with the complex problems of human life, we are forced to adopt broader systems criteria.

Let me remark, before going on to the next section, that this feeling of uneasiness with respect to component criterion measures is coming to be shared by many users of electronic devices. The electronic gadget is the example par excellance of the component measure—we build a resistor of so many ohms—without reference to the demands of the system in which it will become a component. Electronic devices have become complicated enough so that we are forced to re-evaluate how the components interact in determining the over-all goal of the system. This field of study in engineering has received the name "Machine System Reliability". In psychological terminology, it is machine system validity that is being studied. The question asked is: What do we have to do to the parts in order for the whole system to perform the overall task we wish it to perform at some level of predictability?

II. WISDOM AND COMMON SENSE

I did not include wisdom or common sense in the title of this address as a solution to the problem of complexity because it is such an obvious one.

We solve our everyday problems with this device in one form or another, and hardly ever stop to examine the method unless we happen to be philosophers. If we feel that our own wisdom is inadequate, we consult the wisdom of someone else, the "expert". Now, I don't need to flog the idea that the solution to the problem of complexity by the opinion of experts leaves much to be desired. If he is the right kind of expert, however, he can perform an important function in problem solution. He can bring to bear accumulated historical wisdom, i.e., how components interacted in relation to systems criteria in the past, either by reference to his own experience or through study of the great interacting systems of human affairs in the past. This kind of wisdom is an extremely scarce commodity. What we usually find is component wisdom or common sense, which results in emphasis on one aspect of a complex problem with the other equally important aspects ignored. I presume that this observation about the behavior of experts is responsible for man's attempts to generate other methodology, such as the scientific method, to assist him in mastering complexity. But here again we ask, "Which scientific method, systems methods or component methods?" Again the answer, is to be found in the choice of a performance criterion, which, in fact represents the level of aspiration of the scientist. Let us consider, now, some alternatives to the method of wisdom.

III. MATHEMATICAL MODELS

Mathematics, the queen of the sciences, also offers a traditional solution to our systems problems traditional in the sense that mathematical methods have been successful in dealing with many complex interactions in the physical world, and it is quite natural to assume that they would perform equally well in dealing with the complexities of human interaction. Why is it, then, that social scientists are not more inclined toward mathematical model building? Two general answers may be given to this question. The first has to do with the information or data about a complex interaction supplied to the mathematician. The second general answer is that the mathematics for handling interaction problems is still in an early stage of development.

Mathematics provides the optimal language for communicating complexity, but mathematics only operates with the information fed into it. If only component information is put in at one end, no information about the total system comes out at the other end. If we require the mathematician to provide solutions to systems questions without giving him the necessary data, he will make some assumptions on his own in order to wrap up his package. Then we find that we cannot stomach the assumptions, that the mathematical model is too simple, that our wisdom tells us that life really isn't that way, and we become suspicious of the whole mathematical model concept. I would argue that the fault, if there be one, in this controversy lies mainly with the provider of data for mathematical treatment. We stick to our small components when the mathematician needs quantitative *system* information for his special brand of magic.

Here is an example which will illustrate the limitations under which the mathematician works. It is desirable, from the point of view of a tracking system designer, to describe and predict the performance of a man-machine target tracking system by means of mathematical formulae. P. M. Fitts (3) describes a mathematical model, proposed by Ragazzini, for the response of the human operator in the tracking situation. It is the second-order linear differential equation:

$$\theta_{out} = a\frac{d\epsilon}{dt} + b\epsilon + c\int \epsilon dt$$

delayed by .3 seconds (the RT of the subject)

$\theta_{out} =$ the operators response

$\epsilon =$ the error of difference between actual position of the target and desired position of the target.

$a,b,c =$ constants

$\frac{d\epsilon}{dt} =$ rate of change of error

$\int \epsilon dt =$ summation of error information over time T.

The model predicts that the movement the operator makes is a linear function of the rate at which the error is changing, the absolute magnitude of the error and the integral of past error.

Now, I believe that it is fair to say that this model presents only a partial picture of the variables that enter into human performance in tracking. The work of Ellson, Taylor, Tustin and Hick has clarified in what ways the human individual differs from a continuous servomechanism. Among these may be listed learning, set from instructions, interest in the job, rapport with the experimenter, etc. So the constants in the equation are not constants. They turn out to be variables in time and hence are to be described by some sort of learning function. They are also variables with the complexity of the input, as the work of Ellson and Taylor has shown.

The important point to note in this example is that, when we come to test the predictive efficiency of the equation describing the system, it is found to be discouragingly low. Apparently the mathematical model for the man-machine system does not have enough complexity in it to describe the system successfully. This situation I would blame on the aspects of performance which were originally measured. We do not supply the mathematician with an adequate description of a system.

Let us now explore the mathematician's contributions to the problem of complexity. My mathematician colleagues tell me that there are two promising developments for dealing with man-machine systems, namely, (1) the theory of stochastic processes and (2) the theory of games.

A stochastic variable is one, the set of possible values of which is known, but it depends upon chance which of these values the variable assumes. Independent stochastic processes have yielded the classical theory of probability with the familiar models of the die, the deck of cards and the urns filled with white balls and black balls. Independent stochastic processes are at the basis of the kind of statistics most psychologists use.

Dependent stochastic processes, where the set of possible values of the variable are known but the variable assumes a value dependent upon a previous value, look more interesting from the point of view of handling complexity. One may cite here such developments in dependent probability analysis as time series, information theory and the study of communication.

Already, there have been several applications in the psychological literature. Let us consider one such application which is directly related to human interactions. Bales (1) is interested in predicting the interactions which occur in a small group while solving or reaching a decision concerning a group problem. He describes a model for two-person interaction as follows: "Visualize two persons who have met to discuss a problem, and agree on a specific course of action. Let us say that they have a stock of experience, inclinations, impulses, etc., which give rise to certain 'suggestions' in their minds. Each of them also brings along a critical frame of reference—certain generalized preferences, prejudices, values, etc.—in terms of which he evaluates the suggestions that occur to him. Let us say that when persons interact with each other, there are four general types of messages which they send to each other. We will call these 'suggestions', 'positive reactions', 'negative reactions' and 'questions'. A suggestion by one typically leads to a positive or negative reaction or a question from the other. The reaction or suggestion received is a kind of 'feedback', and exerts an influence on the future direction of the process. The alternating process of giving suggestions and reacting to them is a circular process of social interaction".

The above quotation describes a dependent stochastic process since the values of the behavior of each subject are specified or categorized in advance, and which one at a particular time (suggestion, positive reaction, negative reaction, question, is chosen by the subject in accordance with a preference schedule, which it is possible to describe in terms of probability. Thus, let us suppose that each subject makes a suggestion with $P(s) = .1$, makes a positive reaction with $P(p) = .4$, a negative reaction $P(n) = .3$ and questions with $P(q) = .2$.

Then, the two persons interactor may be diagrammed as follows:

	(1)	(2)
Preference Schedule	$P(s) = .1$	$P(s) = .1$
	$P(p) = .4$	$P(p) = .4$
	$P(n) = .3$	$P(n) = .3$
	$P(q) = .2$	$P(q) = .2$

The process is started by, let us say an assertion by (1); (2) reacts by a negative reaction; (1) then reacts with a question; (2) with a positive reaction and so on. The interaction model, even in the simple preference situation given above, is complex enough to require a computer to solve. When the possibility of learning is introduced as the effect of own decisions and kinds of responses received from others on the valves for the preference schedule, the actual computation becomes quite difficult.

The other development toward a mathematics of complexity comes from a desire to predict the outcome of games involving a number of players operating according to a set of rules. The publication of von Neumann and Morgenstern's "Theory of Games and Economic Behavior" in 1943 (6) has resulted in much pure mathematical work to extend the basic ideas to encompass more and more complexity. We shall not have time to give more than one example of the kind of computation required to describe and predict the outcome of a game, but let us illustrate with the simple game of "Her".

This is a so-called 2-person zero-sum game. Each player puts up 50¢. From a shuffled deck of playing cards, the dealer gives a card to the receiver and one to himself, both face down. The man who ends up with the highest card wins but draws go to the dealer. The ace is low in this game. The receiver may compel the dealer to exchange cards, but, if the dealer has a king, he is allowed to retain it. If the dealer is not content with the card he first obtained, or which he has been compelled to take from the receiver, he may draw a new card from the deck. If the drawn card is a king, however, he must play with his previous card.

The game, then, consists of three moves: The first move is a chance move, one card each being dealt, at random, to the receiver and dealer. The second move is a personal move by the receiver, who exchanges his card with the dealer or stays with the original card. The third move is a personal move by the dealer, who exchanges his card with a card from the deck or stays with the card he holds.

The game may be summarized by defining a strategy for the receiver to be a determination of change or stay for each of the 13 cards. One such strategy might be a simple alternation such as:

1	2	3	4	5	6	7	8	9	10	J	Q	K
C	S	C	S	C	S	C	S	C	S	C	S	C

Note that the strategy is a complete set of instructions, a so-called pure strategy. Each player has 2^{13} such strategies. Most of them are poor and would never be played.

Now, There are two essential decisions which make this game an example of a complex, interacting system. First, consider the plight of the receiver. If he decides to change, he relies on his estimate of the dealer's card. Simple probability theory handles the problem since the card was dealt at random. If he decides to stay, however, he must worry about the effect of his staying on the dealer's estimate of the value of his (the receiver's) card. But now consider the dealer's plight. He not only must worry about estimating the value of the receiver's card but also about being bluffed. So the problem is guess and second guess.

Game theory allows us to analyze the game completely. There is no good pure strategy, yet one can compute an optimal "mixed" strategy for either player, i.e., a technique of play which will maximize wins for the receiver and also minimize losses for the dealer. These strategies work regardless of what the opposing player chooses to do. They allow us to solve the problem of interaction in a rational and predictable way.

Now, what has all this got to do with the problem of complexity? It suggests, I believe, that the problem of predicting interactions between people, and between machines and people, may be attacked by new mathematical methods. At the present time, game theory has the following limitations:

(1) Large segments of human behavior are not rational. Game theory needs additional information about how to handle the concept of "value," for example.

(2) Game theory requires a very detailed description of all possible actions that can happen.

(3) Game theory is most successful in handling competitive behavior. The non zero-sum game or the game of cooperation does not lend itself to easy solution by game theoretical procedures.

As a way of studying complex human behavior, game theory suffers from having encompassed only part of the problem, namely, the rational competitive part.

Incidentally, if anyone is interested in the game theory solution to the game of "Her", here it is. The appropriate mixed strategy for the dealer is to hold when his card is 8 or over $3/8$ of the time, and to change 8 and under $5/8$ of the time. For the receiver, hold 7 and over $5/8$ of the time, and change 7 and under $3/8$ of the time. If both players actually play these strategies, the receiver can expect to average about 2 cents winnings on the hand. So if you ever indulge in practical "Her-ing", be sure to make it a fair game by passing the deal for each game, such as is done in cribbage. Actually, I do not recommend "Her" as a game. It is tedious and unprofitable unless you can find a "sucker".

In summary, then, of the contribution of mathematics to our problem we must be impressed with the contributions it is beginning to make in the social science field. Why it has not accomplished a revolution in the social sciences may be attributed to many reasons. I suspect that the developments in mathematics just described may be indications that the mathematicians are ready conceptually for the revolution to occur if, somehow or other, the appropriate kind of information for mathematical treatment can be provided. I shall have a few things to say about this problem a little later, but let us now turn to Systems Analysis as the next method for dealing with complexity.

IV. SYSTEMS ANALYSIS

It should be pointed out at the start that systems analysis is a practical combination of the method of mathematical models, the method of wisdom and the methods of common sense. A new idea has been added, however, namely, the idea of systems evaluations or the attempt to fit components into their proper perspective with the overall Goal of the system as the paramount consideration. Systems Analysis has close ties with Operations Research (2), a scientific art-form that developed just before and during World War II. It shares with Operations Research the following description: "Operations Research deals with problems that are organization wide, and it deals with the *whole* of such problems. It may very likely concentrate study on certain parts, but it does this not because the parts are easy or attractive (which would often be the case in pure science), but because overall examination has revealed that these parts are the critically important ones. Operations Research uses the widest possible set of tools. It may utilize such studies as would be made in time and motion analysis, but it also uses the insights of the statistician, the psychologist, the mathematician, the engineer, The physiologist, the specialist in probability theory, etc., etc. And it puts all these together, into one overall and interrelated analysis". Systems Analysis differs from Operations Analysis principally in time scale. Operations Research characteristically goes after immediate problems while Systems Analysis is most often interested in prediction of the behavior of systems that do not yet exist.

Systems Analysis deals with *quantitative* interrelationships between the important variables determining system performance. It relies heavily on the use of high-speed computers for playing out the consequences of interaction. We may quote from a cleared source (5) the following description of the process:

"A bomber itself is a system of the elements (speed, altitude, etc.) that make up its character; it is also a component of the larger bombing-attack system consisting of bases, bombs, bomb-sights, electronic equipment, methods of employment, etc. and the men who operate them. A generalized aircraft study interrelates speed, altitude, range, payload, and weight. Such factors as the number of engines, wing area, and size of crew compartments are brought in as a basis for calculations of vulnerability and reflectivity (echoing area of aircraft with respect to radar impulses). If it is assumed that the bombsight has a certain probable aiming error, then the study of the damage a bomb can do to a target is figured in terms (among others) of this probable aiming error. Calculations of this kind are made as component studies by specialists.

"When all this component material has been collected and appraised, a vast sorting process begins. Large numbers of weapon combinations and weapon designs are studied to permit selection of the preferred ones. Then comes the big job—the systematic combining of all the components under a cost limitation.

"The attempt to find the best combination of characteristics at the same time, rather than the best individual characteristics, is nothing more or less than scientific method applied to problems of decision".

Certainly we can agree that this somewhat journalistic description begins to sound like an approach to the problem of complexity. Many special methods find their place in this overall technique but, Systems Analysis deals primarily with the prediction of *physical* characteristics of weapon systems. What happens when we go to the real-life situation of the marriage of man and machine in systems? How do the human components interact with the machine components? Which components of man-machine system should be men and which should be machine? When cost is introduced as a constraint, how far in the direction of mechanization of systems should we go? These latter questions depend for their answer on studies of man-machine interaction which have never been carried out. We shall consider some of the reasons why they have not been done in the next section, in which I wish to describe the final method to be considered, namely, a method with the unpronounceable name of Systems Synthesis.

V. SYSTEMS SYNTHESIS

In order to save myself from this tongue twister, I shall refer to it hereafter as S.S. It is the man-machine and man-man counterpart of systems analysis as described above for the prediction of preferred hardware combinations. Right now it has the status of a glint in the eye of a team of psychologists, mathematicians and physicists, of which I am a member, who are attempting to work out a feasible procedure for obtaining the basic data upon which S.S. can proceed.

S.S. turns out to be first of all, a laboratory-computer method, requiring rather extensive laboratory facilities, including the availability of high-speed computers. I am happy to say that we opened the doors of a Systems Research Laboratory to subjects recently and the first of a group of man-machine system problems is underway. The control of input is made possible through the use of IBM computers, which allow us to present complex "real" problems to the system. The system itself is a low order abstraction of a military problem. It involves the interactions between a group of 28 people, associated machines and communications network working against a systems criterion. Since this is a classified military system, I cannot go into further details at this time.

Let us now return to mathematical models again. In a sense, the Systems Research Laboratory is a large computing device for grinding out the interactions of machines and people. One of the primary goals of the research program, however, is to discover how to construct mathematical models for this interaction. The mathematician in S.S. becomes an integral part of the data-gathering team. He discovers by actual experience whether or not his assumptions about behavior are credible and consistent with reality. The psychologist, on the other hand, in joining this partnership agrees to attempt to identify and measure variables at a level of abstraction appropriate for mathematical synthesis.

Von Neumann and Morgenstern (6) have stated the mathematical program: "The importance of the social phenomenal, the wealth and multiplicity of their manifestations, and the complexity of their structure, are at least equal to those of physics. It is therefore to be expected—or feared—that mathematical discoveries of a stature comparable to that of calculus will be needed to produce decisive success in this field".

We believe that there should be a concurrent program in the social sciences to provide an optimum climate for the new mathematics and that systems research looks promising to provide such a climate.

VI. THE FUTURE OF SYSTEMS SYNTHESIS

One should not avoid the responsibility, in a Symposium on Current Trends, for some extrapolation of the trends into the future. The solution to the problem of complexity in the social sciences via mathematics has been a "current" trend for so many years now that possibly the best extrapolation would be to agree with von Neumann-Morgenstern suggestion concerning the necessity for new mathematical techniques before real progress can be achieved. I cannot help but think that some optimum blend of observation, controlled experimentation, abstraction and generalization will eventually work. The great leveller of theory construction is the laboratory, where concepts can be put to operational test. If a laboratory can operate with systems rather than component criterion measures, I believe that we will achieve the optimum climate for solution to our pressing problems of complexity.

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Linear programming is a means for determining the best course of action to follow under limiting or restricting conditions in situations where there are a large number of solutions possible. It involves the use of advanced mathematics in the execution of the solution, but the greatest skill in linear programming is in the formulation of the proper statement of the problems to be solved. A skilled management man will formulate and set up the problem, the skilled mathematician will work out the details of the solution. After the mathematician has worked out the details, an automatic calculator can be instructed to carry out the rules, automatically producing the results in a minimum of time. The non-repetitive task, that of the skilled procedures man, is involved in recognizing the variables that exist, putting numbers on the factors, some of which are not ordinarily quantified, and in stating the problem in such a way that it makes the mathematical solution possible.

The value of linear programming lies in its ability to produce better answers to problems involving a larger number of variables than has been possible in the past. It is practically impossible in many cases to evolve "best solution" or plan by cut and dry methods. Usually we can only obtain some possible plan with little regard as to whether it is a "best" plan.[1]

Design of structural frameworks. A framework of rigidly joined homogeneous beams is subjected to concentrated external forces, which are balanced by reactions at the supports. Each beam reacts to the resulting internal bending moments, at first by elastic bending, and after a certain value is exceeded, by plastic flow. As soon as plastic flow starts at any one of several critical points of the framework, the entire structure is in danger of collapsing. Given a set of applied forces, the equilibrium equations relating them to the bending moments they produce, and the maximum allowable bending moments at the critical points of the structure, find the largest permissible factor by which the applied forces may be increased without endangering the equilibrium of the framework, and find the resulting bending moments at each of the critical structural points.

Sites and management of river dams. To eliminate the periodically rampant destructive and costly floods, the Missouri Valley Authority, in collaboration with the Army Corps of Engineers, plans to harness its waters for productive purposes by building a series of dams, to be completed in 1960, that will act as catch basins for floodwater, as storage reservoirs for agricultural irrigation, and as an energy source for the production of hydroelectric power. Linear programming proves a useful tool in the study of optimal location of the dams, taking into account the variable seasonal rainfalls at the headwaters and downstream, fluctuating widths of river beds, other local topography, and variable local water and power requirements.[2]

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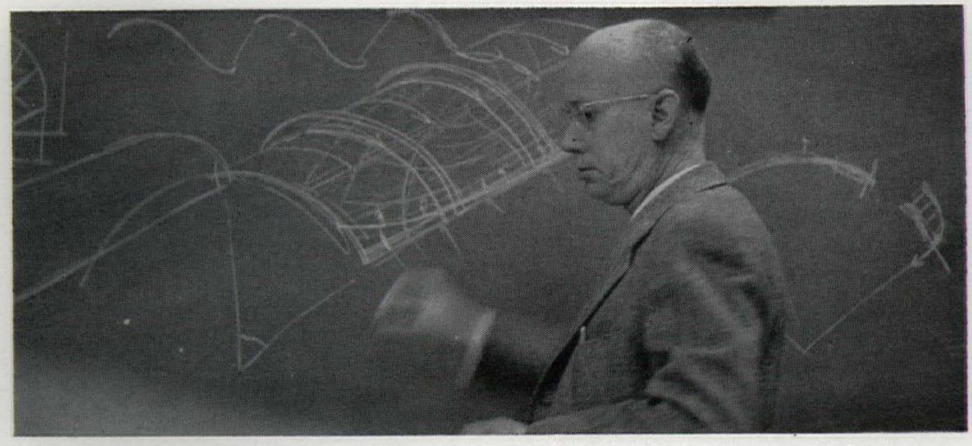
[1] E. F. Ormsby. An excerpt from a paper presented at the combined meeting of the National Association of Cost Accountants and the National Machine Accountants Association in Akron, Ohio. Courtesy of International Business Machines Corporation, New York.

[2] From a paper by Kurt Eisemann, Applied Science Division, International Business Machines Corporation, New York.



EDUARDO TORROJA

Spanish structural engineer, born in Madrid, 1899—Torroja lectured at the School of Design in February, 1957, developing a course in structural theory with the fourth and fifth year classes. He is the author of the article "Bridges and Aqueducts" on the following pages.

The work of Eduardo Torroja is perhaps little known in this country, and so here we present a brief introduction to a few of the significant structures that he has designed.

Torroja is in every sense a creative engineer. His achievements are remarkable because they encompass the entire realm of structural engineering. Not only is Torroja a capable designer but he is also a brilliant theoretician; his articles in technical journals and his books on theory have made valuable contributions in the field of theoretical structures. Furthermore, Torroja was one of the earliest pioneers in the study of the behavior of structures through models. The testing of models is carried on in the Technical Institute of Cement Construction, which he established and directs.

In considering the structures presented in this page, it is important to note the wide variety of problems, even in so few examples, undertaken by Torroja and to realize that they are all early works. In each case, they are problems with specific limitations as to function, materials, system of construction, and economy. Through his profound understanding of structures and his imaginative daring, Torroja has brought to each problem a solution which is not only visually pleasing and structurally sound, but also original. His significance as a designer then lies in the fact that his structures are authentic creations, the work of a bold and progressive trailblazer. This is especially true in the field of thin shells which have become a standard weapon in the esthetic arsenal of all stylish designers.

Pictured are: 1) Cantilevered thin shells for the Hippodrome, Madrid. 2) Thin shells for indoor courts, Madrid. 3) Groin vaults, subway station, Madrid. 4) Cantilevered truss canopy for "Las Corts" Stadium, Barcelona. 5) Viaduct over the Esla River, Zamora. 6) Space truss for airplane hangar, Torrejon.

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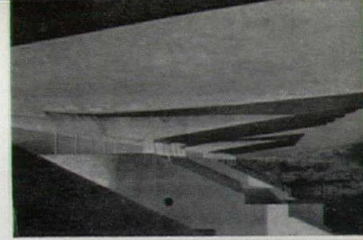

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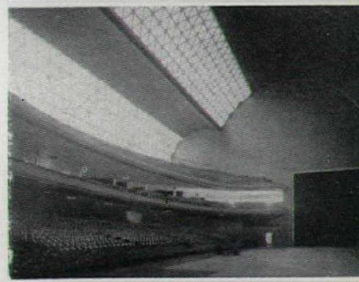

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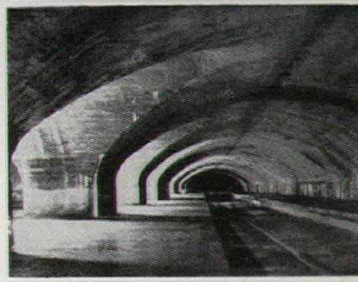

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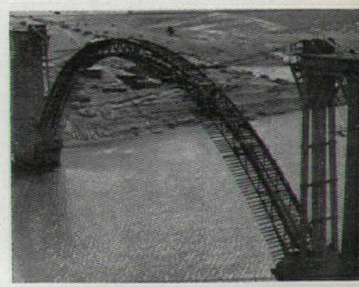

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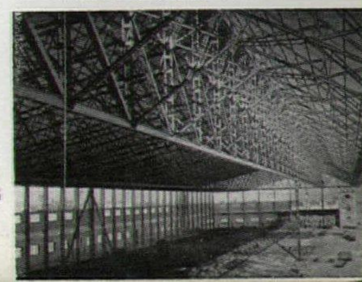


BRIDGES AND AQUEDUCTS

EDUARDO TORROJA

Reprinted from Dr. Torroja's book, RAZON Y SER DE LOS TIPOS ESTRUCTURALES. Translation from the Spanish by Stanley T. Ballenger, Modern Language Department, N. C. State College.

The Golden Gate Bridge with its 4,200 foot span between piers, is the largest span up to the present time; it is of special interest because it is a suspended bridge, a type of structure which allows maximum lightness and minimum dead load. Both are of great concern in dealing with such large spans.

It is evident, with no need to quote extreme cases, that the construction of bridges raises serious structural problems. As F. Stussi says: "The problem of great spans has always fascinated both specialists and non-specialists. To construct a bridge with a span greater than any attained previously not only requires great technical knowledge and ability, but also intuition and creative daring, since it represents a triumph over forces of nature and progress in the battle against human insufficiency."

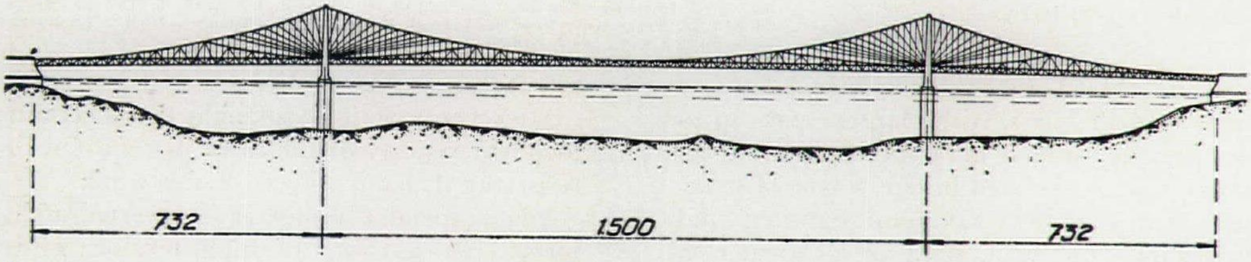
In these large suspended spans, however light they may be, the live load is small compared to the dead load. The beam which constitutes the road deck can then be relatively slender, since it need resist only the bending stresses which are produced by the possible variations of the live loads along the span; and, in the extreme case of an aqueduct which has a completely uniform live load from one side to the other, the theoretically necessary stiffness would be null. As a general rule, however, whenever there is a live load, the elongations of the cable cause bending in the beam which increases as the rigidity of the beam increases. Hence, it is not necessary to exaggerate this rigidity.

However, practice has taught that a certain torsional rigidity of the beam is required to resist the dynamic effects of the wind.

The suspended bridge is an inverted arch, formed by a cable of high tension wires whose strength-cost ratio is greater than that of standard structural steels, and from this fact arises one of the principal advantages of this type.

As with any arch, it must transmit horizontal reactions to the ground unless it has three spans proportioned and arranged so that the cables are anchored at the ends of the deck beam. The structure is, in a certain way, the inversion of the trussed arch; the cable-arch works in tension and the stiffening beam absorbs in compression the horizontal components which the former transmits through the anchorage.

Beginning with this type of structure, it is interesting to follow the evolution that bridges undergo as their dimensions, especially the span, decrease; because, contrary to what occurs with the floor structure or deck of a building, the structural type of the bridge changes totally, not only with the material, but in particular with the span, as well as with the height of the roadway above the bottom of the valley and the foundation conditions which are linked to the presence or absence of water under the bridge. Each type clearly shows its specific advantages and disadvantages and each valley finds in one of the



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types the bridge best suited to it and which the technician must choose and adjust.

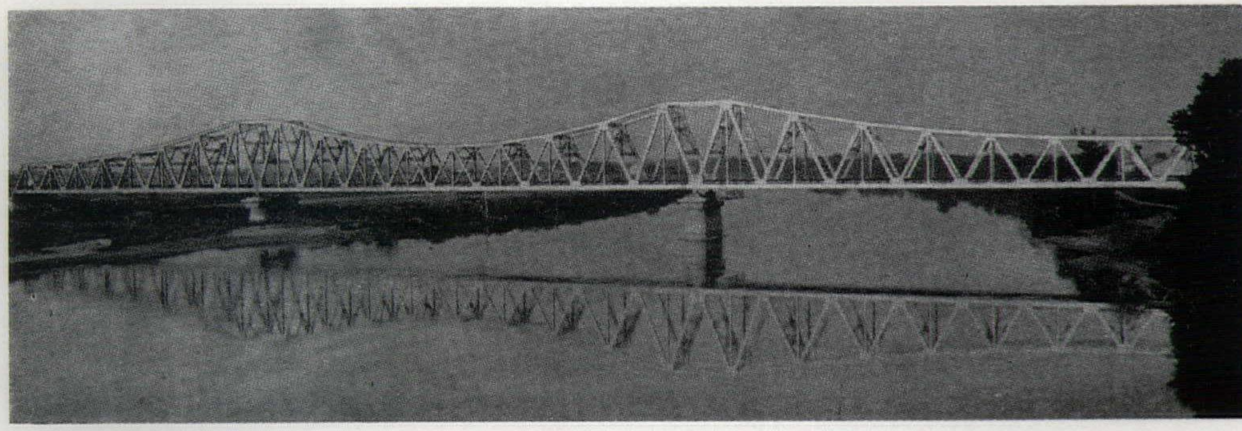
As the span decreases and with it the sections and dead load of the different elements, the live load increases its relative importance. The structural problems of the beam, in particular those of bending, become steadily more dominant over those of the arch; the slenderness of the beam cannot be maintained. With the decrease of span, bending moments in the beam, and therefore its thickness, decrease much more slowly than the tension and curvature of the cable, and the two tend to coincide.

The Florianopolis type of suspended bridge, (figure 2) characterized by the fusion of the two elements—cable and upper flange of the beam—in the central part of the span and by trussing of the parts of the cable near the support with guys originating at the intersection of the deck and pier, is the result of the above tendency. This type was proposed for the Messina Bridge with a 5,000 foot span, but it has been used more in suspended bridges of much smaller dimensions.

The form of this type of bridge when considered as a beam conforms readily to the distribution of bending moments. The guys complete the action of the beam, but they can work only in tension and with excessive inclination, so that when the span is reduced, it is preferable to use the trussed beam, following more or less the same outline as the cable (figure 3). Thus the beam has a maximum thickness over the supports where the moments are greatest, and although the large members under compression are always a drawback, this ceases to be critical because the general dimensions have decreased.

With a rigid beam, the distribution of spans can be made more freely, meeting the requirements of the valley and the foundation conditions. These large continuous beams require free expansion to allow thermal movements, which involves costly supports because of the heavy loads they must carry.

It is necessary to fix the points of inflexion or zero moment by means of hinges which at



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the same time allow free expansion. In this manner, the continuous beam is transformed into large cantilevers which sustain relatively small spans between them when the extreme ends of the cantilevers are anchored or counter-weighted as at Quebec (figure 4) or when each pair of cantilevers is stabilized on a double support as at the Firth of Forth (figure 5). This type of solution is the one which, at the present stage of development, attains the greatest span without horizontal thrusts, spans much greater than those of continuous beams.

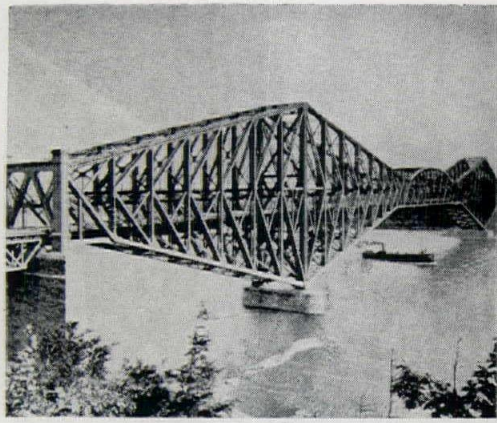
Nevertheless, the net advantage tends towards the continuous beams as the span is reduced, and greater simplification can be obtained by making the beam of constant thickness, although with members of different section, facilitating the use of scaffolding and formwork, and thereby simplifying construction.

If the span continues to be reduced, the lightness which triangulation can achieve as compared to a beam with a solid web disappears, and the latter becomes more advantageous because of its greater rigidity, its better aesthetic effect, and the ease of construction which it offers, both in fabrication and assembly.

The greatest simplification is obtained when the span and the bending stresses are so small that standard sections or those formed simply by three welded plates can be used.

The use of plate girders in short spans over high steel piers to form viaducts over wide valleys has been defended for many years against its aesthetic flaws because of its simplicity and speed of assembly where there is a lack of materials for making masonry or concrete piers economically on a large scale, or where the great height of the roadway would make these piers too expensive.

The plate girder has its optimum application in spans of medium length. Girder bridges for railroads are being replaced by structures of a continuous concrete slab of greater mass capable of putting the track ballast of the road to structural advantage.



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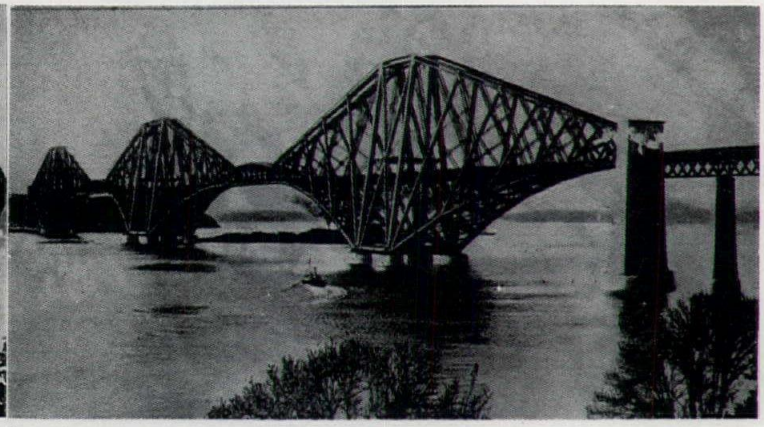

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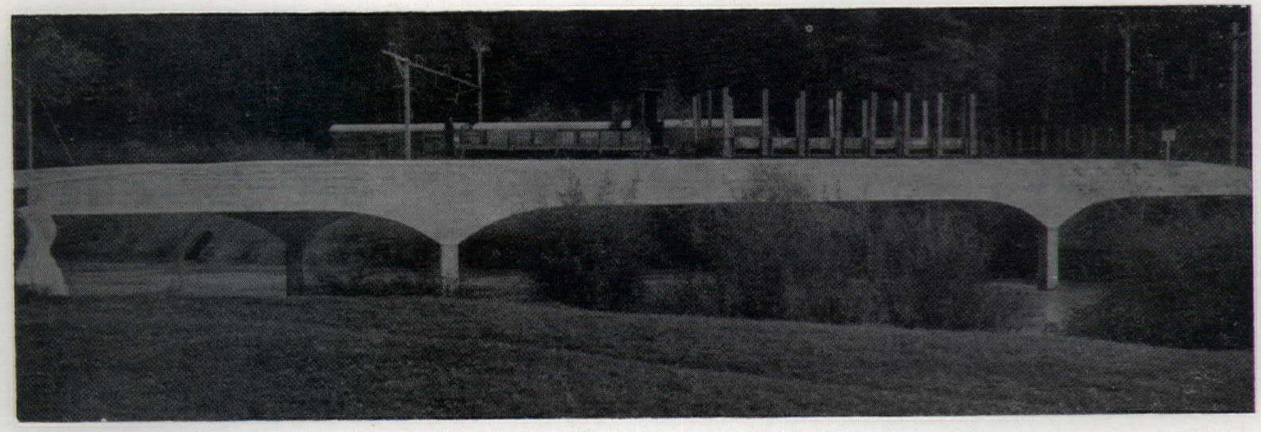
But these spans are defended more for aesthetic and other reasons than for constructive and economical advantages. The welding of their great webs is costly and complicated; and in order to construct the enormous steel sections which their flanges require, it is necessary to utilize the whole road deck for the upper flange, repeat it for the lower flange, and reinforce all the webs with stiffeners. The plate girder requires excessive stiffening and weight compared to the trussed system above a certain span and hence, its optimum field of application is found only below this span.

The lower limit of this field is determined by the strength of concrete. The necessity of making the deck of concrete, or of macadam on metal decking with its risk of oxidation, makes the use of concrete more satisfactory than steel below a certain span, and even more economical, if economy depends upon the cost of the materials in the locality.

Especially if the deck above the beams is to be reinforced concrete, it is logical to take advantage of it as the compression flange of the beam—we shall disregard the possibility of mixed structures which are, as yet, poorly developed—and make the web of the beam concrete. Its dead weight comes to be beneficial in small spans, giving the structure the mass necessary to diminish the harmful effect of vibrations. Thus spans between 25 and 80 feet are the most appropriate for solid web concrete beams and upper deck.

In narrow bridges, the Π section is the classic because of the perfect utilization of the minimum number of elements. With increased widths of highways, the transverse spans increase in number according to the demands of the slab which is to work in bending between them, but the fundamental characteristics of the type remain unchanged.

With its upper flange in compression, this type of multiple Π section bridge lends itself very well to resisting the positive moments corresponding to a simply supported beam. When the width of the valley requires more than one span, the introduction of intermediate sets of piers solves the problem very



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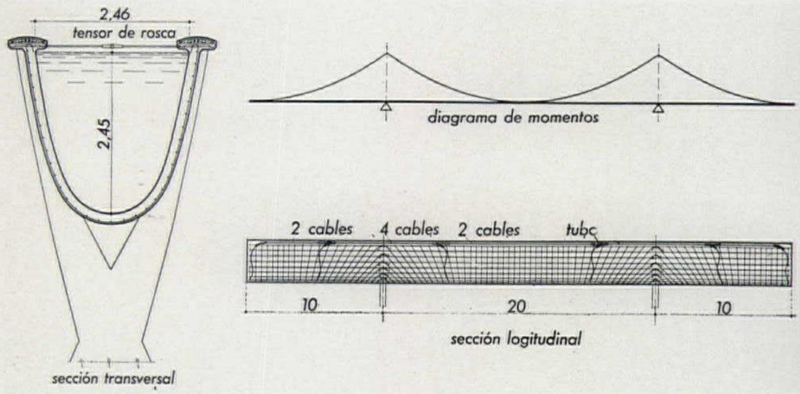
simply and economically. In this case the beam supports can be the extension of the piers, if this is the type of foundation used, simply by inserting a subsurface transverse sill to allow for errors of alignment in each set of piers, or to distribute the live load more equally over the piers in each set. In this way, the structure is statically determinate and absorbs, without difficulty, any differential settlement of the foundations.

There is no doubt that the continuous beam allows a reduction of the moment of inertia and the maximum values of the bending moment. The reduction is very great for the effects of the dead load and quite perceptible, although not as much, for those of the live load. But, in this way, there appear negative moments over the supports which require haunching of the beams (figure 6) or the provision of an extra lower flange. As this flange is required only near the support, its weight causes scarcely any additional bending and only a slight complication in the formwork.

We see that, if the free height below the grade is so small that the beams must be placed above the deck structure the deck would still be well used in a part of its length. This solution is neither visually pleasing, nor is it economical, since it requires that the beams be separated at the expense of the lateral resistance of the deck structure, and makes no use of the deck as a compression flange for the major part of each span. It is difficult for the deck slab to span without transverse joists the necessary distance between the two major beams. Consequently, another drawback of this type is that the structural deck slab supported on transverse joists is lighter than the required lower flange of the major beams.

On the other hand, the use of this type for aqueducts is quite rational because, as the load is always uniform on all spans, the maximum positive moments are reduced to half of the negative moments. And for its part, the hydraulic, or functional section conforms perfectly to this type of structure.



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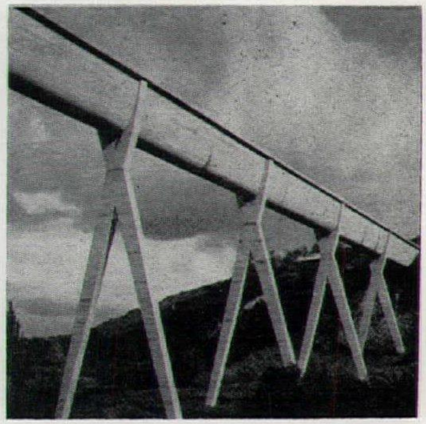

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As a particular case of it, the example of (figures 7, 8) is presented in which, in order that all the moments might be negative, one span is cut and the next is not, creating expansion joints in the centers of the cut spans. The functional requirement of impermeability of the wall is assured by means of post-stressing the tensional reinforcement in the upper flange, completed by transverse post-tensioning from flange to flange to produce compression in this direction on the interior wall, especially in the lower part where the water pressure is greatest.

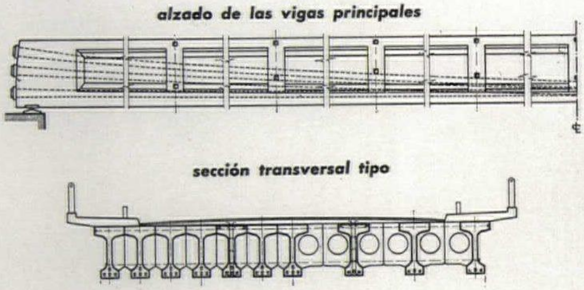
Returning to bridges, it is observed that post-stressed concrete bridges with solid webs manage to surpass the spans which are economical in reinforced concrete.

It is true that there is the Lafayette bridge in Paris with its double diagonally-braced beams of reinforced concrete in 230 foot spans; but because it is an exceptional work that has not been imitated or copied in spite of its obvious merit, it cannot be placed in this comparative view of types. Because reinforced concrete does not lend itself to triangular structures as naturally as steel, it is used more in the solid web beam which is uneconomical in excess of an 80 foot span.

On the other hand, post-stressing has attained spans of 240 feet, and with it, projects have been attempted in economic competition with the steel plate girder. It is a difficult question to decide whether, in adopting post-stressing in these constructions, various other imponderable factors of an economic nature have been involved.

For rather large spans, this technique permits the use of elements of less thickness and greater lightness than is possible with current reinforced concrete. The smaller area of its reinforcing allows a reduction of the thicknesses and an increase in unit stresses. Against this, it requires greater expense and more precision in construction.

Prefabrication, so daringly started by post-stressing, led to lighter structures by obtaining concretes which could be more carefully prepared in the work shops and which were therefore stronger.



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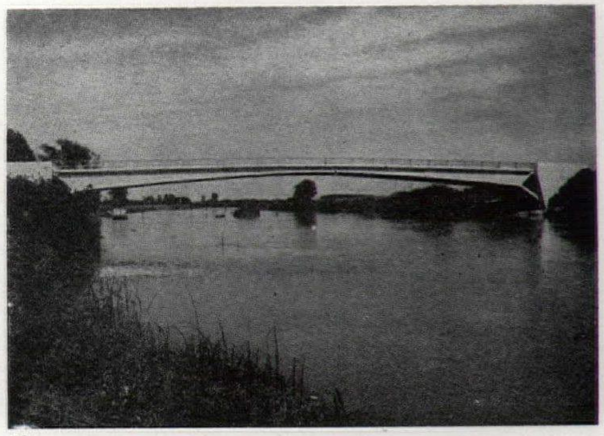

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On the other hand, as a result of this structural type, these solid web beams frequently take the form of a box or I (figure 9) because of the necessity to absorb efficiently the compression produced by the post-stressed eccentric reinforcing, and the moments which it produces in the direction opposite to those of the live load.

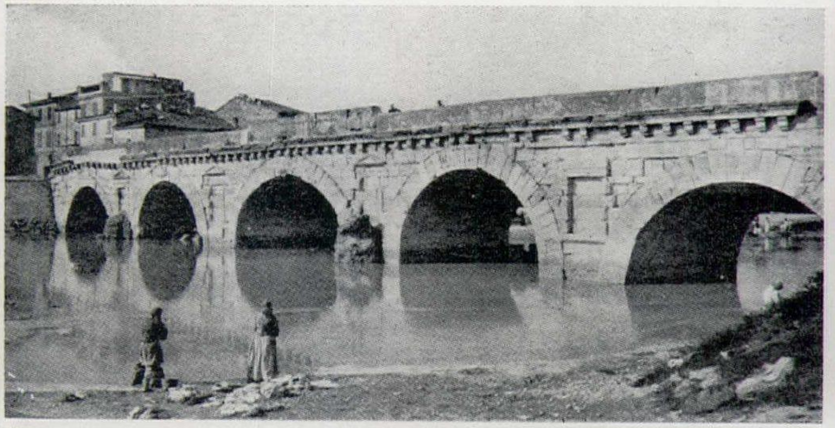
The solution of the Esbly bridges which utilizes to a great extent the action of the arch (figure 10) is possible only because of the ingenious solution developed for the construction process of assembling end to end the successive boxes which form the beams and casting them.

When the span is further reduced, the finished beams are prepared in shops and then the bridge can be built by their simple juxtaposition side by side; or they can later be made to act together by a subsequent transverse post-stressing. Their relatively small dimensions make possible economical transportation and assembly which completes their careful mass fabrication in the shop.

Finally, if the spans are reduced even more, the deck slab by itself is sufficient to span them, and one-way slabs or two-way slabs with simple or rigid supports become plausible. As monolithism reduces the bending moments in the slab, transmitting them to these other elements, the advantage or disadvantage of establishing rigid connections with these elements will depend on the thickness of the slab and on the existence of other bending which must be absorbed by the piers and retaining wall at the extremities of the bridge.

Thus we reach the case of a single span, the post and lintel; and if the span is reduced still more, the footings of the foundations can come so close together that it becomes preferable to establish a single footing forming both supports of the bridge. But then, the closed form which results is more economically solved by burying a prefabricated circular tube in the embankment of the road.

After following this discussion step by step from the impressive structure of the Golden



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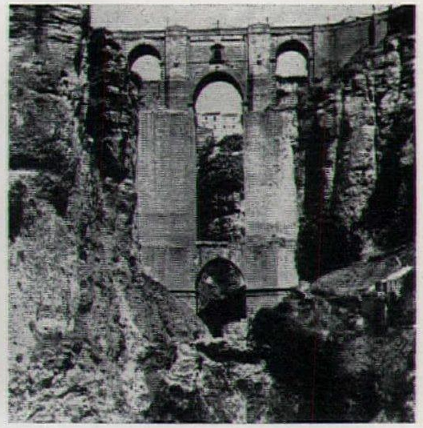

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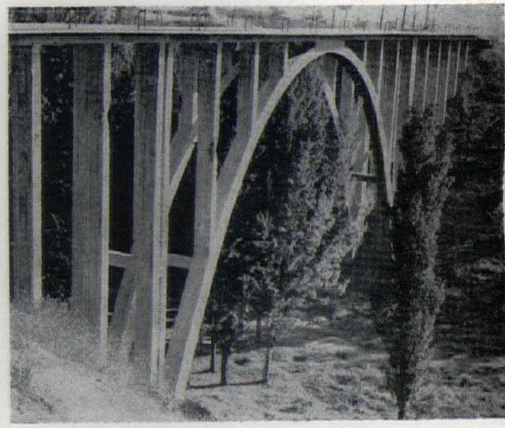
Gate down to this simple tube, there is nothing more to say unless it is to remove the tube and end the speech.

It will be necessary to retrace ourselves by another road; because, after all, the tube is an arch closed upon itself, and we disregarded arched and vaulted forms in the beginning, forms which have been traditional and satisfactory for bridges. The tube can be considered as the embryo of the vaulted bridge; the egg which through growth and successive evolutions reaches the maximum spans.

Imagine then that the modest tube increases in diameter. Soon its footing will be useless and its circular and continuous form inadequate. While the vault remains encased in the embankment, its directrices will seek the average funicular of the pressures which the latter transmits to it under the action of possible live loads acting on the pavement. Soon it will require stabilizing elements or ribs which can go on its exterior to keep the interior smooth if water is to flow through it. But as the dimensions continue to increase and the embankment, because of its greater height and volume, is more economically replaced by a bridge structure, an arch will appear with a road deck above and a light or heavy spandrel.

As long as the distance between the arch and the road deck is held at a minimum, the small economy of volume which can be achieved by lightening the spandrel causes too much complication to be worthwhile. Consequently, the vault surmounted by massive spandrels has been the classic solution of almost all arch bridges constructed repeatedly up to the last century—a solution which lends itself perfectly to the use of frangible materials (figure 11).

As long as the height of the spandrel was small as compared to the width of the vault, it was preferable to make a fill of dirt or loose stone between the walls of the spandrel. When the height was great, these walls were made so thick that they joined to form a single massive wall bounded by the extrados of the vault, the plane of the pavement, and the two



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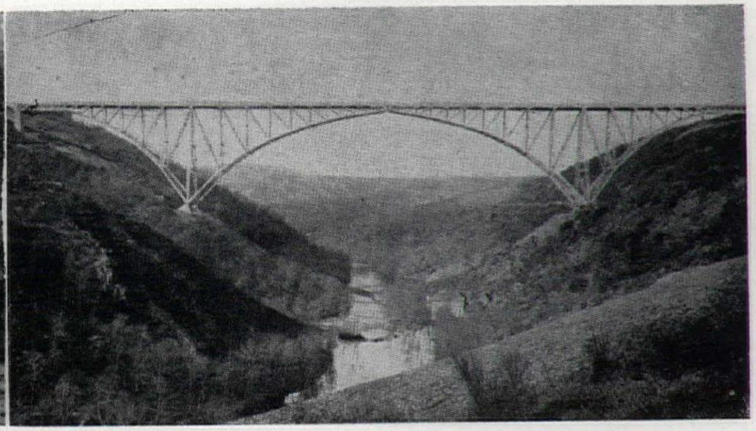

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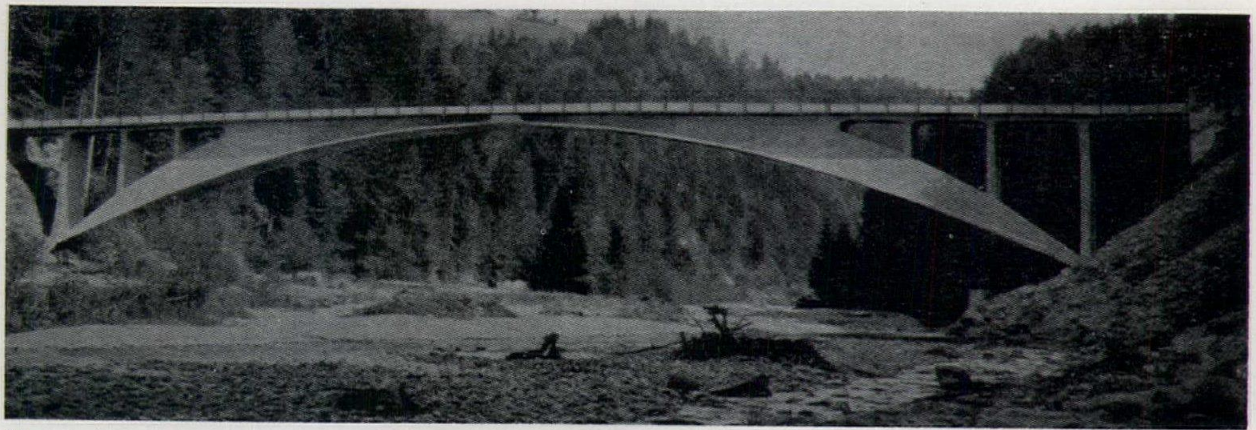
vertical planes of the facing. This is the case of the viaduct which crosses and almost fills the Ronda Gorge (figure 12).

It is understood that as the dimensions are increased it becomes important to lighten this massive wall in order to decrease its volume and reduce the load on the vault. For this purpose, some, the Romans for example, stuffed the fill with large hollow ceramic bowls; others, like the Achaemenidians or the Sassanidians of the Middle East, dared to establish longitudinal lightening by placing a series of barrel vaults on small supporting walls parallel to the spandrel wall and resting on the vault. But the horizontal thrusts of these vaults tend to cause the exterior spandrel to fail, and consequently, do not allow great lightening or great height of the spandrel.

On the other hand, rigidity in the plane of the spandrel produces high tension through the action of thermal expansion and contraction. And when stone or brick is to be replaced by concrete, contraction aggravates the effect and prevents the attainment of large dimensions; it is necessary either to hinge the vault or to try to give it somewhat greater elasticity and deformability under the influence of these forces.

The logical solution without hinges is the use of transverse lightening arches whose horizontal thrusts are easily absorbed by the abutments of the bridge. The basic arch surmounted by smaller arches, or in the more modern and simple solution, by bearing walls, which support the road deck has been repeated hundreds of times with a certain degree of elegance. The rhythm of the arcade can be extended along the sides of the valley; the small transverse walls can be transformed into isolated piers supporting the beams of the slab or can end in capitals which directly support the slab, and the lightening can be carried even further by breaking the basic arch into mutually braced twin arches (figure 13).

However, so long as the possible variations of the live load along the arch are not small with respect to the dead weight of the struc-



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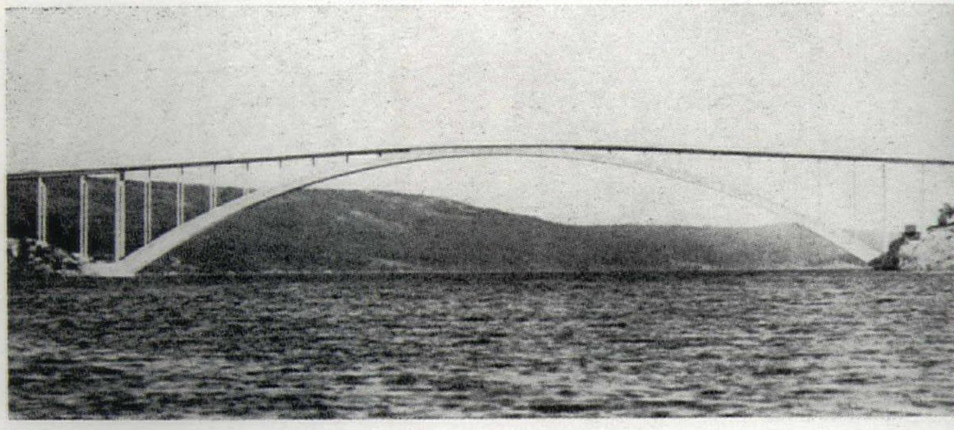
ture which, in bridges, becomes dominant only when the span of the arch attains a certain size, the arch cannot be lightened beyond a certain limit fixed by the bending produced in it by variations of the live loads. The only way to avoid bending in the arch would be to triangulate the spandrel by spreading and inclining the transverse supports, and hinge the arch to avoid thermal effects (figure 14). This solution can be economical and interesting when it is possible to provide hinges capable of supporting the compression of the arch. The type is more suitable for a steel structure than one of concrete; but even with this material, it is perfectly feasible within a certain span limit to use plastic hinges.

The type of spandrel, as well as that of the arch, varies with the proportions of the arch. When the rise is small and the height of the slab over it is small, it is natural to fuse both elements, greatly increasing the thickness of the arch through the spandrel portion and reducing it at the hinges at the center and extremities, achieving the type conceived by Maillart which is rational as well as economical (figure 15).

Given a constant span, the horizontal thrust and the thermal effect increase with the reduction of the rise. Hence it is not good to reduce the rise too much. When the low elevation of the road deck above the valley requires too shallow an arch when the arch is entirely below the deck, the arch must be raised above that plane (figure 21), in spite of the complications presented by having to increase the separation of the arches to make room for the roadway between them and the extra bracing required above the minimum height necessary for circulation.

The guys by which the slab is hung can be inclined to form a triangulation. So long as the dimensions are not so large that the dead load completely dominates the possible variations of the live load, the section of the arch is determined by the necessity of producing a relatively strong moment of inertia. It seems, consequently, that if the guys can be triangu-



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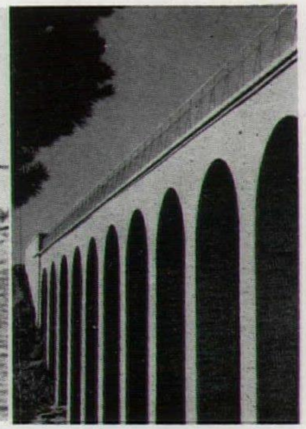

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lated, it is logical to use the triangulation to maintain the funicular of forces at the center of the arch and to be able to lighten it.

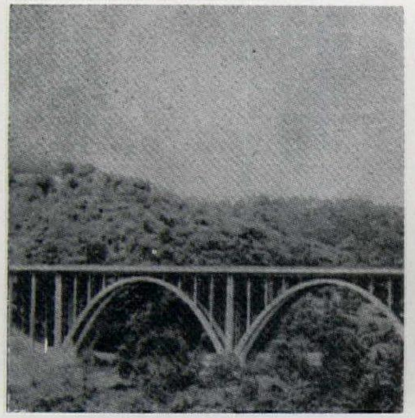
But it must not be forgotten that the introduction of this triangulation restricts the deformation of the arch, and therefore, the arch is not sufficiently flexible to absorb the thermal effects without great stress. To avoid this, the arch must be converted into one with free expansion whose horizontal thrusts, instead of being absorbed by the ground, are restrained by the deck slab.

On the other hand, when the span is great, the lengths of the diagonals are too great to work under compression; therefore triangulated arches can only present advantages for relatively small or average spans and even then have no clear advantage over triangulated beams of parallel or semiparabolic chords.

Obviously, the technician whenever possible would prefer the arch below the slab rather than above it, because the span of the deck between supports is reduced and the arch can be braced towards the center of the span. The largest reinforced concrete bridges: Plougastel, Tranneberg, Elsa and Sandö (figure 16), have been built in this manner.

But when foundation conditions do not compel large spans, it can be said that the rather small spans are always more economical. Just as a well elevated road deck is required to make a long beam solution more economical than a solution with short beams on a series of piers—whether the result is aesthetic or not does not enter into the question —the prefabricated multiple arch bridge on piers of the same material frequently competes to advantage with the long arch because of the additional cost of the formwork which the latter requires.

When the various arches are arranged one after the other, and if the live load does not act equally on all, the thrusts on those with the greater load are not in equilibrium with the neighboring unloaded arches. This difference of thrusts must be absorbed by the piers, bending moments in the latter increasing as their height increases. Therefore, as the



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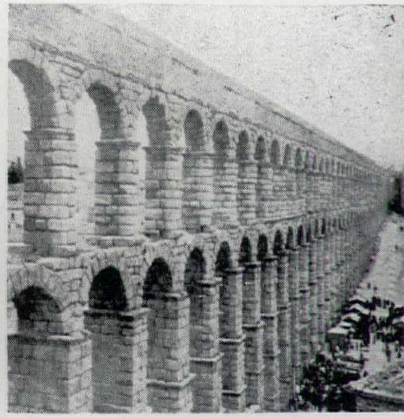

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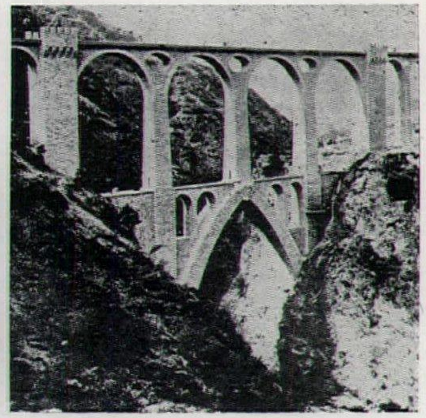

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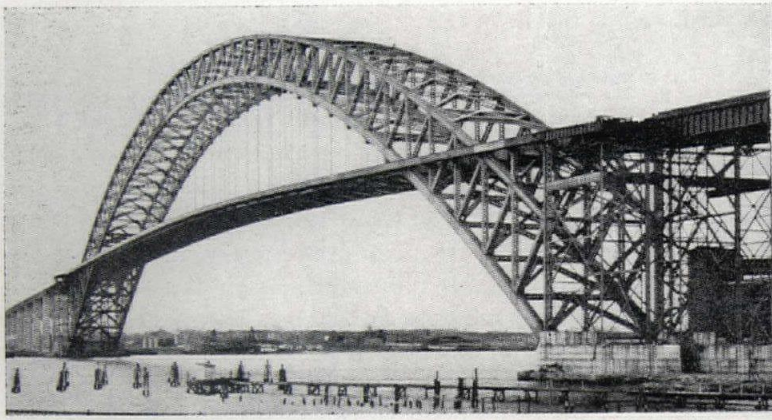
height tends to increase, the span tends to decrease. But at the same time, the number of piers must increase. Thus, the selection of the optimum span is somewhat difficult to make and usually trial and error selection is necessary in each case. If the possible variations of live load from arch to arch are small, the spans can be large; such is the case of aqueducts in which bending in the piers is zero.

In high viaducts, multiple arcades with massive spandrels present the disadvantage of great rigidity if the structure is built of concrete. This is so true that in the viaduct of figure 17 in which this type with small spans was adopted for various reasons, the engineer preferred to cut all the arches at the center and convert the structure into a series of piers with four cantilevers supporting the square slabs of reinforced concrete.

All of these difficulties and the subsequent increase in costs have caused multiple arcades of masonry, built so often in the last century, to be replaced by a series of arches in reinforced concrete springing from the ground that are more elastic and have greater spans (figure 18). Nevertheless, when masonry is economical, the traditional multiple arcade comes into its own.

The outstanding examples of this type, from the Roman aqueducts (figure 19) with their tiers of intermediate vaults to brace the piers and save scaffolding, to the great and enduringly satisfactory ones of Sejourne, continue to demonstrate the logical perfection of the type. Other materials have come to surpass them in daring and in economy, but whenever local conditions permit the economic use of these materials, the engineer will repeat the type.

The viaduct of Font Pedrouse (figure 20) with its great pointed arch spanning the deep valley, following with its two arms the funicular curve produced by the load of the pier which it supports at the keystone and its own dead load, reflecting with the series of smaller arches the rhythm of vertical piers rising up the hillside, could serve as a rational and expressive symbol of all the constructive tech-



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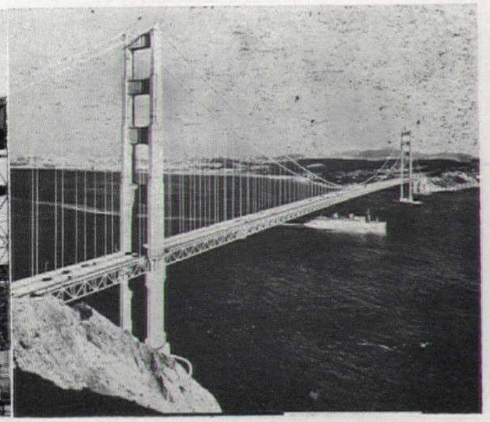

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nique of an epoch which knew how to live with dignity and to which the technicians of today owe more than many of them believe.

The materials, the means, and the techniques of today are different and their possibilities certainly greater. The lightness of the suspension bridge of San Francisco with its special steels, the grandeur of the reinforced concrete arch of Sandõ, the strength of the welded plate girder, and the subtleties of the post-stressed concrete at Esbly which are opening a new path to prefabrication, are triumphs of which the present generation can be proud; but the designer must be careful not to do away, for vanity's sake, with the simple advantages of the traditional but more modest types which continue and will continue for a long time, to compete with these in the perennial problems which continue to be of prime importance.

Now, when particular conditions demand and permit great spans, the possibilities of reinforced concrete with its great arches must be utilized. As in the case of beams, however, the economical span in concrete is less than that in steel because of its greater dead load as opposed to the greater ease of assembly characteristic of steel. The essential types of steel arches do not differ greatly from those of reinforced concrete, aside from their natural tendency to triangulation. With them, such bridges as those in Sidney and in Bayonne, New York, that attain spans of 1700 feet (figure 21), have been constructed.

Finally, when one reaches or tries to surpass these spans, the resulting sections which are too heavy for easy assembly and too light to work in compression limit, complicate and increase the cost of the arch solution. The presence of buckling begins to proscribe compression in the basic elements, and, faced with the necessity of utilizing materials to their limit, and to benefit from all the possibilities of refinement which cables in tension offer, the designer sees himself obliged to pass over the arch and go to the suspended bridge to attain maximum spans. Hence, the Golden Gate Bridge . . .

THE THING, THE VEILED SCENE, AND THE WALL

FRITZ BULTMAN

The author is an outstanding young (b. 1919) New York artist who has studied in various countries and whose work is included in several distinguished collections. The following lecture was delivered at N. C. State College in May, 1957.

I have chosen three concepts about what constitutes the visual through its emotional appeal. On going to museums that contain work from many epochs one is struck by the unity and continuity through time and space of a few basic visual concepts, and the possibility of sensing and feeling art from cultures far from ours. An eminent anthropologist once maintained that all we get from primitive arts is their aesthetic, because we do not fully understand the culture from which the art sprung—the fallacy is apparent; if this were true, art of any epoch would be totally un-understandable to a succeeding epoch; but we do understand it—besides the form, color, and iconography, we understand its joy and tragedy—its openness or secretive quality . . . in other words, its emotional content is felt and also its emotional intent understood.

With no pretension that they are either categories or all-embracing, I would like to indicate three concepts of what have constituted the visually emotional center of painting in the past and in our time. Three instinctual preoccupations of painters that come to clear expression in contemporary art . . . I will name these concepts: The THING . . . the VEILED SCENE . . . and the WALL. They interweave with each other with varied emphasis in the same and succeeding epochs . . . in the production even of a single painter. Yet each is a clearly defined attitude of the artist in his relationship to his material and to his art of painting. The material in this case is his sense of urgency toward his image. I use the word emphasis, for as color and form are interdependent and emphasized either by instinct, free will or preoccupation—so these ideas of what constitutes the core of a painting are never static, but interchanging, growing concrete and important—and then on the verge of becoming universally accepted—dissolving; all to be reintroduced in another context at another time. For the development of painting is never direct, but one that grows, reaches a point of saturation, fails and then starts in a new direction from old positions. It is a growth unknown to organisms—it is always a spiritual growth.

In reference to Picasso's *Guernica,* shortly after it was painted, Andre Gide wrote: "What matters is that it should have a center of inspiration, failing which all its elements scatter and the work must necessarily lack composition." I believe that these visual concepts that I have indicated arise out of the artist's sense of time and urgency and constitute at once the center of inspiration that Gide demands and the true subject of the artist. For it is never the single statement but the motive behind its single or multiple utterance that is the intention of painting. . . . I may paint "It is a beautiful day", once or a dozen times, but not until I have painted with the urgency and repetition of Bonnard does the beautiful day become my image. It is not the day, but the way and how that is the real center and the real inspiration.

THE THING

I have used the concept THING because, whether it be image, portrait, still life, scene or abstract concept . . . it is the immediate and urgent presentation of some thing that is paramount. All obstacles between the painting and the spectator are removed (by the painter) and the thing is presented in the freshness and clarity of the first day. It represents *isolation* and *intensity* of the material embodiment. It is somehow akin to sculpture in its aim to make us sense and feel the presence presented at the same instant as seeing. The time element is "at once". We find this quality immediately in the magically intended prehistoric paintings of animals and humans, where the absence of any scene is a usual convention. But if a scene is represented, all else is subordinated to the central bare presentation—a hunt or a rite—which is not a scene of people hunting or dancing, but The Hunt or The Dance.

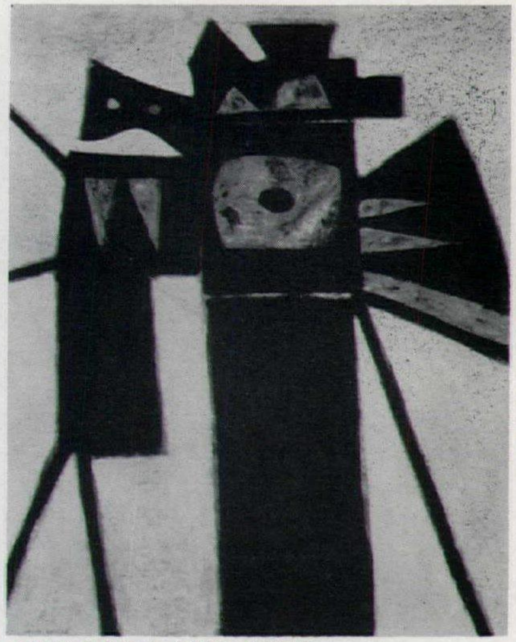
Jackson Pollock in his early painting is involved with such magical and isolated images and rites, but here the source is different. This time, instead of being the totem of the tribe or a public tribal festival, it is the interior totem of the artist—equally awesome—and the rite is that half-memory of the subconscious mind that joins aborigines to Madison Avenue, huckster and king to president. It is the totem and rite of the all-leveling subconscious. About these paintings Pollock wrote, "When I am in my painting I am not aware of what I am doing. It is only after a sort of 'get acquainted' period that I see what I have been about. I have no fears of changes, destroying the image, etc., because the painting has a life of its own. I try to let it come through."

There was no direct inspiration between this prehistoric, aboriginal work and Pollock, though he wrote of Indian sand painters, but there is an awareness of the heightened joy and terror of this world from the inside. The painting as well as the image come from different sources—it is only the urgency of presentation that is the unifying agency. This and man's ability to find within himself the needed response to the outer scene.

In Post-Abstract Painting there is less sense of the museum, less dependence on models of the past, less nostalgia than in art of the academies. There is a sense of continuity of the immediate past in the same way that Cubism is the logical reaction and continuity of Impressionism. It is a paradox. Post-Abstract painting is at once less inventive, less original in style and more original in way and more direct in content. There are "souvenirs" of Picasso's women in DeKooning's women, but something is different. They are more woman and less idol. The point of view has changed away from the brooding eternal image to something completely natural and singular. It is a quality of which Dubuffet and Gottlieb partake—it is the explicit Thingness of their art, like Rubens or Goya or Hals, who could evoke or provoke a human image against nothingness. It is the thing presented for the sake of its own intensity, like an ikon or a Gothic saint.

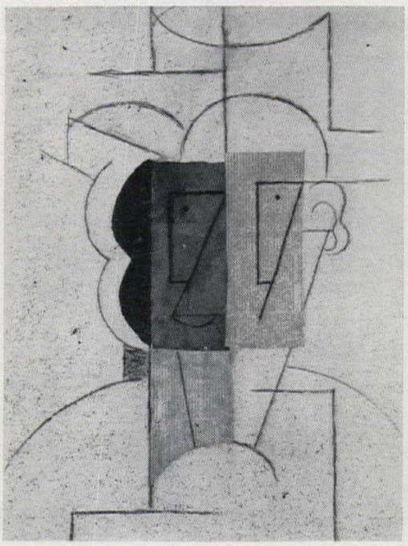
Sometimes this thing must be presented by subterfuge, as in Dutch realistic still-

The Burgundy Drinker, Jean DuBuffet
Courtesy Museum of Modern Art



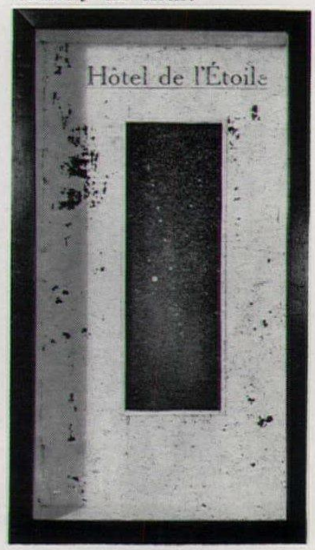
Ancestral Image, Adolph Gottlieb
Courtesy the Artist

Man with Hat, Pablo Picasso
Courtesy Museum of Modern Art



Collage, Robert Motherwell
Courtesy, Sidney Janis Gallery

Hotel de l'Etoile, Joseph Cornell
Courtesy the Artist



lifes and Harnett, where the immediacy of the thing is confusing and its rivalry with reality a sort of joke. Or again as Picasso did in his heroic collages that were a reaction to analytic cubism and in which he brought back to the totally abstracted object the dimension and impact of the thing that had been minimized or excluded from painting for almost 50 years. (These collages and the exact realistic pencil drawings of the same time that hark back to Ingres are not accidental.) These collages with their introduction of "real" material set in motion a dicotomy between the real and real and the abstract and abstract. It is but a step to Arp and Motherwell's collages, and another to the constructions of Joseph Cornell. In Arp and Cornell the concept of the thing betrays its rivalry to the natural dimensions of classical sculpture—where the materials are in scale, but the concept is not.

In these examples what matters most is the element of immediate comprehension of the exterior forms with an after image left by the impact. There is the quality often found in children's are of "see this woman" here and now, and also the after image that will be with you in memory for a long time that is a part of magic.

THE VEILED SCENE

In 1864 the Symbolist poet, Mallarmé, wrote apropos of his poetry: "Describe not the object itself, but the effect it produces" and over and over in his essays and letters occur phrases like "What I am trying to say is so intimate, so veiled, so vague, that I am afraid I have been too precise in places—and let me close with a recipe of my own invention: I follow it myself . . . 'Always omit the beginning and the end of what you write. No introduction, no finale.' " When I started to think about this paper and came upon the idea of the VEILED SCENE as a description of a large area of painting, a friend directed me toward these essays and letters. Not identical in program, but akin in ultimate effect, the Symbolist poets and the Impressionist painters were supremely aware of the mystery of the VEIL of light and shadow that at once reveals, unifies and obscures. This veiling by light and shadow that has been one of the preoccupations of painters since the early Renaissance—and I am thinking of Massaccio and Leonardo—that is, for me, the center of painting in its artfulness. It causes the spectator to wonder, to linger, to return and only slowly reveals its full content layer by layer. Light and shadow are not the only means of veiling . . . we are now faced with the multiplication of the thing until it loses its single identity . . . the obstacle that hides the thing . . . the metaphor . . . the allegory. Time is delayed and memory and reverie and wonderment are involved. Here we have the fullness of the means of painting, for as the THING infringes on the rights of sculpture and thereby limits its own function, the WALL wishes to include architecture in its province. The eloquence of this type of painting lies in the inability of the artist to speak, to reveal fully *all*. One is aware of the painting's continuity beyond the frame and beyond the limits of the space involved. The spectator has been made to move back a pace in order to take in, to penetrate the apparent presentation, for in this vision we are never

Agony, Arshile Gorky
Courtesy Museum of Modern Art

The Attic, Peter deKooning
Courtesy Sidney Janis Gallery

Corot, Courtesy Metropolitan Museum

Guernica, Pablo Picasso
Courtesy the Artist

quite sure that we have seen everything, or if we have, quite what is meant by it. For me, the idea of Corot's painting is one symbol of this vision. How gradually over the crystalline clarity of his Italian landscapes he drew the veil of trees and leaves and introduced his nacreous figures all lost in light and reverie. The other symbol is Picasso's *Guernica* in which, faced with his immediate reaction to a terrifying human catastrophy, he used symbol and metaphor to the utmost to manifest that gamut of feeling and reaction. "It is the invisible harmony that surpasses the visible," by clarifying it to the feeling through the veiled rhythms.

From this point it is possible to understand Pollock's paintings that followed the *She Wolf* and *Totem* and realize that these images are there too, but purposely obscured and generalized. Or to examine the early DeKooning paintings like *The Attic* and realize that this is not an abstraction, but a situation, one that is straining to emerge. Pollock's image underwent several of these changes, of veiling by paint and of being revealed.

In speaking of his early painting Rothko wrote: "I think of my pictures as dramas; the shapes in the pictures are performers—They have been created from the need for a group of actors who are able to move dramatically without embarrassment and execute gestures without shame—neither the action nor the gestures can be anticipated or described in advance. They begin as unknown adventures in an unknown space."

In writing this Rothko took in not only his own painting but those other painters for whom the gesture with its echoes of other existences, the vegetable and the insect for example, masks and intensifies the directness of their expression. I am referring to Matta's and Gorky's agonized figurescapes, where a frightful but beautiful drama is unfolding. The existence of the painter's world is implicit in a meaningful gesture, whose vitality and expression lie in their allusions to forms specifically non-human.

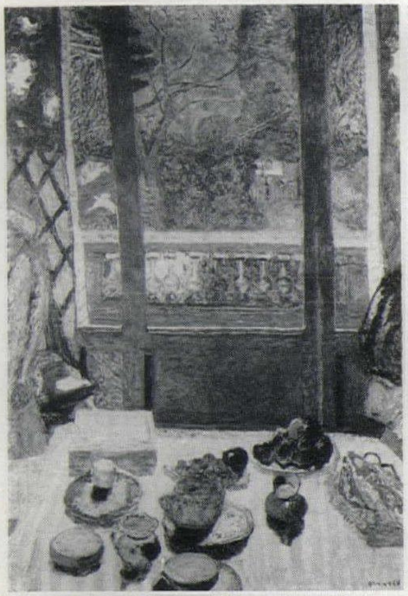
Thus, by the veil of light or paint or symbol or allusion, the painter is able to produce his own position in regard to the spectator and in regard to the reality of time and space. His own position and atmosphere, his climate—we are dealing here with just these properties . . . the situation in space and time that is expressive of the whole inner and outer world of the artist. It is the situated appearance of the artist in the universe.

THE WALL

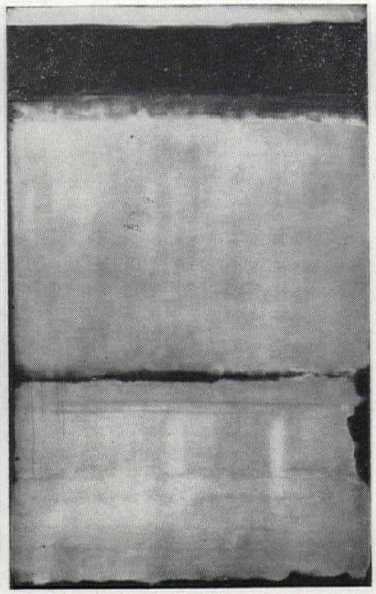
When a painter comes to a clear understanding of his position in regard to his own work, there is always another avenue to explore—this is more by instinct than design. When Rothko wrote the foregoing statement his painting must already have been in that transition that precedes change. For when the painter needs to pass beyond the subjective and conceives his art as possessing absolute value outside change and fashion, there is the WALL. Sometimes it is expressed as mural art, as in Roman wall decorations.—Scale plays an important part in this vision, but not necessarily. For Mondrian's paintings are modest in scale and they are the most intense expression of this impulse. Detachment from the particular and the personal are more important, for this lets the expressive means of the medium, color and form, come to fruition—and the purity of the means freed from expressing the singular and unique gain great vitality and robustness, and standing for themselves thereby gain another expressiveness. For each of us knows in daily experience how the appearance of abstracted colors or forms can affect our mood and feeling—a spot of red on a dark day, for instance.

It is strange that one of the painters to paint in this direction and to demonstrate that the WALL is not of necessity bare of simple human dimensions is Bonnard, who refers in his Notebook to making a painting as a modiste does a hat and of how a painter can learn much about his art from the charm of a beautiful woman; perhaps by this observation he means her unawareness and lack of self-consciousness. For somehow by stressing the commonplace and the ordinary and negating the ephemeral, he is able to detach his art from the changing conditions of daily life at the same moment as depicting it. He creates his image of the WALL by a fullness of means neglected by the Impressionists from whom he sprung—by "a fullness of means". I wish to explain how his color and form, instead of creating the picture of light-filled form such as Monet creates the light itself. But above all he reawakens for the modern world that deceptive impassivity of the WALL itself. He was fully aware of scale as a contributing factor—for he states that for certain concepts, a certain size is necessary. The figures, the furniture, the interiors, are not just bathed in light, but each creates its own light, a light that pushes toward the surface of the canvas. Mondrian saw his own painting as a rending of the VEIL, he wrote, "It is my conviction that humanity after centuries of culture, can accelerate its progress through the acquisition of a truer vision of reality. Plastic art discloses what science has discovered; that time and subjective vision veil the true reality."

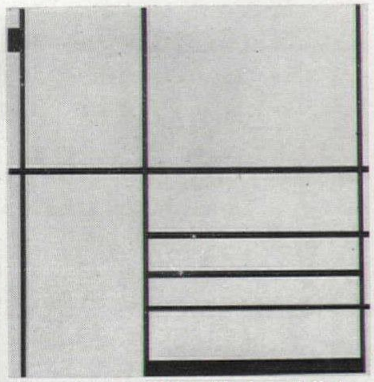
Mondrian in such statements reveals his committment to a positivist attitude toward life and painting. At no time in the history of painting has any single painter recorded in words with such clarity and profundity his position as a painter. He offered his art as an island of calm, a point of dynamic equilibrium in a world where man is really oppressed by time, by illusion and by the subjective. There was a tremendous urge in his art to create a form in painting that had the fullness of nature, yet was completely poised and balanced —completely man-made and artificial in the deepest meaning of this word (wrought purely with the means of art), to compete in one way with nature, yet in another more profound way to unite his creation with nature, or to create another order of nature that we call the Classic. As the Greeks purged their demons and the oriental gods of their magical and monstrous aspects and created their Olympians—so Mondrian "saw the tragic in a wide horizon or a high cathedral" and by his conception of total space . . . "actually all is space, form as well as what we see as empty space" . . . and of rhythm. "This reduction of form and color—a freeing of form and color from their particular appearance in nature—



The Breakfast Room, Pierre Bonnard
Courtesy Museum of Modern Art

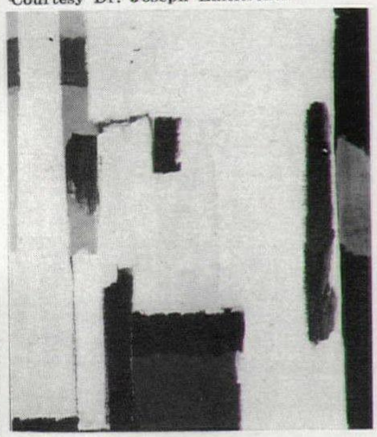


Number 10, Mark Rothko
Courtesy Museum of Modern Art

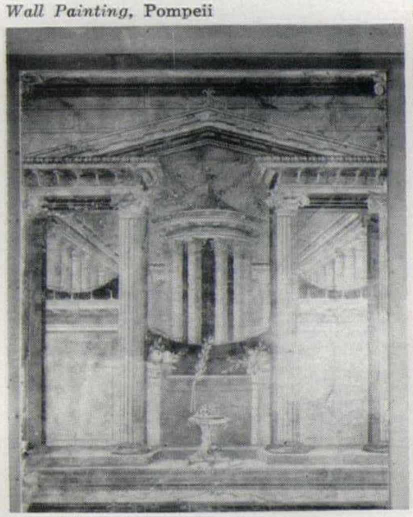


Composition in White, Black, and Red
Piet Mondrian
Courtesy Museum of Modern Art

Untitled, Giorgio Cavallon
Courtesy Dr. Joseph Ealtitscheil



Wall Painting, Pompeii



T, Adolph Gottlieb
Courtesy Metropolitan Museum

Botticelli
Courtesy Metropolitan Museum

is necessary to free rhythm, and consequently art. Clearer rhythm produces clearer equilibrium." By these means and a passionate attachment to these means, he created a great Classic form. In a way his art is the ultimate of the European tradition and planted here will bear fruit for a long time. For his art does not contain only the culmination of a style, but rather a new way of seeing and examining reality with a firm conviction of ethos and objectivity. On a purely technical level, Mondrian's insistance on the ultimate two-dimensionality of the painting, its apparent passivity and control of parts, has given to the following generations of painters in this country a sense of the picture that is a standard to measure against.

Rothko by intuition and feeling carried his free moving "dramas" into the area of the deceptively quiet WALL. He bypasses the whole early 20th Century struggle, of form versus color that so preoccupied Mondrian, and wed the Roman wall to the Chinese banner. For him the two-dimensional wall becomes "the body of light". Every part is at the surface of the canvas and what started as the embellishment and complement of the wall ends by dissolving it into pure light.

I have used the words "deceptively calm," "deceptively passive" in this section, for I would say that this is the feeling of this type of painting—it stands way back and it is the art that you must go toward, for its surface is not that of enticement and allure. It is the artist saying "here is the distilled essence . . .take it or leave it". And if you go and penetrate the surface that may at first appear as decoration, you will find purity, balance, equilibrium and something imperishable.

This has not been an attempt at mere classification, but rather one way of viewing what might otherwise seem a proliferation of private styles. Art never becomes private by being personal, but rather the opposite. If we calculate too much on the present, the effectiveness of the work is limited and lost to the future. There is more danger in meeting the models and standards that society and our fellow artists set up for us than in being concerned with the conviction of our private selves. For the artist, the act of painting is a manifestation of the human position, "the unification of man with the universe."

These comments give no license to reactionary ideas or artistic laziness. On the contrary, since a painting is at its conception a part of its time, and at its finish a part of the past, the artist has not as his duty or obligation but as his extreme position the exhortation "To be absolutely modern." You cannot escape it; a painting in *trompe l'oeil,* to name an exaggerated case, betrays the time in which it was painted—despite any historical interests of the artists. It betrays its time, today in the real sense of the word too, for I believe that never before in the history of modern painting have the avenues to it been so open, been desired so open by the public. A painting expression, so long as it presents that "feast for the eyes" known as the plastic condition, and if it is a true manifestation of the human position of the artist, will find its place in time. This is inevitable.

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