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Construction Economy through Engineering Research and Design

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Synopsis.

What are the possibilities of achieving construction economy through research and design is eminently demonstrated by living examples of two federal organisations in North America. They are Bureau of Reclamation, U.S.A. and the National Research Council, Canada. Both of them were established under unavoidable circumstances when government participation in these major adventures was a pre-requisite for development of vast natural resources and arid lands in the two countries. In America the major burden of national research and design practice is borne by private enterprise while the Bureau is engaged only in a specific field of water resource development with its activities as a federal agency. In Canada, on the other hand, the National Research Council is responsible for conducting research in all the possible fields which are essential for building up that vast land--climatically a problem, so thinly populated and so richly gifted with unlimited resources of nature. Direct participation of the government to handle any major projects which serve as a key to open up its resources is necessary in the early history of any country.

However, with the passage of time more and more responsibility is shared by the private enterprise and the initial federal activity serves as a kick-off force. Signs are already there that Canada is following in the footsteps of the States in this respect. The Research Council is finding it necessary to derive strength from a chain of private research units which follow a coordinated policy.

Pakistan is a newer country than Canada even. It has the problems of any newly created country in the world and in addition many more due to its limited resources and geographical anomally to bridge up two independent halves through air and sea links.

Even though it abounds in man power yet there is extreme dearth of technical people. It has a vast undeveloped area but there is scarcity of diverted water and electric power. It is short of forest wealth because

soil erosion and other destructive forces have denuded its hill slopes and its plains. It has some promising sites for multi-purpose projects, yet there is dearth of machinery and external finance to translate the paper schemes into physical achievements. Its rivers are a potential source of fertile silt laden fresh waters which cause recurring flood havocs and dump themselves into sea as waste. There may be hidden mining wealth in its mountain frontiers which have yet to be investigated and utilised. There is absence of a communication system to open up these land-locked areas. It is apparent that no other country can benefit than Pakistan from research and engineering designs aiming at maximum economy commensurate with set standards of quality under its present needs. It should be useful therefore for us to study working of foreign bodies from this angle and examine the part research and well balanced designs are playing to promote their objective of accelerating pace of development with maximum efficiency and economy. The author of this paper had an opportunity of visiting both the Bureau of Reclamation and National Research Council during 1954 under the auspices of the United Nations Technical Assistance Administration. He has touched only that aspect of their working which can illustrate their performance through research and planned designs. The paper aims at giving an account of pertinent achievement of those agencies and their possible application to our conditions and benefits.

Bureau of Reclamation†

Historical. This body took its birth 54 years back to implement the Reclamation Project Act of 1902 which was promulgated by President Theodore Roosevelt for the development of the 17 Western States. The first settlers found that vast uncivilized area just a land of rolling prairies, sage brush deserts and rocky chains. The precipitation was meagre and climate dry with abundant sunshine. The rivers were fed by melting snow on the towering mountains but flowed untapped into sea causing major flooding problems and large scale destruction in their wake. In the initial stages the task before the Bureau was quite simple of constructing small dams to achieve diversion of river waters which as compared to the major projects built later appear dwarfs and just "Beaver dams" in constrast. Gradually with utilisation of the easily available resources, the problem of water diversion became increasingly difficult. It was a major task then to transport water from surplus area to the points of shortage. The organisational set-up of the Bureau which started with a simple origin both in the office and the field was compelled to grow to be able to meet the challenge of problems which attained more complications and threatening volumes. A number of fact finding committees set up by the Congress and federal officials thoroughly scrutinised each and every acivity of the Bureau. Land users opposition and the label of "Reclamation Cacket" had to be boldly met by this body. These measures were dictated by the fact that large sums of money had

†The word 'Reclamation' is used in a different sense in America from our conception of reclamation of fully developed and irrigated lands gone out of production for various reasons. There reclamation means development of virgin soil and making it fit for irrigation and Agricultural production.

been placed by the Government at the disposal of the Bureau, correct utility of which had to be ensured by the federal agencies in the best interests of the settlers, The construction of Boulder Dam (Hoover Dam now) which controlled the Sorrowful Colorado is a land mark in the history of the Bureau. Through this evolution of engineering skill reclamation projects were executed to encompass hydro-electric power, irrigation, industrial and municipal water, flood control, check against detritus, silt and salinity, afforestation, recreation, fish and wild life and other direct as well as indirect benefits.

During 1952 at the time of celebrating its golden jubilee the Bureau had a record of gigantic achievements to present. With a total investment of 250 million dollars in 50 years of its existence it constructed approximately 200 dams, 19,000 miles of canals, developed 6·7 million acres of land, settled 2 million persons, installed 48 power plants generating 4×10^6 k.w. power, erected 350 pumping plants, built 200,000 irrigation structures and 9,400 miles of transmission lines. In addition a large number of linked works like railways, roads, community settlements, etc., were also constructed. The outstanding achievements are: Hoover, Grand Coulee and Shasta dams, Tracy pumping plant and developments of Colorado, Columbia, Central Valley and Missouri River basins.

Financial justification of the Bureau's existence.

It has been estimated that nearly 40% of the invested capital has already been recovered by the B. O. R. through direct benefits. The cost of land which has been developed through these works and the accummulated value of agricultural production far exceeds the federal investment. Indirect benefits such as flood control, improvement of health etc., if evaluated will raise the level of returns still further. It has been estimated that Central Valley Project (C. V. P.) in California alone has achieved a flood protection benefit against Sacremanto and San Jouquin rivers totalling 7·9 million dollars.

Present working.

The activity of the Bureau though slightly curtailed these days still demonstrates interesting problems. The American River Basin Act approved by the President in 1949 introduces a new formula for a joint venture of construction of Folsom dam between the B. O. R. and U S Corps of Engineers. Colorado-Big Thompson Project, which is underway, is a magnificent addition to the Bureau's outstanding record of achievements.

Activities in the foreign fields.

It was natural that with a vast experience of land and water resource development within America the world should look to the BOR for solving similar problems in foreign lands. The Bureau recognised the need for placing its technique and useful experience for strengthening fight for other nations against hunger and want and started a foreign operation administration wing just prior to commencement of the present Republican regime. Just at a time when their experience started to flow for the benefit of distant lands, they had to close the foreign activity which took its rebirth as International Co-operation Administration (First as T. C. A., then F. O.A. and now I. C. A.) as an independent organisation. Many of the workers on this body are drawn either from BOR or US corps of Engineers; the two set-ups having maximum planning, design and construction experience in the United States.

Need for research and design.

(1) **Growing needs and complications and diminishing resources.**

With increased development a large number of problems and complications had to be faced by BOR. The initial simple and easy-to-conquer development facilities having been exhausted, they were compelled to look for new avenues to meet the growing demand of settlers. The original settlers who were pioneers in development of the western states underwent real toils and made things rather easy for the late West bound land users. Then started the land rush. The development of valleys and basins by these people interfered with natural flow pattern of the water cycle Flood problems became serious. The demand for water for use on the land for drinking purposes in municipalities, for industrial and power needs and other necessities for life know no limits. The Vanishing "Frontier" conception meant an alarming load on the Bureau because it had to meet the challenge of multiplying population. Once more difficult tasks had to be surmounted. Higher dams had to be built to store maximum possible quantities of water, generate more power, protect additional areas against floods. The sites which were rejected in the first choice because of poor foundation conditions, active seismic activity, very difficult terrain for temporary river diversions and construction problems had to be developed as a necessity. Water flowing at lower levels had to be raised to great heights by gigantic pumping sets to meet priority in demand. Continental divides had to be pierced through to effect long transportation of water from surplus areas to the water hungry lands. River basins in one zone had to be diverted to feed other basins. Central Valley reclamation has been achieved by 500 miles of water transportation from the Colorado river. The Colorado—Big Thompsom Project which is under execution aims at diverting the Colorado river basin on the western slope of the Continental Divide to the eastern slope.

(2) **Co-ordination to interstate, Federal and International interests.**

The B. O R. has to co-ordinate its working with a large number of federal as well as state agencies; a large number of national standing committees, commissions, etc. before it can translate any of its scheme into reality. For the sake of its reputation and existence it has got to put up real sound schemes based on thorough investigation and most attractive design features. For example, the project plan for the Colorado-Big Thompson Project has been reviewed by the National Resources Committee, the Committee on Irrigation and Reclamation of the U. S. Senate, the U. S. Department of Agriculture, the Colorado State Planning Commission and other federal and State agencies besides many consulting engineers. The proposal for the development of Columbia River Basin, as framed by the Bureau, was subjected to a detailed criticism and exhaustive comments by the affected states of Idaho, Montana, Novada, Orgon, Utah, Washington and Wyoming. It was also examined by U. S. Departments of Army, of Agriculture and Commerce and the Federal Power Commission before it could be called a co-ordinated plan. Similarly the project for development of the Colorado River basin was criticised and commented by the affected states of Arizone, California, Colorado, Nevada, New Maxico, Utah and Wyoming. It was examined by War Department, Department of Agriculture, Federal Power Commission in addition. The major headings under which plans and interim reports are scrutinised are :—

(*a*) Scope and purpose.

(*b*) Division of water.

(*c*) Consumptive use versus stream depletion.

(*d*) Urgency for early development and obstacles to that development.

(*e*) Basin concept.

The Bureau of Reclamation besides putting up with the comments from the above bodies has also to meet searching quaries for Congress Canal Committees and international commissions for the international projects with common use to Canada or Maxico.

(3) Conflicting requirements of multi-purpose projects.

The conflicting requirements of multi-purpose projects throw a challenge to the engineering skill in design and research so as to produce optimum results. Some of the outstanding features for such a study are enumerated here :—

(*i*) A storage reservoir which caters for best irrigation service should be full in summer and then be drawn upon to feed the reducing supplies in the rivers during periods of water shortage with regulated supplies to prolong the availability of flows for the maximum part of the year.

(*ii*) A hydro-electric power reservoir should be full at all times for the high head maximum power generation.

(*iii*) Flood control and regulation capacity of a reservoir should be available to the maximum degree especially after floods so as to cater for the next floods.

(*iv*) Water requirements for municipal and industrial needs make it imperative that the reservoir should be full during summer and water be available to augment the low stream flows so as to check against the threat of water pollution, extra load on water treatment cost due to the deterioration in the water quality and water shortages.

(*v*) A reservoir which caters for navigational requirements must maintain a pre-determined level to provide a minimum draft to the craft.

(*vi*) Reservoir supply for salinity control should be maximum to keep the highest pressure of fresh water against salt water intrusion.

(*vii*) Reservoir which caters for sediment problem should be empty except during flood flows.

(*viii*) A reservoir which is to meet the sanitation needs must have maximum storage of water for all times for proper purification of the effluents.

(*ix*) Fish and wild life demand that reservoir should be stable in its volume of water during spring and summer to protect fish growth and plant food.

(*x*) A reservoir which has to provide for recreational henefits and promote tourism should be full or nearly full at all times.

(4) **Operational problem.**

The Bureau handles operation and maintenance of water development and power projects both on a long range and an interim basis. It is able to test the efficacy of the research in the labs and the truthfulness of designs. This makes its knowledge more mature and provides necessary confidence for undertaking a major task on which it was to embark. Operational and maintenance needs dictate the setting up of a very efficient research and design organisation which should provide quick solution to the problems as soon as they menifest in the field, causing minimum possible dislocation to the service. There are quite a large number of laws relating to water users' enterprises which bring about complications. An idea of a a wide variety of these interests may be formed from the following list of water user's enterprises :—

(*a*) Individual and partnership.

(*b*) Co-operative and mutual.

(*c*) Irrigation districts.

(*d*) Commerical enterprises.

(*e*) Bureau of Reclamation.

(*f*) State enterprises.

(*g*) Bureau of Indian Affairs.

(*h*) City water and city sewerage disposal.

(*i*) Miscellaneous.

The design standards, operational and maintenance schedule and the very planning is influenced by the water user's interests which an organisation like the B. O. R. has got to respect.

(5) **Cemmerical aspect.**

This brief account may serve to give an idea under what freedom of action and limitations the Bureau is permitted to function. It has to cater for a large scale private interstate and federal and international interests within the framework of fixed laws. It has to put up with the diminishing trends of cost-benefit ratio on many of the new development projects—single purpose or multipurpose due to reduction in the volume of resources and rise in construction costs. Agriculture slump tendencies in America have to be put up with. Liberal surplus food products disposal by the country to help feed other lands of the world is a policy which does not help in boosting up the internal agricultural economy either. There is a bitter opposition to the present federal undertakings of bodies such as the Bureau and tendency is more towards private enterprise. The number of checks and watch dogs is becoming a developing labyrinth in her way of working. Under a shadow of all these handicaps and in such an unfavourable atmosphere, the Bureau has to make each and every project it handles an attractive and commercially sound proposition. The reimbersable costs repayment must be ensured within a period of 4 years for irrigation projects, counting 10 years as the initial development period with interest free stock provided by the Federal Finance. In case of commercial electric power and municipal water the repayment must be ensured within a period of 50 years with interest.

How then is the Bureau of Reclamation able to meet conflicting requirements, work under serious limitations imposed and still provide an attractively cheap water and power service to land users ? The following part of the paper will provide an answer to this question.

General.

It is impossible for any organisation like the F. O. R. to accompiish such a large scale construction, surmount limitations of site and resource availability and plan for provision of most efficient source of benefits with maximum economical project investment without a proper backing of research and a continuously improving design service. The Bureau could avoid major construction hazards in the field and guard against wastage of public funds through a system of advance research with models. The designers had gained enough confidence by testing the structures not only in the laboratories but also in the field and particularly through operation and maintenance. Such a complete organisation consisting of planning, design, research, construction and operational activity had built up enough experience commencing with a humble start, to give adequate confidence to its workers to tackle more complicated and difficult jobs as the time went on. This is a record of continuous expansion and growing improvement as dictated by the prevailing conditions. Situation created by world war II and then the Korean War demanded first priority of national materials to feed the battle fronts. Paucity of construction materials, machinery and men during such emergencies impose major restrictions on a body like the Bureau. It could survive only if it had the requisite force of research and design to adjust its requirements through alternative sources without losing strength and economy both in the first cost and operation as well as maintenance of the structures. Research has to provide quick answer to make substitute materials available for which co-operation of and co-ordination with private industry is of first importance. Effects of departure from the standard materials have got to be indentified. Designs are adjusted according to the materials which are forthcoming. The fundamentals of achieving the same cost benefit ratio or rather improving upon the existing financial feasibility through conventional practices is never relaxed. Such a flexibility in working, quick readjustment to new standards and design criteria and even the procedure of "design as you go" on rush jobs can only be possible if the administrative set-up of a body caters for such arduous responsibilities. Such quick adjustments are possible only through continuous process of research which should keep on investigating into alternative raw materials, utility of locally available indigenous deposits and industrial products, substitutes for the existing construction machinery and methods of its use and new techniques for money saving. The standard designs should be well defined to cater for set specifications but should also permit adjustment at time of need as demanded through modifications in the guide specifications and other construction exigencies. This the Bureau is wonderfully equipped to achieve and has already given ample proof of its capabilities in this respect through actual performance.

Engineering Centre.

The engineering centre is the focal point of large scale technical activities of the Bureau which is handling all sorts of problems on the field of reclamation engineering. It is located at Denver, Colorado, where teams of engineers, technicians, physicians, chemists and geologists are engaged in solving the complexities of proposals as they are received from the field districts. The hydraulic, soils, concrete, structural, chemical and other laboratories with which the centre is equipped are among the most comprehensive set ups in the world and eminently provided to solve water resource problems.

Research.

All types of research ; analytical and experimental has rendered major contribution to the progress of reclamation engineering. Research has introduced new ideas, concepts, materials, and methods by dint of which construction economy could be achieved without forsaking strength of structures. Research has to function as a co-ordination link between the preliminary site feasibility study, survey in the field, laboratory tests, design activity, field construction and operation. Each and every phase of the project activity has to be subjected to scrutiny of a well co-ordinated research procedure so that increasing magnitude of improvements are introduced at all stages of the work. Research is the only means to provide an advance answer to the suitability of a particular structure under given set of hydraulic, climatic, physical, geophysical structured and geologic conditions. If one would compare the small cost on research with the cost of the present as whole and consider the benefits derived from it, it would appear, it is certain that it more than repays itself. It is difficult to estimate the financial savings in exact terms which research achieves by serving as a guard against construction mishaps and costly failures in the field. Research has played a dominant part in Bureau's past achievements and is destined to have a major impact on its future undertakings.

Site survey and feasibility studies.

Selection of site for a multipurpose project is governed by definite considerations. Requirements of data needed for the purposes of research will however provide a specific guidance to the field engineers as to the lines on which they must proceed to assimilate this information. For example investigation for the economic, agricultural and engineering feasibility of land and water resources call for a lot of information from the the field. The procedure for measurement of rivers, data regarding their hydrologic characteristics, snow surveys, run-off forecasts, gauge-discharge corelations has to be streamlined by research so that it can serve the best utility in irrigation, storage, power generation and flood control designs. Research organisation may also render indirect assistance to check up the application of water laws, water riparian rights and international agreements to the proposed development projects. Similarly the information which has to be collected for research purposes in connection with electrical studies such as location of the power house, net work analyser system for examining the electrical transmission systems and the economic feasibility of power demand points will clearly identiiy the information needed during site survey and feasibility studies of a given project.

Such feas, bility studies also include examination of foundation conditions, geologic problems, seepage losses for the storage reservoir and ground water conditions. Geologist and material experts have to callect all possible information about the local building materials at site for concrete, earth and other strnctures proposed. Similarly drainage of lands earmarked for irrigation, salinity control and reclamation of areas already gone out of production should receive due attention in the feasibility studies. It can be briefly expressed that presence of a research organisation will be a blessing to lay down concrete steps and details of the data which should be collected from the field for purposes of making different studies. Such as record will be helpful not only for research but also for design requirements.

Analytical studies.

Research activities can be broadly classified into two categories, analytical studies and the laboratory Research. With the introduction of large scale application of electronics quite a substantial help has been rendered to the engineers in solving analytical problems involving higher and complicated mathematics. It has thus been possible to solve many problems in the realm of stress determination and made knotty design problems which were declared indeterminate so far. These analytical studies are generally used to check the accuracy 0f designs through special instruments wherever needed and pave the way for new ideas and improvement on the current designs. Those problems which are of a specialised nature and outside the realm of analytical studies are undertaken through laboratory research.

Some of the important analytical studies made by the Bureau which are outstanding on their programme are listed below :—

1. Cooling of Mass concrete.

Application of Heat flow theory has been studied as an economical method of cooling of mass concrete on large dams. It has already effected oonsiderable savings on the conventional methods in use previously.

2. Earth Dams.

Useful analytical studies for earth pressure and stability have been made in connection with earth dams and other structures.

3. Reservoirs.

Problems such as forcasting seepage from reservoirs, deformation of earth's surface below the reservoir sites and in their close proximity have been studied through analytical methods.

4. Wave analysis.

This has been determined from canal flows and also connection with erosion phenomenon of stored water in reservoirs etc.

5. Hydraulics.

Studies for hydraulic engineering cover, flow in open channels (including those under tidal influence) and examination of hydraulic machinery and structures, in detail. Problems created by operation of pumps, turbines, valves, gates, governors which tend to cut down their efficiency and economical services are investigated and eliminated. For example water hammer and surging phenomena enalysis are very useful to ensure proper working of penstock, pumping suction and delivery mains and underground irrigation pipes. Control of water hammer studies through surge tanks and air vessels has yielded very beneficial results.

6. Mechanical problems,

Application of analytical studies to mechanical field is quite interesting. It centres round stress analysis of different types and shapes of shells such as cylinderical, spherieal and conical which has helped solve a number of complicated design problems. Such a research has helped to increase the length of unsupported pipe span through improved system of design. Stiffener-ring and shell analysis conception has contributed considerable saving in reduction of number of supported joints and saving in cost.

7. Structural field.

Analytical research in the field of structural engineering has been an outstanding achievement at the engineering center.

(*a*) Stress analys is.

Analysis of stresses in curved gravity and arched dams by trial load design method has been highly developed by the Bureau. Such an analysis has developed improved techniques of design and resulted in very economical construction with better stability of the structures.

Photo elastic analysis has enabled the design of statically indeterminate structures. It has helped in determining stresses in plate girders and runner blades of turbines. The Bureau has wonderfully developed the technique of stress assessment at interior points of structures sueh as gravity arch and buttress dams, piers, columns through use of polariscope and interferometer. These instruments help in solving many other design problems as well.

The Beggs-Deformeter is used for stress determination in building frames, conduits and lined tunnels.

(*b*) **Vibration studies.**

Close study and analysis of vibration effect on power plants, bridge piers, girders, trestles, various structural members of other anciliary construction has provided useful data to achieve economical design.

(8) **Electrical Field.**

Analytical research in the electrical field has produced many useful results and solved so many problems. Standards for stability of bus bars have been developed through analysis of their vibration. The proximity effects produced by transmission of alternating current in the circuits carrying large bulk of power have been analysed. Special sag Formulae have been developed through such and other allied studies which are beneficially used by transmission engineers.

Net work analyser has been effectively utilised to study the impulses of various factors on the electric transmission system on a miniature scale and then lay down the standards producing the most optimum results. Such a study yields answers to various questions such as rating of electrical generation machinery, circuit breaker interrupting duties, system relaying and overall system stability.

Laboratory Research.

Research work in the Bureau's laboratories has made a major contribution in all fields of her activity particularly through hydraulics, structural and material testing investigations. These laboratories have become iudispensable in all stages of planning, site determination, designing, constructing and operation of the projects.

A large number of probiems, hydraulic model research has solved which could not be tackled through analytical solution. Similar is the case with structurel research and the study of construction materials. Laboratory research work can be considered under the following headings :—

(1) **Hydraulic Research.**

New dasigns.

Hydraulic model studies have led to achievment of economic designs, safe and dependable construction, improvement in operating characteristics and safety in operation. Working models and utility of their studies as applicable to prototypes has been made in respect of dams, spillways, canal structures and outlet works, silting and stilling tanks. Such corelations have also been achieved in favour of hydraulic machinery such as turbines, valves, gates pumps, penstock, trash structures etc.

Oparational problems.

Besides achieving the design of new structures considerable saving has been achieved by prolonging the life of the wearing parts of machinery, through consistant process of research. Problems of cavitation pitting, airlocking, corrosion and erosion have been studied and their damaging effects reduced. Great economy has been achieved by suitable design changes perfected through research which could enable the discharge effiiciency to be increased by reduction in the water passage.

(2) **Electrical analogy.**

Great use has been made of electrical analogy system particularly through use of electronics and membrance analogies for solving ground water, salinity and sedimentation problems.

(3) **Structural studies.**

Model tests on girders, colums, structural frames, gates etc., for determination of stresses, strain, deflection and other physical defects developed in structures has rendered valuable contribution to sound design and construction techniques. Such a study has been profitably applied to determine behaviour of foundations ; characteristics of materials especially the stress-strain relations. A number of special machines such as a 5 million lb. capacity universal testing machine, the triaxial testing machine and other devices through optical, mechanical and electrical means are set up in the laboratories to enable studies in the wide field of structural studies.

(4) **Material Testing**

This is an ever developing field where not only new uses of existing materials are found but new materials for the existing uses are constantly developed. Through a comprehensive research of properties of construction materials and determination of methods to save more costly ingredients by substituting comparatively cheaper items the Bureau has been able to achieve the maximum economy as compared to other means of saving. And this has been done to cater for the same structural strength with added improvements in behaviour of these structures both during and after the construction. Large scale test have been carried out to determine the suitability of natural materials.

The one field where maximum work has been done is investigation into properties of portland cement and to develop its composition to suit various applications and the concrete technology. Some of the out standing studies made are listed below :—

(*a*) Proeedures have been developed for evaluating and designing optimum concrete mixes.

(*b*) Study cf concrete aggegate properites through petrographical analysis.

(*c*) Determination of alkali-aggregate reactivity in uses of puzzolanic materials and investigation into saving of cement use through such materials available nearest to the site of construction.

(*d*) Investigation into use of air entrained concrete and savings in cost expected through its applicatlon.

(*e*) Prepart concrete technique and its application in new concrete and rehabilitation for the old structures.

(*f*) Determination of protective coating to control deterioration of concrete.

(*g*) Fixing standards and guide specifications which with maximum simplification can result in reducing the cost of building on the projects.

(*h*) Control of mixing, transporting and placing of concrete and proportioning it for desired quality and workability.

(*i*) Studies for thermal properties of concrete measurements for its volume changes.

(*j*) Investigations into durability, permeability, strength elasticity and other properties of concrete.

(*k*) Investigations into use of prestressed concrete.

Earth materials.

Studies of earth materials in different localities of construction present interesting problems of their own. There is more freedom of tests for concrete materials than the earth and the soils because of sampling limitations in case of the latter.

(1) One dimensional and three dimensional consolidation tests have been developed to yield useful information about properties.

(2) Behavior of earth dams ofter construction has been studied.

(3) Design and location as well as spacing of protection filters and investigated.

(4) Chemical and microscopic examinations of soils have been developed.

(5) Soil tests have been utilised for better knowledge of foundations through laboratory technique, which have also helped in fixing the design of earth dams aud laying down their construction procedure.

(6) Canal linings is yet another field where application of special soil study, sediment behaviour, etc., have been investigated.

Other materials.

Besides concrete and soils useful works has been done on various other materials used in construction and for upkeep of various structures. For example research has been made on paints, oils, bitumastic materials and metals. Bentonites and other clay minerals have been studied. Protective coatings to prevent corrosion have been examined. Chemicals have been developed such as weed killers, and their economy has been studied. Quite recently application of radio active isotops have been determined to determine the behaviour of these weeds which has helped in their effective control and destruction.

Field Research.

Application of research is not limited to the design offices and engineering laboratories. It has to perform a co-ordinating link between various phases of a project commencing right from its conception, to design, execution through to the operation stage. In the absence of such a link, the research men in the laboratories fail to know how far their findings are applicable to the site conditions. Research problems keep on changing due to the impact of the field situations in case of those projects where a continuous laboratory and implementation programme must proceed hand in hand. A few typical examples where a strong link between research in the laboratory and the field has yielded profitable results are considered below :—

(1) Low cost canal lining materials have been developed through research on prefabricated asphalt, asphalt membrane, earth compacted and non-errodable soil linings, etc.

(2) Improved operational methods have been evolved in the field of water measurement through refinement of measuring devices.

(3) Great advancement have beeu made in the field of drainage and reclamation of saline lands through chemical, physical and other analysis of the soils coupled with drainage investigations.

(4) Internal stress study in concrete dams, permeability observations, measurement of pore pressure, internal stresses and consolidation tests on earth dams have led to be considerable economy in the execution of these structures.

(5) Joint siesmic studies have been undertaken by the Bureau in collobration with the coast and Geodetic survey department-Seismograph stations have been set up at Hoover, Shasta, and Hungry Horse Dams to record the siesmic disturbances which after analysis have provided very useful data to utilise these factors for design of new structures

(6) The Bureau has built an experimental embankment near Colorado which is functioning as an important aid for field study of research. Various substitutes for stone facing such as soil cement, etc. are being investigated as alternatives for construction of earth dams in those areas where there is dearth of stone pitching material.

(7) There are other lines of research in the field such as study of cathodic protection of steel structures, snow pressure on structures, seepage from canals, ground-water studies where the Bureau has done considerable work. They have also investigated into such porblems as periodic inspection programme, operation, maintenance and rehabilitation of existing structures.

Research both in the laboratories and the field has thus rendered great help to the Bureau in evolving sound designs and take sure and definite steps for execution of their projects. It has helped that organisation to make its financial feasibility studies workable. It has provided answers to the problems in various fields in a sure and dependable manner. Such studies infused the necessary confidence in the mind of the workers who could launch on bigger and more complicated programme of construction through improved and more economical designs. It was only through research that they could predict results of what they were planning to accomplish.

Design practice.

Conclusions derived through research cannot be faithfully translated into actual implementation without the medium of design. In certain cases design and research have to be complementary to each other and should proceed simultaneously. The useful data compiled through research can serve no purpose unless design standards are equally high to make the most economical utility of the research results.

Design can be divided into functional and structural. Functional design caters for the study of the purpose of the proposed structure and its planning to fulfil this purpose. Structural design is the planning and proportioning of the elements of the structure to suit its function. One of the general problems of design is to evolve co-ordination between the functional and structural designs so as to keep the costs to minimum.

The first step in design of every major structure is the preparation of basic structural designs. Such design criteria will record the basic structural requirements and will serve as master drawings for preparation of the detailed drawings. Some of the outstanding accomplishments of the Bureau in the field of design standards are listed below :—

Uniformity of design.

In its early history the Bureau was following the policy of custom designs specially prepared to meet requirements of each and every case. In subsequent years it was found that such a procedure was proving quite costly because it not only created delays but also brought about complications in the construction procedures. Accordingly variation in designs was eliminated and standardisation followed as far as possible. A set of standard designs, guide designs and type designs was prepared to have as much uniformity in the design practice as possible. This practice reduced the construction cost very considerably. In some of the large projects it cannot be helped but to have specially prepared designs. Whereas designs for canal outlets, trash racks, radical gates, can be standardised without difficulty, valves and pumping plants have to be designed individually depending on the specific conditions of their operation.

Building activity.

Improvement in the concrete designs offered a substantial source of economy. It was accomplished through research procedure and studies made on materials as stated before. Quality of concrete was improved, its capacity to sustain bigger stresses was increased and designs were established to do away with such complications as the finishing restrictions. Dimentional tolerances were specified and schedule of finishes for different types of concrete jobs were also laid down which resulted in big cost savings. Through better control on handling and placement of concrete and also through rigid control on its quality it has been possible to achieve working stresses upto 1,300 psi in concrete dams and increased stresses of 24,000 psi in steel which achieved considerable savings in material quantities and cost of construction.

It may be useful just to reproduce here the design data and a few standards as extracted from Bureau of Reclamation Manual design supplement to show how exhaustively uniformity of designs and their standards has been dealt with in this book for guidance of their engineers.

(1) **Loads.**

Data for loads considered for design purposes is dealt with under the following headings :—

Design loads, dead loads, live loads of different types, live load reduction, crane loads, impact, construction loads, snow loads, effect of climate, wind loads, earthquake forces, hydrodynamic loads, foundations and stability, load design precautions, earth pressures, temperature and shrinkage stresses, range of temperature, temperature reinforcement, hydrostatic pressure, hydrostatic uplift, special loads, tortional loads, vertical hydraulic loads, other hydraulic loads, deflection loads.

(2) **Foundations.**

Stability analysis : sliding, uplift, overturning, foundation loadings, allowable bearing values, underlying stratum of smaller bearing value, effect of water in foundations, loads for maximum pressures, settlement, pile foundations, soil examinations, various types of piles, pile materials, pile spacings, bearing values, group reduction, other types of foundations such as mat etc.

(3) **Structural Analysis.**

Methods and assumptions, moments of inertia, lengths of members, deflections, preliminary sizes, support of roof loads, final analysis, continuous beams and slabs, rigid and continuous frames, typical frames, major and minor sideway structures, load combinations, building and retaining walls, slabs on elastic foundations, footings, concrete turbine cases, steel turbine cases, concrete requirements per KVA, allowable unit stresses, combined loadings, review of unit stress.

Dams.

Question of design of dams to study achievements of economy which the Bureau has attained can be considered under two separate headings of concrete and earth dams.

Specialised problems of designing large concrete dams have offered the Bureau many possibilities for construction economics :—

(*a*) Through stress analysis of concrete gravity and arched dams by the trial load methods considerable savings in the materials have been made possible. The observed stresses in the dams after construction have confirmed the design data, on which their construction was based and this has further strengthened the scope of economy in this field. In some cases 15% saving in the volume of concrete has been achieved which has resulted in economy running into millions of dollars.

(*b*) Hungry Horse and Canyon Fary dams have adopted lean concrete in the interior with a surface layer of richer concrete. Both dams have been designed to make use of puzzolanic admixture and air entertainment concrete, saving cement cost and controlling adverse chemical reactions.

(*c*) Cooling of concrete after placement and block and slice construction of concrete dams continues to improve both the qualitative and structural economy.

Technique of earth dam construction has also progressed with equal effective results.

(*a*) Zoned earth dam construction has led to design and construction improvements, more utility of earth dams and bigger range of savings.

(*b*) Maximum use of locally available soil strata has contributed to major economy through zoning during actual contribution subsequent to advance soil studies.

(*c*) Hydrostatic and flow conditions in earth dams have been thoroughly examined, phenomenon of pore pressure measurement has been perfected which has helped in detecting drainage deficiencies and increasing the structural stability of dams. Greater heights of earth dams have been built, more difficult situations have been controlled and water storage through earth dams which was declared impossible under certain conditions so far has been made possible through this intimate link between research and design.

(*d*) By detailed foundation investigation it is possible to adopt design of selective grouting practice instead of wholesale grouting which results in considerable economy of construction.

(*e*) The influence of selection of proper earth moving machinery and other mechanical devices for construction of earth dams is really great on the cost of execution. Therefore Bureau's efforts in laying down proper specifications for purchase of equipment in handling various construction jobs have yielded very good results in not only cutting down the cost of purchase but construction itself. Such a judgment has however, been based on the thorough studies of varying local conditions under which the machinery is to operate.

Control Works.

Research and design for the control works and equipment to operate the dams such as gates, valves, turbines, pumps, penstock, etc. have also contributed a considerable share in saving final cost in providing a specified service. Bureau's investigation into the problem of dissipation of hydrostatic energy has brought about new designs for spillways, penstocks, draft tubes, intakes, forehay, trail race and surge tanks. There is constant improvement in the service they render, increase in their capacities, efficiency and relative reduction in their first cost and cost of operation.

Canal and conveying structure designs.

Standard canal designs such as widths, outlets, crossings, etc., have developed standard methods for construction: Great improvement has been made to economise cost of canal linings by ommitting steel reinforcement and reducing costly material utility in this technique. Special instruments have been developed to measure the seepage along the canals and check the efficacy of various types of linings and to test the theoretical designs and data after their implementation in the field. With development of asphalt concrete, asphaltic manbrane and colloidal sediment l:nings overall costs on the main canals and their distrbutaries have been appreciably reduced.

Steel pipings have been replaced by reinforced cement concrete pipes for design of siphons and other conveyance structures.

Power plants and systems.

The Bureau has conducted large scale experiments and produced effective designs in the field of power house installation and their safe operational as well as maintenance technique. They had to handle unprecedental size of generators and problems connected with transmission of huge bulks of power over great distances aiming at an uninterrupted and economical service, Design of foundations, based on construction loads, erection and vibration loads all dictated necessity of competent designs to meet their challenge.

Location of the power house whether on ground or underground, study of various alternative system of their construction, use of alternative types of building materials were all planned to keep the cost of construction minimum possible. Protection of power centres through dependable design of circuit breakers was a big achievement which could be made possible by a joint and co-ordinated effort of the Bureau and the private industry. Handicaps created by weather, distance and terrain for long distance transmission have been successfully conquered through systematic research and comprehensive designs. Design standards derived through the studies on net work analyser have accomplished really dependable and very economical results.

Pumping Plants.

With cheap hydro-electric power it is possible to benefit from lift irrigation system in uncommanded areas in absence of the gravity flow of canals. Some of the pumping plants put up by the Bureau are the largest in the world and operate under very difficult hydraulic and physical site conditions. Their efficient operation called for intelligent designs and large scale research. At some points the problems of cavitation, vapour pressure, vibration and utilisation of off-peak electric loads have been solved most economical manner and have become singular achievements to be quoted as examples of the world over.

Construction machinery.

It was impossible for the Bureau to achieve such an ambitious construction programme without paying concentrated attention to all phases of constrcution activity beginning with the contract procedures, design of construction machinery and down to economical operational and maintenance schedule of the equipment. A close co-ordination is established between the design procedure so that at time of construction the problem of procurement of machinery is as much simplified as possible. Standardised designs help in large scale use of standard type of machinery which is planned after consulting the private manufacturers and as a result cost on its purchases, maintenance operation, etc., is very much reduced.

Illustrative Examples.

1. *Specifications and Contract Procedures.*

Modern specifications and contract practice has played a very important role with the Bureau of Reclamation in lowering the cost of construction. They have eliminated a large number of uncertain factors and "Escalator" clauses in these specifications and in doing so have reduced the contractor's risks. They have ensured a certain minimum basic quantity of work and a possible added qnantity, so that there is no doubt left in the mind of the contractors as to the minimum guaranteed volume of work they are tendering for. A particular field where extensive work has been done in this respect is concrete and concrete materials. The Bureau has established a healthy co-operation with the Association General Contractors of America (A. B. C.), and on their representation the following defects have been rectified :—

(*i*) Too many references to the judgement of contracting officers and consequent lack of clean cut definition in Government requirements.

(*ii*) Lack of specific statements which would establish the degree to which the Government will permit local irregularities in formed and unformed concrete surfaces.

(*iii*) Insufficient definitions of types of concrete froms for different classes of work.

These drawbacks have now been rectified and as result considerable economy has been achieved. The system of type and guide specifications has been well simplified, which has further helped in giving freedom of action to field engineers, but at the same time without leaving too many options for him to exercise. This has paved the way for prompt execution and in a economical manner.

There are large number of instances where considerable savings have been achieved by the Bureau in adopting these procedures, which it may be difficult to convert into actual monetary gains.

(2) **Canal Lining.**

Delta Mendota Canal lining has been done without the originally designed steel reinforcement. This has resulted in a saving of 3 million dollars.

(3) **Pumping plants.**

Grand Coulee Pumping Plant on the Columbia Basin Project is the largest in the world and consists of 12 units each capable of lifting water 285 feet with a capacity of 1350 cusecs. Tracy Pumping Plant is one of the chief features of the Central Valley Project (C. V. P.). This handles 4600 cusecs against 200 feet of head and lifts Sacramento River* Grand Coulee Pumping Plant has been installed with special measures adopted to control its vibrations while dealing with pumps of such big capacity. Granby Pumping Plant handles great fluctuations in its head touching 94 feet and operates in rocky mountains at an attitude of 8100 ft. To avoid cavitation and vapour pressure problems a subterranean installation has been adopted. The pump is fitted up 107 feet below ground level.

All these pumping projects are irrigating 2·75 million acre' of land and render it productive. Their design capacity and installation have been made economical to the maximum degree through the research and design activities of the Bureau and as a result the operational costs have been brought down very low within competitive range as compared to the normal surface flow irrigation system.

(4) **Conveyance Structures.**

The Soap Lake Siphon in Columbia Basin Project is a typical instance, where R. C. pipes with a thin steel water retaining shell 22-25 feet in diameter, 2 miles in length and working under hydrostatic heads touching 225 feet have replaced the normal steel pipes. This has achieved a saving of 27 million dollars for the first cost and a huge reduction in the maintenance cost.

(5) **Colorado-Big Thompson Project.**

Besides other interesting features of this project which is a marvel of engineering field, the one instance of Flat Iron Pumping Power Plant is prominent. It exhibits how during the low power demand periods surplus electricity is used to pump large quantities of water into high level storage reservoir from the Flat Iron reservoir into the Carter Lake. In time of accute power demand the stored water is run back to generate power by releasing the storage from Carter Lake. It is thus possible to ensure system stability and make use of the hydroelectric power in the most economical manner.

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*Water to make it usable for irrigation on uncommanded highlands.

(6) **Research and design practices on concrete.**

(*a*) *Puzzolanas.*

Large scale investigations have been made on the use of puzzolanas depending upon the need which vareis from point to point. For instance two different specifications were followed for David Dam and for Hungry Horse Dam. At Davis puzzolanas have been used to reduce the expansion expected from alkali cement and agregate reaction. At Hungry Horse the objective was to minimise the use of cement, which could not be procured at economical cost at the job site. Whereas Davis used locally calcined shale, Hungry Horse made use of fly ash arranged from Chicago. In both instances the use of puzzolanas achieved large scale saving of construction costs on these dams. It was possible to achieve a saving of 4·5 million dollars at Hungry Horse and ·625 million dollars at Canyon Fery Dam through the use of Fly ash puzzolana.

(*b*) *Concrete aggregates.*

The application of petrographical studies have enabled investigations into qualities of concrete aggregates from different sources in different areas which have been earmarked in the area of dam construction activity.

A number of defects on dams and other structures have exhibited that if petrographic analysis of the raw materials would have been made and corrective measures adopted these shortcomings wolud not have arisen. Such experience and vast analysis of natural deposits in various regions have rendered very useful service in saving millions of dollars which would have been spent in rectifying these defects otherwise.

Studies bave been made on deposits of sand and gravel along the course of the lower Colorado River from the vicinity of Hoover Dam to vicinity of Parker Dam. Deleterious aggregates have been identified.

It is found that at Hoover dam cement aggregate reaction has developed in lining of a drainage channel. Aggregates used at Davis Dam have proved to be deleterious. There is a serious distress of the concrete at Parker Dam because of cement-aggregate reaction. Geni-Wash and Copper-Basin dams are seriously distressed. Crown of Cooper-Basin dam has been defected 5 inches due to lengthening of the arch in expansion. Pump gallery in Parker Power House which used high alkali cement shows sign of cement-aggregate reactions.

It is evident from what has been stated above that besides the knowledge about the quality and strength of the aggregates, the Bureau has carried out additional research to examine suitability of a given aggregate for a specified quality of cement for a particular service. Past defects have been analysed and very useful data compiled for future applications. Through this laboratory research individual cases of choosing the best suited mixtures which gives most dependable service under given set of conditions with given cement and aggregates are designed on their individual merit. This has already contributed to the Bureau's efforts for providing the improved service.

(*d*) **Prepacked concrete.**

This is yet another illustration to show how the Bureau is constantly improving upon the techniques and materials for different systems of construction and thereby effecting increased economy in their constructuion costs. Prepacked concrete is a very useful system of concreting method which has helped not only in rehabilitation of old structures but also for concreting in concealed and difficult locations such as for scroll settings, second concrete placement layers for hydroelectric, turbines pumping and other complicated machinery. It is done with clean, graded coarse aggrgate and pumping the voids of the aggregate mass full of a special intrusion mortar containing sand, portland cement, puzzolana filler and certain patented agents.

Low drying shrinkage, favourable water-cement ratio, better wetting and flow properties, favourable high delayed compressive strength, better bonding strength between prepacked to ordinary concrete, good elasticity and better durability against weathering and salt water action has justified use of this concrete.

Repairs to Arizona spillway tunnel at Hoover Dam, repairs to Barker dam and a number of other jobs, both new and for rehabilitation, prove that the Bureau has reaped a large scale benefit by using this patented method of concreting. Life of the damaged structures has been prolonged and new construction executed on throughly well grouted and compacted foundations through this system.

This general description and a few specific examples have been recorded to show how the Bureau with its initiative of research, sound engineering designs, coordination at all phases of the project progress, expert execution, dependable operation and trouble free maintenance is launching its reclamation programmes with the essential motive to cut down the overheads to the minimum possible level. The overall effect of many years' of laboratory studies and designing practice has led to progressive reduction of contract costs and improved services. The ultimate cooperation between the engineering centre at Denver, construction engineers in the field and operation executives for the works already in service has built up a nucleus of profitable results not only on the current programmes but will also have its far reaching effects on the future economy of Bureau's achievements.

Appendix No. 1 gives an account of various projects and their problems solved through laboratory research with the amount of savings effected.

Appendix No. 2 exhibits organisational chart of design and construction branch of the Bureau of Reclamation.

Acknowledgement.

The author is highly indebted to the administrations of Bureau of Reclamation U. S. A. for their permission to use the photographs and reproduction of various organisational charts.

National Research Council Canada.

National Research Council of Canada provides one of the best examples of government initiated research in an undeveloped country and establishes the necessity for such a step without which development cannot proceed on any sure lines. Active work was commenced by the National Research Council (N.R.C.) Canada at Ottawa during 1932 even though it took its birth in 1916 during the first world war. The number of workers touched a figure of 3000 during world war II which has fallen to a normal level of about 2500 now. Atomic energy research has been dissociated from N.R.C. and is being handled now by a separate crown corporation.

Research in the fields of agriculture, forestry, mining, fisheries has a longer standing in Canada. It was subsequently realised that the country was too big, natural resources vast, human skill and population too little to meet the challenge of an overall development on large a scale. Individual research activities of various provinces were therefore co-ordinated through this research council and a federal body established which could stimulate the research activities in the country and feed its requirements in various fields. It was not possible for Canada to follow the example of its neighbour and establish privately sponsored research organisations. It had to make a start in this direction with somewhat unhampered freedom of action. In the absence of strong private research organisations as established in U.S.A. and favourable attitude of the country towards investment of public funds for research, Canadian Government could launch a full scale programme under federal control. The research was channelled and promoted at provincial as well as private level through a planned system of co-ordination. Even though the government had invested public funds in these corporations yet they were run on the pattern of private companies to facilitate their work and make it possible to realise the achievements in minimum possible time. For example Hydro Electric Power Commission Ontario, Canadian National Railways, Trans Canada Air Lines, Polymer Corporation are all functioning on this pattern.

N.R.C. today has two regional laboratories at Saskatoon (for the prairies) and Halifax (for the Martime provinces). The hub of its activities are radiated from its 400 acre federal centre on the Montreal Road at Ottawa where all the engineering divisions are now located. The present annual budget of the council runs to about 15 million dollars. Rather than commenting on all the activities of the N.R.C. it is considered more profitable if one specific instance of the Division of Building Research is quoted here. The author had an opportunity to study activities of this division in more detail and it is one of the best administered and run divisions of the council.

Division of Building Research.

This division of the council concentrates on carrying out research to meet the demands of construction industry in Canada. The division is housed in a building which is the first building in the world to have been created especially for building research :—

(a) The first concrete step taken by the division was to produce a national building code. This book lays down standards in an advisory capacity only, ever since its publication in 1941 but it has been widely adopted in the construction industry throughout the country. The standards are revised from time to time as continuous operation as demanded by changing condition in the industrial products, demands of people, economy of building and requirements of Government and real estate development bodies.

(b) Building industry in Canada considered severally has not reached a stage where private research could be economically justified. Therefore they share the benefits of research activities at the N.R.C. by spending an insignificant amount as compared to the benefits they derive.

(c) The division carries out predominant research in the housing field and works in close co-operation with another public agency as Central Mortgage and Housing Corporation. This body is responsible for all the federal housing activities.

(d) The basic function of the division is to effect improvements in the standards and economy in the building practice for benefit of the people of Canada. It has therefore to concentrate on special problems relating to the country. These problems are :—

  (a) Building for extreme cold weather including materials and heating studies.

  (b) Study of actual structures under Canadian conditions.

  (c) Foundation and soil conditions in different regions of the country.

  (d) Engineering problems associated with snow and ice.

  (e) Even though the division is only five years old it is operating a laboratory in Saskatoon, test huts at Ottawa, Saskatoon, Churchil and other places as part of a major research programme.

  (f) The division is organized into two groups one dealing with building practice and the other with building research. In the later are sections dealing with building design, building physics, building services, fire research, building materials, foundations and soil mechanics.

  (g) There is a detailed system of field investigations and the division has established a well co-ordinated system between the field data recording and testing system and the laboratory research studies. For example the test procedure for prestressed concrete beams which were to be used for a bridge on Readue Street, Ottawa was detailed in the division. The results predicted in the laboratory were then co-ordinated with the data obtained by actual tests in the field. The author had a chance to go into details of the divisions work on this project.

(*h*) Paint posts have been set up in various parts of the country to study the effect of varying climatic conditions on different types of paints.

(*i*) Research has been carried out to save steel and other metallic structures against corrosion and rust through cathodic ray system.

(*j*) A climatological atlas of Canada has been prepared which is the first publication of its type in the world. It depicts typical climatic and seismic analysis information which is so vitally needed by architects and building engineers throughout the country.

(*k*) Working of N.R.C. and this division has clearly established that research must be divorced from operation. Wherever the two functions are combined there is utter confusion and neither of the two activities proceed on satisfactory lines.

(*l*) The division issues a number of research and progress reports which are of immense value to the public in solving their house building problems. The enquiry page of their progress reports undertakes to give answers to some of the typical problems commonly faced for new construction of houses or for their upkeep.

(*m*) The division co-ordinates its activities with a large number of associations such as Canadian Construction Association (C.C.A.), a number of committees such as Building Advisory Committee and other bodies which promote the scientific building practice in the country. It associates itself in furthering all such nation building activities and renders the maximum service it can through its research programme. Through its active co-operation C.C.A. has been able to produce such useful publications as "Guide to Better Building Procedure" and has helped the government in simplifying the contract procedure and eliminating objectionable bidding practices.

(*n*) The division is finding it extremely hard to attract really top notch people on its rolls because of the question of salaries in competition with private industry and under the shadow of the public service rules. They have been compelled to relax these rules considerably to attract really top research workers from all parts of the free world.

It may be of some help to describe the projects which the division had on its programme on 31st December, 1955.

(*a*) **The Canadian snow survey, its purpose, history and future development.**

The associated committee on soil and snow mechanics initiated such a survey in 1946. This was to supply data to hydrologists, design engineers and others dealing with snow and its water contribution problems. The survey is being continued with active cooperation of the Meteorological Division of N. R. C. and final observations are being placed at disposal of the agencies requiring their utility.

(*b*) **Chimney studies.**

Such problems as efficient draft, best design of flue passage, insulation of chimney walls in cold countries, study of influnce of different types of fuels, building codes to specify the best design of chimneys, have been studied by the division by making a full size model. Very useful data has been obtained from this study.

(*c*) **Conductive Flooring.**

During winter reduction in the relative humidity, use of insulated type of floorings such as synthetic, plastic and asphalt tiles etc., produce electrostatic charges. Research has been carried out by the division as how to design the flooring on a conductive design to avoid these hazards.

(*d*) **Fire Fatalities.**

Fire research section of the division has carried out useful investigations into fire deaths in buildings. They are collecting data to be able to generalise their observations on the cause of fire fatalities.

(*e*) **Winter construction.**

Winter construction under severe Canadian climatic conditions is a real engineering feat especially for major projects such as the St. Lawrence Seaway scheme which proceeded unhampered by climatic influence. Some years back such jobs had to be closed during winter which resulted in a very heavy extra construction cost. Today through research it is possible to control these weather interferences and permit building to progress uninterupted except for some projects such as road work etc., where it is not safe to carry out a number of construction operations on the frozen soil. Thorough research has been carried out by the division to determine the effect of winter construction on construction costs as a whole as compared to summer construction. Such a study will largely assist in relieving the seasonal unemployment during winter which at present is a national problem for Canada.

This brief note about N. R. C. and a specific account about one of its divisions dealing with Building Research hardly suffices to do full justice to present full activities of this body and portray the useful work it is doing for development of Canada. However it is hoped that these few lines may keep in forming an idea about the importance of research, necessity of its full scale government sponsorship and the economy it is likely to achieve in the early history of any new country.

Research and investigation problems in Pakistan.

The paper has indicated how engineering research is vital to contribute extensively to the construction economy. Examples have been given of two leading cases in North America both under the Government management. However, the trend is to set them as an example for encouraging such an activity in the private field. Certain other instances have been indicated where private enterprise has played a very useful part in this respect. The problem facing Pakistan make it imperative for us to strengthen such activities in order that deficiency of our resources may be overcome by utilizing our own indigenous materials and products for achieving best possible results. We are facing deficiency of adequate building materials such as cement and steel and also lack attractive sites to control forces of nature and harness them for the benefit of man-kind. Our geographical position is such that the rivers flowing in our territory are with their mountaineous catchments in most of the cases outside our country. It is quite difficult to achieve a co-ordinated exploitation of such investigations and have proper regulation and development works combined with the storages in the upper catchments. This could be an ideal situation to strengthen our economy. However, the river system in our territory, as it has fallen to our lot, has to be utilized to the maximum advantages. This creates special problems which can be surmounted through a very strong research backing. The areas which used to be once fertile and responsible for making this territory as the grannery of India is now being threatened by progressive menace of salinity and water-logging. Agricultural production is falling down due to such damaging factors. As a result canal irrigation which used to be once a source of happiness to the inhabitants of the area has become source of destruction of the rural economy. The storage sites on our river system for the purpose of building our dams are certainly not ideal. However, we have to make the best use of such available facilities. It is a problem also to find any alternative storage sites to be kept as a stand-by to the big storage works and the dams which are going to be executed under the Water Treaty with India. Construction of large scale links and allied works for these replacement jobs will bring about quite a difficult repercussion in the existing pattern of drainage and water resources utilization. This will pose a big challenge which will have to be faced with bold-ness through comprehensive investigation and proper research.

The problems in various development fields both in East and West Pakistan demand a large scale activity not only in terms of financial investment but also for procurement of specialised human workers. For example. there is a tremendous population pressure on the limited land in East Pakistan which will necessitate growing multiple cropping to feed millions of people in the deltaic land of that Province. In West Pakistan, there are large tracts of land which are lying undeveloped and uninhabited for want of water resources.

It is evident that if we are not vigilant enough to launch large scale projects for utilization of our natural resources, we are likely to waste our financial resources which are already scarce. We have to accept the designs to suit the existing facilities rather than vice versa. There is a growing tendency to study the methods used by some of the foreign countries and try to copy them and fit them into our own economy which brings about dis-jointed efforts. It is very essential for us to keep the position of our economy in our mind so that without ignoring our limitations and to ensure utilization of the indigenous materials and resources, we should be able to mobilise our manpower for achieving our projects. We may be forced to use certain amount of inescapable machinery and equipment but there is a necessity for bringing about a balanced co-ordination between manpower, methods, money, machinery and materials for this purpose. Even if certain projects may not be completed according to the ideal specifications, as being followed in some of the foreign advanced countries, we should be contented to accomplish results in our own modest way keeping in mind that we cannot achieve those ideal conditions. Research activity has to provide the best solution, in encountering these problems.

Eversince our independence, research and investigation facilities have not received the required attention. As a result some of the Laboratories which we inherited and of which we can be proud have not expanded in proportion to the developmental activity which we have undertaken during the last decade. The approach to demand a financial justification in even setting up a Research Laboratory is basically wrong. It is sometimes impossible to bring out the tangible benefits of research work even though the intangible results which may be achieved may bring in heavy and substantial savings. Very often research activity has to produce results over a long span of period but its overall contribution to strengthen the country economy is substantial to warrant financial investment in this field. It is imperative that certain proportion of the money allocations meant for development projects must be spent as a pre-requisite to strengthen and expand our existing research Laboratories or to set up a chain work of new centres in this field. It has been already experienced that the first five year plan suffered the maximum short-fall in the sub-sector of survey and investigation because we were not equipped with such facilities both in terms of material and men to undertake such an activity.

Research and specialization becomes a handicap in Government service, whereas it is the greatest asset in private enterprise. Scarcity of private consulting Engineers, Building and Construction Industries, private research and test house activity has further done a serious blow to this important phase of our national development activity. It is important for us to review the special problems which continue to strangle the development of our research laboratories in the country. Mere construction of the buildiags and setting up of equipment and machinery does not automatically solve our probblems in this direction. We have to ensure that a set of first-class workers must be there to man and operate such Laboratories. The present system of the remuneration and working facilities which are accorded to these workers require complete change. These specialised worker should be able to concentrate their very best without bothering about their future promotions and scales of pay etc· They should have a clear line before them where their promotions may be ensured automatically so that they are not all the time trying to consider their posting in these Laboratories as a sort of punishment. It will be timpossible oherwise to attract the best talent and top brains in the field of scientific, and engineering research and to manage such like Laboratories. For example, the Irrigation Research Laboratory at Lahore, which is one of the oldest instituions in Indo-Pakistan Sub-Continent has not developed to the level it was expected because of scarcity of workers. In addition, the equipments an other facilities which should have been added to these institutions have also not been provided. However, the basic inherant deficiency has been due to lack of top-notch workers in these organizations. If their administrative problems are suitably solved, it is certain that such like employees who have natural aptitude for research will be automatically attracted to work at these places.

Many of our development projects are being financed under foreign aid programme. The consulting Engineers in most of the cases are also foreign firms. They have a tendency to propose experimentation, testing of the models and other facilities to be carried our close to their headquarters in the foreign countries. This is damaging our own itnterests and the likely expansion chances of our existing research Laboratories in the country. This is a serious national loss which we should guard against in future. Even if there may be certain delays in such experinments to be carried out within the country and the final results may not be of ideal standards to begin with yet we should make it mandatory for such experiments to be tried within our own Laboratories. After certain initial handicaps, we will soon be independent to organise research activity in these fields *i.e.*, dams, storage projects etc , which we may not have done in the past.

It is hoped that this paper will, enable experienced workers and specialists in this field to supplement it with their useful views on the subject. It is essential that Government should give this problem a serious thought in order that our handicaps in the past are thoroughly investigated and the plan of action is proposed for establishing a net work of these institutions throught-out the country for future. Research activity has to be considered as an important pre-requisite and an unavoidable step which is dictated by conditions of our economy. This will save our financial resources many times more as compared with the relatively small investment which we may have to put in for establishment of such an activity. We have to seriously review this question in order to justify our existance on the world map today. The other countries are marching ahead so fast and achieving various results in the scientific and engineering fields by strengthening up their large scale research activity. We must do something in this respect, if we want to claim some position, Even with remote relation to such nations, otherwise, we shall be left behind so much that it would be impossible for us to recover this lag at any time in the future.

Recommendations.

It is possible to lay down a few recommendations on the basis of the study of the two government organisations from North America made by the author from a specific view-point as recorded in the paper which may suggest their useful application to our conditions in Pakistan. It may not be adequate to generalise things on the basis of as brief an account of activities of these bodies as covered here but a mere statement of their efforts to achieve economy through research and design will not suffice unless the utility of such a study is projected into possible local application :—

(1) The first requisite to ensure proper exploitation and utility of the country's resources and to make full scale development possible at the earliest opportunity, is the establisbment of a net work of regional research institutes which should be co-ordinated through a national research programme. These institutes should not only handle scientific and industrial research but should also undertake engineering research.

(2) In the initial stages of development of Pakistan, research will have to be essentially a government sponsored activity. However, the organisational set up for the research institutes or councils, should be on the pattern of company constitution so that they are of maximum benefit not only to government agencies but also to private enterprise.

(2) The research activity should be completely dissociated from the operational responsibilities of the existing government departments.

(4) Salary scales and other renumerations fixed for the workers saddled with research responsibility should be fixed on such a basis that top people and real experts in various lines should be tempted to serve on the research organisations.

(5) Research programme selected in these research centres should be based on the most urgent needs of the country. It should be flexible enough to meet the demands of the industrialists, the private consulting engineers and other individuals as well.

(6) Government administered research organisation should encourage and coopt the association of any privately established engineering bodies whether consulting or contracting in the country. There is no doubt that existence of such private engineering firms which are established on sound lines will be of immense help in furthering the research potential in the country.

(7) Even though our resources are plentiful and untapped at this initial stage of our development and we may not be facing the limitations of opportunity, yet the research can only

guard against any wasteful and unwise expenditures on projects planned for implementation of our targets.

(8) Any organisation or any authority changed with the responsibility of land and water resources development must appreciate that it will be through a systematic research and design standards that the land users can have a real economical service for irrigation, electric supply etc.

(9) As far as possible multi-purposes projects should be preferred over uni-purpose schemes because with comparatively lesser capital investment they render more direct and indirect benefits and ensure full utilisation of available resources. The conflicting requirements of a multi-purpose project have to be thoroughly investigated both through field and laboratory research and a sound engineering judgment exercised to achieve most optimum results.

(10) Research must be proceed according to a well co-ordinated plan linking research in the laboratories, field (both in initial feasible determination and construction as well as operation) and the designs developed on basis of the data collected.

(11) In the fields of dam construction greatest possible stress should be laid to caary out research for utilisation of maximum indeginious materials. The economy which has been achieved in foreign countries in the field of concrete design and materials or for each zoning technique on earth dams is more pronounced that any other effort to cut down the construction investment.

(12) Designs for control works, outlet works and construction machinery should be developed on the basis of standardisation as far as possible with co-operation of the manufacturers. This will not only reduce the capital cost on their procurement but will also eliminate bugs in the maintenance and operational fields.

(13) Except for unavoidable situations where individual designs are imperative, every effort must be made to standardised

design procedures. This will achieve an appreciable economy besides saving a lot of time consumed in construction.

(14) Simplification of contract clauses and specifications and adoption of certain measures to remove the element of uncertainty in the mind of contractors while tendering, will reduce the construction cost.

(15) It will be only through a system of country wide research that various local factors bearing on climatic, seimic, soil, snow and other conditions can be exactly determined and made available for their judicious application in the construction industry.

In the absence of a well established research network and thorough design standards in the country we are compelled to accept foreign advice though very often, conflicting it may be. We do not have confidence in ourselves and are just groping in the dark. Unless our ideas are tested on the envil of research and translated this into execution through the medium of design, we cannot be certain about performance of the structures we erect. Very often the capital spent on research does not appear to bring forth tangible and quick results but it does establish a base and a systematic potential on which alone the future of a new nation like ours can be squarely built.

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BIBLIOGRAPHY

(1)	"Reclamation in the United States" ...	A.R. Golze.
(2)	"50 Years of Reclamation" ...	Bureau of Reclamation
	Financial Report to the Nations' Stockholders 1902—1952 ...	U.S.A.
(3)	The Reclamation Programme 1948—54 ...	-Do-
(4)	Bureau of Reclamation Manual ...	-Do-
(5)	Design Supplements to Bureau of Reclamation Manual ...	-Do-
(6)	Project reports of various dams and other projects ...	-Do-
(7)	Dams and Control Works ...	-Do-
(8)	Interim reports of the Secretary of the Interior on "The Colorado River," "The Columbia River."	
(9)	Grand Valley Diversion, Missouri River Basin, Colorado—Big Thompson Project } Abstract Reports	-Do-
(10)	"Contribution of research to Bureau design and construction" ...	W.H. Nalder
(11)	"Design for Construction Economy" ...	L.N. Mc Clellan
(12)	Proceedings of training conference on earth and concrete control ...	Bureau of Reclamation, U.S.A.
(13)	"Building Research in Canada" ...	National Research Council
	A progress report of building research division ...	Canada.
(14)	"Government sponsored Research-A Canadian View" ...	R. F. Legget

Appendix No. 1

SOME EXAMPLES OF LABORATORY ACCOMPLISHMENT

Project	Problem	Solution	Estimated savings	Remarks
Friant Dam	Can quantity of cement be reduced ?	Local pumicite found suitable as pussolanic admixture.	301,000	Applicable to many Future projects
	Car longitudinal joints be eliminated and amount of concrete be reduced ?	Measures to control temperature eliminated need for the joints and reduced thickness of concrete section.	300,000	Applicable to many futureprojects.
Boulder, Parker, Seminoe, Marshall Ford, Grand Coulee, Shasta, and Friant Dams.	Is the usual treatment of contraction joints in concrete dams necessary or worth the expense ?	Usual treatment with watergastar paint is more harmful than helpful.	46,000	Applicable to many Futvere projects Better structure resulted.
Shasta Dam	Can concerete aggregate from nearest and cheapest source, although of inferior quality, be made suitable by processing ?	(1) Can be made suitabie by proper treatment. (2) Can be transported to job by conveyor belt instead of by rail.	1,285,000 100,000	

Pit River.	To increase safety factor of bridge.	Butt welding of reinforcing steel proved stronger than traditional lapped-joints ; amount of steel reduced.	19,000	Applicable to many other special situations.
Grand Coulee Dam.	To improve knowledge and specifica tion oi cement.	Lab. research and improved specifications reduced cost of cement. 11,000,000 bbls. of cement for Grand coulee at 8 per bbl. less than for Boulder Dam.	900,000	Estimated only for Grand Coulee, but applicable to all new projects and future construction.
Boulder Dam	(1) Is practice of using richer concrete on upstream faces of dams necessary or justifiable ? (2) Will an additional layer of gunite be required ?	(1) Unnessary and unjustified. (2) Not required.	400,000 46:000	Estimated only for Boulder, but applicable to all subsequent dams.
All project in 16 16 years of lab. opration.	Can design of concrete and control of placing achieve safe reduction in amount of cement used ?	Yes 30,000,000 cu. yds. of concrete placed with at least one-tenth bbl. of cement per cu. yds. less than formerly.	6,750,000	Applicable to all future dams.
Boysen Dam.	Was proposed scheme of rail-road relocation the best and cheapest ?	No. Geologic studies showed feasible of one long tunnel replacing many short tunnels and deep cuts.	1,000,000	In addition, lower maintance costs anticipated.

Appendix No. 1

SOME EXAMPLES OF LABOBATORY ACCOMPLISHMENT—*contd.*

Project	Problem	Solution	Ettimated savings	Remarks
Horsetooth Reservoir Dams Green Mt. Dam Montezuma Diversion Tunnel	Is the usual amount of exploratory drilling necessary ?	Through geological study reduced amount of drilling	35,000	Examples only ; similar savings common to most recent projects.
South Coulee Dam.	Will the proposed foundation grouting be adequate ?	More than adequate. Geological ftudy indicated proposed grouting could be cut in half.	100,000	
Newton Dam.	Must riprap be obtained from a distant source ?	Geological and lab. studies showen inferior local rock was good enough for the purpose.	30,000	Representative of many similar accomplishments.
Friant Reservoir	Pumicite deposit to be inundated by reservoir, so was stockpiled above high water. Owner said pumicite was impaired and worthless ; claimed $500,000.	Lab. studies proved pumicite was unimpaired, claim disallowed.	500,000	Representative of many similar problems, of mineral appraisal.

"C" Line Pumping Plant	Are piles being driven in the foundation improving the bearing capacity of the foundation ?	No. Geological studies indicated fundation being hormed and pile driving should be discontinued.	7,500	Better foundation obtained also.
Moon Lake Dam	Has best earth material been selected for the embankment.	Closer material found, lab. studies led to changed design using less material.	50,000	One example of economy of systematized materials studies.
Marshall Ford Dam.	Must portions of embankement materials be hauled from pit 4 miles from site ?	Laboratory tests showed materials from damsite excavations could be used in embankement.	50,000	One example of economy of systematized materials studies.
Fresno Dam.	Does foundation require the designed downstream cut-off trench and pumping system ?	No.	30,000	One example of fitting design to natural site condition.
Friant-Kern Canal.	Must the entire canal be lined ?	Geological studies and related tests indicated that one 19-mile stretch need not be lined.	2,000,000	One evample of fitting design to natural site condition.
All currently scheduled jobs.	Development of a cold applied joint filler for canal linings.	Newly developed joint filler cost 11 per pound less than nearest competitor.	130,000	Savings applicable to all future work.

Appendiv No. 1.

SOME EXAMPLES OF LABORATORY ACCOMPLISHMEMT—*concld.*

Project	Problem	Solution	Estimated savings	Remarks
All currently scheduled jobs.	Development of a cheaper curing compound for concrete.	Newly developed compound requires only one coat instead of three as used formerly.	150,000	Savings applicable to all future work.
Boulder Dam.	Can air vents as dssigned in the intake towers and tunnel plug outlets be eliminated ?	Hydraulic model tests indicated that the air vents could be eliminated.	125,000	
Grand Coulee Dam.	Is the spillway design the most effective and economical ?	No. Hydraulic model tests permitted redesign rising less concrete, one less gate and decreased power house excavation.	$5,080,900	
Boulder, and Grand Coulee, Shasta Dams.	Is tbe proposed architectural treatment the most effective and economical ?	No. Architectural model studies led to simplifications of railings, windows and detail.	130,000	Similar savings have been made in most other in most other major Bureau dams.

Boulder, Grand Coulee, and Shassa power Plants.	To achieve a more economical design for water jet pumps.	More economical design achieved through laboratory research.	71,000	Similar savings will be applicable to all furher powerhouse.
Grand Coulee Power house.	To Check efficiency of designed draft tubes and inlet connections.	Final designs based on hydraulic model tests increased power output valued at 40,000 annually.	200,000	Figure based on five years generation. Savings will accumulate at $40,000 annually.
Angostura Dam.	To check proposed design of spillway.	Proposed design parcticable but very expensive. Hydraulic tests led to much cheaper design.	500,000	New type of design will have extensive further application.

Total savings accomplished by these examples through reserach ... $20,336,500