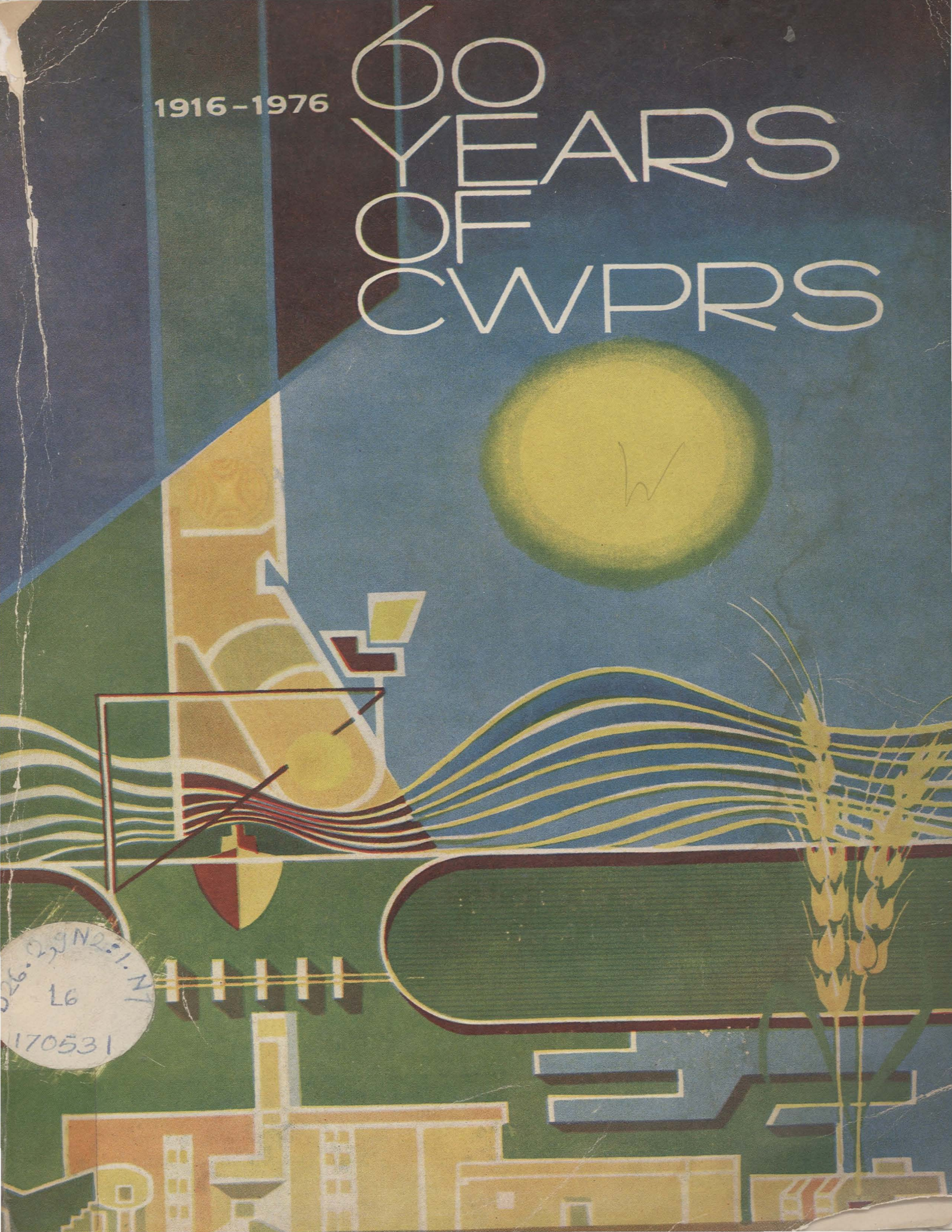


1916-1976

60 YEARS OF CWPRS



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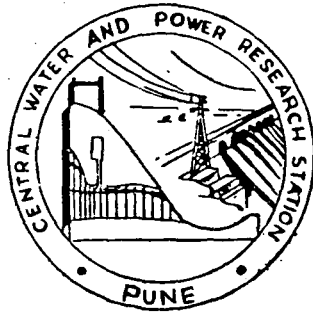
अंधं बलं जलं च आहुः

प्रणेतव्यं विचक्षणैः

—महाभारत

**Water is a mere blind force, though tremendous
It has to be guided by proper discrimination**

central water and power
research station
pune



DIAMOND JUBILEE SOUVENIR

1916 - 1976

DIRECTOR : P. C. SAXENA

NOVEMBER 1976

GOVERNMENT OF INDIA
MINISTRY OF AGRICULTURE AND IRRIGATION
CENTRAL WATER COMMISSION

*DEDICATED to all those Known and Unknown,
Engineers and Scientists, Technicians and Non-Technicians,
Mazdoors and Others,
Who Toiled and Laboured to Earn Name and Fame to
CWPRS*



राष्ट्रपति भवन नई दिल्ली - 110004
RASHTRAPATI BHAVAN, NEW DELHI - 110004
INDIA

August 20, 1976.

I send my congratulations and best wishes to the Central Water and Power Research Station, Pune, on the occasion of its Diamond Jubilee Celebrations.

I am happy to note that the Research Station has, since its inception, grown from strength to strength and has made notable contributions in the field of hydraulic research. I wish the Diamond Jubilee Celebrations all success.

Fakhruddin Ali Ahmed



उपराष्ट्रपति, भारत, नई देहली
VICE - PRESIDENT
INDIA
NEW DELHI

August 11, 1976.

I am glad to know that the Central Water and Power Research Station, Pune, will observe this year as its Diamond Jubilee Year. I understand that the organisation has decided to launch an ambitious programme. I send my best wishes for the success of the celebrations. I wish the Research Station continued prosperity.

B. D. Jatti



प्रधान मंत्री, भारत
PRIME MINISTER
INDIA

August 11, 1976.

All life is sustained by water and progress depends on power. The Central Water and Power Research Station, Pune, has done pioneering work in hydraulic engineering. The studies undertaken there have promoted many of our important irrigation and power schemes.

This year the Research Station completes sixty years. My good wishes for its diamond jubilee celebrations and for continued good work.

Indira Gandhi



कृषि तथा सिंचाई मंत्री

भारत सरकार

नई दिल्ली-११०००१

MINISTER OF AGRICULTURE & IRRIGATION

GOVERNMENT OF INDIA

NEW DELHI-110001

25th September, 1976.

My best wishes on the occasion of 'Diamond Jubilee' of the Central Water and Power Research Station, Pune.

Indeed, this Research Station can look back with pride upon its growth from humble beginnings to a Centre which is now providing technical leadership and guidance not only to engineers in this country, but also carrying on investigations for several other countries.

The Station has developed an expertise which is of immense utility to the country in the sense that it conducts the basic investigations which form the foundations of designing irrigation and power projects which have a very high priority in our national development plans.

Now that we have launched on many major schemes in order to speed up the expansion of irrigation and power facilities, especially to our rural areas, the work of the Station will assume greater importance as it will be called upon both to intensify and to diversify its investigations.

I am sure that it will live up to these new challenges in the same spirit of service and excellence which has characterised its work in the past.

Jagjivan Ram



उप मन्त्री, कृषि और सिंचाई
DEPUTY MINISTER FOR AGRICULTURE &
IRRIGATION
INDIA
NEW DELHI



20th September, 1976

I am glad to know that the Central Water and Power Research Station, Pune, is observing this current year as its Diamond Jubilee Year.

It is a matter of great satisfaction that since its inception in 1916, the Research Station has been growing from strength to strength. Over the years the Station's activities have been extended to the various problems of Hydraulic Research in the fields of river training, flood control, irrigation and hydro-electric structures, harbours, water-ways, coastal protection works, design of pumps, turbines etc.

The thoroughness of its investigations and the soundness of its findings have earned for it an international reputation. The Water Transport Committee of ECAFE (now re-named as ESCAP : Economic and Social Commission for Asia and the Pacific) has recognised it as the Regional Laboratory for serving the needs of the ESCAP countries.

I have no doubt that the Diamond Jubilee Celebrations would inspire all those who are actively associated with this Premier Research Station to scale greater heights of achievement so as to meet the increasing research demands of the country in the future.

I wish these Celebrations and the Commemoration Volume, namely " 60 years of CWPRS " all success.

K. N. Singh



ISSOUFOU SAIDOU DJERMAKOYE
UNDER-SECRETARY-GENERAL COMMISSIONER
FOR TECHNICAL CO-OPERATION

It gives me great pleasure to congratulate the Central Water and Power Research Station on the occasion of its Diamond Jubilee celebrations.

We at the United Nations are aware of the many significant contributions made during the past 60 years by this premier research station of India in solving complicated problems in the fields of water resources development, hydro-power development, coastal engineering, etc. in India as well as in several other developing countries in Asia and Africa. On the occasion of Diamond Jubilee celebrations, we wish to congratulate the staff of the Research Station for their achievements.

The UN Office of Technical Co-operation is happy to have been associated for nearly two decades with the Research station, which was recognized by ESCAP in 1970 as a regional laboratory for countries in the region, in assisting the station as the Executing Agency of the UNDP projects for Photo-Elastic Laboratory, Cavitation Research Centre, Coastal Engineering Research Centre, Hydraulic Instrumentation Centre, etc. The UNDP assistance given by way of supplying the most modern sophisticated equipment required for advanced research, by arranging for the training of laboratory experts in advanced institutions abroad, and by recruiting for the research station eminent international consultants in highly specialized disciplines, will considerably enhance the usefulness of the Research station in finding solutions for the complicated hydraulic problems in the development of river water, estuaries, coastal water, etc.

We look forward to continue our active association and extend our best wishes for success in the future activities of the Research Station.

Issoufou Saidou Djermakoye



Dr. K. L. RAO
MEMBER OF PARLIAMENT
(LOK SABHA)



11th October, 1976.

I am glad that the Central Water and Power Research Station is celebrating its Sixtieth Anniversary. A research station is an institution that man has created, yet which is closest to immortality, for research is an eternal quest. The words 'diamond jubilee' perhaps cannot convey the same meaning. The Central water and Power Research Station has, through its creative and original work, contributed to the development of the economic exploitation of the water resources of our country. Nature has many secrets to be unravelled. Even when many concepts are known, translating them into practical reality is the task of a research institution.

Considering the scarce water resources of our country and the pressure of population, it should be the determination of the Khadakwasla Station to play a major role in developing processes and techniques by which the scarce resources can be exploited. New approaches and methods must be developed to counter mounting costs of projects. I have great pleasure in extending to all the workers at the research station my fraternal greetings and wish the institution many years of productive and creative work.

K. L. Rao



Dr. A. N. KHOSLA

B-15, JANPURA
NEW DELHI

29 September 1976

The Diamond Jubilee of the Central Water and Power Research Station, Pune, is a land-mark in the history of hydraulic engineering research in India of which engineers of the country can be well proud of. I am happy to note that the Diamond Jubilee of the Station will be celebrated in a befitting manner by holding symposia and seminars on important research topics.

I had been watching the activities of this Research Station since the days of late Sir Claude Inglis. On assuming charge as Chairman, Central Waterways, Irrigation & Navigation Commission (now Central Water Commission), in February 1945, my eyes were set on enlarging the scope and activities of this Research Station to meet the growing demands and needs of river valley projects, development and improvement of ports and harbours, flood control, inland navigation, coastal development works, hydrodynamics of ships, etc. It is a matter of personal pride and satisfaction to me that my dream of making this Research Organisation as the strongest centre of hydraulic engineering research has been fulfilled.

It is gratifying to note that the Research Station today is serving some of the developing countries in the World and that it has been recognised by the United Nations as the Regional Laboratory to serve the needs of ESCAP countries.

The problems of water resources engineering are becoming more complex as easy sites for construction of dams have already almost been utilised. In the coming years we shall be required to launch upon projects in more difficult areas posing intricate and complex problems with many challenges to the research engineers and scientists. I am sure that the able band of engineers and scientists of the Research Station, now getting equipped further with generous assistance from the United Nations, would be able to find economical, efficient and effective solutions to various problems and make significant original contributions in the field of hydraulic engineering research.

I am quite confident that the Research Station will be able to scale new peaks of prosperity, progress and prestige with the expertise built-up in various fields.

I wish the Station continued success in all their endeavours. I have no doubt that the Station will continue to serve the country in the coming decades with the highest sense of mission and dedication.

A. N. Khosla

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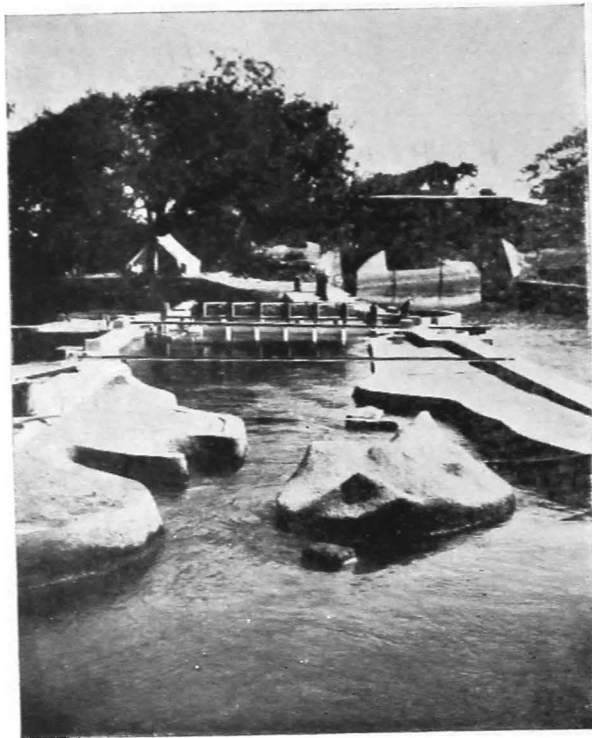
Footprints on the Sands of Time



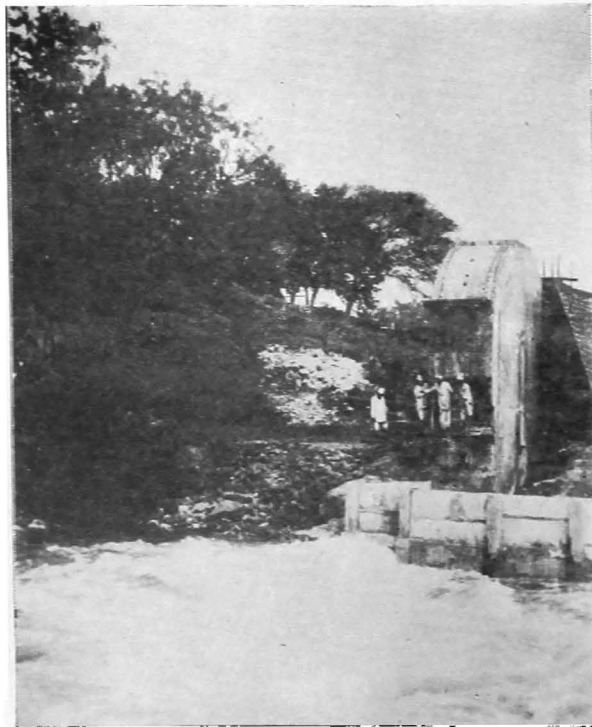
SIR CLAUDE CAVENDISH INGLIS

(3-3-1883 to 29-8-1974)

(Courtesy : Hydraulic Research Station, Wallingford, U. K.)



Sukkur Barrage Model with Bukkur Island
(1929)



Full scale Siphon Spillway Model With 15 m³/s Discharge Capacity
(1933)

Claude Cavendish Inglis

3 MARCH 1883—29 AUGUST 1974

A. RYLANDS THOMAS

and

Sir ANGUS PATON

CLAUDE INGLIS, who died on 29 August 1974 at the age of 91 years, made his mark in India and later in Britain in the field of irrigation and hydraulic research. He was responsible for advances in irrigation management in the Bombay Deccan and made notable contributions on river training and the use of hydraulic models with loose boundaries.

A key to his career and achievements lay in his character. K. K. Framji who succeeded Sir Claude as Director of Indian Waterways Experiment Station, Poona, recalls him as : 'A man of strong character and honesty of purpose, and one indefatigable in his pursuits which reflected unlimited reserves of energy. He expected of his associates no more and no less than what he demonstrated by his own example. He was impatient to achieve progress in his mission of determining rational approaches to hydrodynamic problems and he spared neither himself nor his associates in the work for the benefit of India. It is said that scarcely anyone walked into his room without saying a prayer, but scarcely anyone came out of his room without the happy realization that he had learnt something worth while. He was a good judge of men and all the select research workers whom he fostered have grown to be men of stature in the field. His parting advice at the time of his retirement is characteristic of his own practice throughout his career : "Don't hide mistakes and be *absolutely honest* with yourself in your work...."'

Inglis was certainly not typical of those engaged in research; he would have made his mark in any walk of

life. To a casual acquaintance he was assured, cheerful and good company. To his associates and assistants at work he was dedicated, efficient, outspoken, demanding and sometimes ruthless in the interest of the work, but without rancour. In explaining technical matters, some found him difficult to understand and this led to misunderstandings. To those who understood his methods and would go with him in complete loyalty he provided inspiration and enthusiasm, but he had no use for fools or knaves. His achievements in hydraulic research were due to his capacity for original thinking coupled with intuition and insight into the physical processes encountered in his problems. He would not accept a new idea or theory unless he thoroughly understood it and found that it was consistent with his own logic. Once he had made up his mind there was little scope for argument; his view was the right one—and it usually was. His ambitions were not for personal power but for the achievement of the particular objectives which he was convinced were right. His energy was matched by a determination to have things done in the way he wanted, against any opposition. With such a character it is not surprising that he was different things to different men. To members of his staff at Poona he was their 'guru' or wise teacher. Others found difficulty in working with him and inevitably he made enemies, but he also had staunch friends.

Sir Claude's son, Brian Inglis, writes : 'Although himself involved for so long in laboratory-type research, he always insisted that its purpose was to confirm, modify or cast doubt on a 'hunch'; the hunch must,

he argued, come first. He would go out and brood over a problem from, say, a hill overlooking it; the solution would come to him and the experiments were there to prove it had been right. He had no use for researchers who had no field experience, which no doubt accounts for some of his critics' barbed comments; particularly as he had no glimmering of a notion of tact ("the trouble with Inglis", one of his colleagues in India observed, "is that he can't be content with showing a man is a fool; he must show he is a bloody fool").

Off duty, Claude Inglis had a sense of humour. For example he was obviously amused when he read in the *Times of India* a poem beginning as follows :

Who said ' Modules ' ?

If you want to pass a globule
Made of pani through a module*
You must study C. C. Inglis—Engineer.
For the subject of my rhymes
Fills the Engineering Times

With some stuff that makes my head feel rather queer.

Claude Inglis was born in Dublin on 3 March 1883, the seventh child of Sir Malcolm Inglis, J. P., Deputy Lieutenant of the County of Dublin, who was knighted for his public services. Though both his parents were Scottish, the influence of the Irish environment in his upbringing was quite apparent, as well as the influence of an English public school. He was educated at St Helen's School, Dublin (1892-96), Shrewsbury College, England (1896-1900), and at Trinity College, Dublin, under Professor John Jolly, Sc. D., F. R. S. He enjoyed music, playing the cello and the piano, and while at University was Registrar of the College Choral Society. He took up golf at an early age; trained by one of his brothers (who played his long game left-handed and his short game righthanded), he became a scratch player and represented Ireland. He remained a keen golfer until late in his life his eyesight began to trouble him.

Early Years in India

Like some of his brothers he evidently had ideas of going abroad. He visited Australia when a student but returned home and in 1906 applied for an appointment

in the India Service of Engineers. These appointments were made annually by the Secretary of State for India, but it was the custom for those appointed to remain in one province for the whole of their service. They would, however, be moved periodically from one district to another within the province. Inglis was posted to Bombay Presidency, in the Public Works Department, Irrigation Branch. He arrived in November 1906 and was sent to Sind. Irrigation in India was administered by the provincial governments. The head of the department was a Chief Engineer, who in some provinces was also Secretary to Government in complete administrative control of the department. In Bombay Presidency one Chief Engineer was in charge of irrigation in the Deccan and another in Sind. Under them were Superintending Engineers in charge of circles in each of which would be four or five Executive Engineers in charge of divisions or districts. The divisions were divided into subdivisions.

On arrival in Sind, Inglis was appointed as Assistant Engineer attached to the Executive Engineer, Jamrao canal. It was the practice for young engineers to be given positions of responsibility at an early stage and he was soon given charge of a subdivision where his duties were chiefly the management of distribution of water from the canal to the fields, also the maintenance of the canal and distributary channels and structures in his subdivision and the design and construction of any small engineering works required. He had an office and outdoor staff, he would travel over the area, staying at 'dak' or inspection bungalows provided for the purpose, making daily inspections on camel or horseback to see that the channels were flowing properly, the available water was distributed fairly and none wasted, and deal with complaints and report to his Executive Engineer who would also make occasional inspections with him. It was an open-air life and reasonably healthy except for the malaria and risk of contracting other diseases found in sub-tropical countries. In the evening one played games at the club or, when on tour, perhaps went out to shoot small game for the pot. Inglis became an excellent shot at snipe.

From letters written to a friend at home he enjoyed his new life and found his colleagues and seniors good company. He wrote : " The PWD men here have been kindness personified. One of them came round on his

* Module—a device to control flow at a fixed discharge.

own accord, wrote out a list of all the things I would require, took me to the Point to Point races and finally came round the bazar with me and selected the whole of my kit." He had great respect for his Executive Engineer F. St J. Gebbie, and admired his qualities. Inglis was apparently diligent in his work and pleased his seniors. It was not long before he applied his critical eye and wanted to make improvements in the system, and it pleased his 'ego' to have his ideas approved, especially if he thereby scored over his contemporaries. He wrote: 'B...and W... went to a conference with the Commissioner and H...tells me B... gave the Commissioner the choice of two proposals—both of which were mine—either to remodel the Jamrao, reducing all minors (small distributaries) to less than 15 miles and making a lot of new distributaries, or else to use my profiles, giving us additional powers. B... and W... talk about my proposal to reduce the length of minors as if it were an inspiration. In fact they have both said that I deserve and will get great credit for making the definite assertion. Heavens! I knew that before I had been on Jamrao a month. What none of them realise is that the profile idea as worked out is more or less of an inspiration.'

Transfer to the Deccan

After three years he was promoted to First Inspecting Assistant Engineer, when he supervised the work of three subdivisions and in 1911 he was transferred to Bombay Deccan as Executive Engineer, Godavari canals, with the object of introducing northern Indian methods of irrigation to the Deccan. The irrigation system in the Deccan was, however, different in that water was supplied from reservoirs filled during the monsoon. Whereas in Sind rainfall was at best irregular and at worst nil, so crops depended entirely on canal water which was in great demand, in the Deccan rainfall was very regular during the monsoon months and many crops were grown on this alone. During the dry season much use was made of wells and the available supply of canal water generally exceeded the demand, and he advised against the proposal. The government encouraged the growth of sugarcane on canal water as this required intensive irrigation. This led in time to waterlogging of low-lying areas and the consequent evil of salt efflorescence and permanent damage to black cotton soil.

In 1913 Inglis was appointed to Poona Irrigation District where he had charge of the Nira canals and had the opportunity to study the problems of waterlogging at first hand. In 1916 a new division was formed, the Special Irrigation Division, to deal with this problem by soil classification, land drainage and reclamation and research in connection with these. Inglis was put in charge. He was doubtless well pleased at the chance to initiate and develop such work on his own and it was his first taste of organized research. Six graduates from the Agricultural College were appointed to work under him in co-operation with the engineering staff and 60 acres of land near Baramati, which had been good land but following canal irrigation had become the worst salt-affected area on any canal in the Deccan, was taken over for drainage and reclamation experiments. The Agricultural Department had tried drainage without success; Inglis investigated the soil and geological conditions and demonstrated that drains in a soil of low permeability had only a very local effect but if the relatively permeable murum (decomposed trap) beneath were tapped, large areas could be drained. He found that drains 2.4 m deep were feasible and could be regarded as the economic limit.

Then followed the survey, under his direction, of half a million hectares of land commanded by canals in the Bombay Deccan. Ground surface and subsoil contours and ground water depths were plotted showing the depth of surface soil, the directions of natural subsoil drainage and the locations of permeable material which would be intersected by new drains. The permeability of the subsoil was measured by observing the rate of rise of water in boreholes. An interesting feature of the soil survey was the discovery that much time could be saved by examining the weeds growing in the soil. After a careful study it was found that some 20 out of 120 common weeds were good indicators and these, when combined with observation of materials exposed in wells and in banks of streams, and in subsoil bores made with hand augers, made it possible to assess subsoil successions down to a depth of 2.4 m with a high degree of accuracy. V. K. Gokhale, soil physicist, became particularly skilled in this aspect.

Sugarcane irrigation was already controlled by the 'block system', in which one-third of a block area

could be used for sugarcane and the remainder was allowed only light irrigation. Inglis wanted further controls to prohibit sugarcane in very shallow soil where seepage would be greatest and in deep black cotton soil where drainage could not be provided, and allow irrigated crops only in soils most suited to them. He used his persuasive powers to induce the Government to adopt his proposals against opposition from the farmers who disliked Government interference in their operations and from some officers of the Irrigation Department who would have to submit applications for irrigation to Inglis's office for approval, but there can be no doubt that such measures were needed to restrict further damage in low-lying lands.

In the meantime, Inglis had successfully drained the experimental area at Baramati and had found that damaged soils could be reclaimed by leaching, chemical treatment and cropping with rice, showing that reclamation was feasible though perhaps costly. In the following years, several drainage schemes were constructed in damaged areas commanded by irrigation canals in the Deccan, mostly surveyed and designed by W. A. Evershed, Executive Engineer, Irrigation Research Division and his staff, under Inglis who had in 1927 been promoted to be Superintending Engineer in charge of the newly created Irrigation Development and Research Circle.

The responsibilities of the Special Irrigation Division also extended to other aspects of research concerned with irrigation. In 1918 an expert from England had advised that effluent from the Poona sewage scheme should not be used on the land but should be chlorinated and discharged into the river. This would have been costly, so the Government accepted Inglis's alternative scheme for mixing it with canal water and using it for irrigation. To induce the farmers to use the mixture and to determine the best methods for its use an experimental farm was established. This was first run by the Agricultural Department but was later handed over to the Special Irrigation Division to run. The opposition of the farmers was overcome when they saw that excellent crops were grown, particularly sugarcane from which the out-turn was better than that from neighbouring crops with normal fertilizers.

In 1924 Inglis was made responsible for river gauging in the Bombay Presidency and in a Technical Paper on rainfall, runoff and floods (1930) he derived a formula which has since been in general use in the area. He also directed and edited the draft of a new irrigation manual for the Bombay Deccan and investigated weed growth in the canals and measures for their control. About the same time Inglis became involved in a controversy in regard to the future policy for irrigation management in the Deccan. The Director of Agriculture and some irrigation engineers held the opinion that sugar factories could not succeed on the Deccan canals. There was already one company cultivating sugarcane in a large area on a systematic basis; the cane was processed in a factory to produce refined sugar. Apart from this, sugarcane was grown mostly by small farmers who produced unrefined sugar or 'gur' for local consumption by operating simple crushers, the juice being heated in open pans. Inglis believed that the establishment of more sugar factories was needed to ensure the economic viability of the canals, especially the Nira Right Bank canal, recently constructed, where the demand for irrigation by local farmers was very sluggish. Government ordered a special investigation which vindicated Inglis's view and, after some delay, action was taken to encourage the establishment of sugar companies in the area. In due course several factories started operation by private companies and these created a steady demand for water.

Hydraulic Research in India

The experimental station for hydraulic research grew from a small beginning in 1920 when, to control the distribution of water from the canals, a measuring device was needed. After testing and calibrating, Inglis produced the 'standing wave flume', a simple critical-depth meter which was semi-modular, i. e. the discharge passing was independent of the tail water level provided the hydraulic jump was not drowned, which could easily be seen. This was an advantage because the farmer could not increase the flow by deepening his channel downstream and the discharge could easily be determined by reading the upstream gauge. The same principle was applied to the design of semi-modular outlets from distributaries and the use of these flumes and outlets became standard throughout the Deccan

irrigation system. Inglis also developed a full module, in which the discharge was fixed by the dimensions and was independent of head and tail water levels within a working range. This had been invented by A. S. Gibb of the Punjab Irrigation Department and consisted of a spiral with several baffles, without moving parts. A number of these were used to control outlets on the Nira canals.

Much work was done on siphon spillways for reservoirs, which offered advantages over free overfall weirs in allowing a higher water retention level, and over gates because of their automatic operation and reliability. Scale effect in models was explored by constructing a large and a small siphon of the same design, geometrically similar; the large siphon having a discharge capacity of 15 m³/s. It was located downstream of Khadakwasla dam, near Poona, and must have been about the largest model tested anywhere at that time. In some of the tests alternate priming and depriming persisted, with a loud intermittent gurgling roar which could be heard for miles.

Khadakwasla presented such advantages for a hydraulic model research station over the canal site previously used that it was expanded and all hydraulic research work was transferred there. A large discharge was available from the reservoir under pressure through eight sluices, each separately adjustable. The water was clear for most of the year and was not wasted after use, being discharged into the irrigation canal. The climate was never too cold for the operation of large models in the open.

In 1928 when the Sukkur barrage in Sind, the largest in India, was under construction, Inglis was asked to advise on certain aspects of hydraulic design. Following model tests he condemned the design on five major points. His recommendations were accepted and the design modified accordingly. Further requests for advice followed, many concerned with the design of structures on the new canals in the Sukkur barrage scheme and the exclusion of sediment from canals. Enquiries also came from further afield, notably from the Railway Board in connection with Hardinge bridge as described later. Though research with rigid models had been carried out at laboratories for some years and isolated

tests had been done with river models having mobile erodable beds, the Poona station was probably the first where large models with mobile beds were systematically used to elucidate hydraulic problems.

About this time the Government of India in consultation with the provincial governments established the Central Board of Irrigation as a coordinating body, mainly on technical matters and research, administrative control of the irrigation departments being retained by the provincial governments. Two or three meetings were held each year, attended by delegates from each member province. Inglis was from the beginning a delegate from Bombay and took an active part in the discussions. Subjects were selected on which delegates would submit papers and the discussion was often stimulating.

Though several provinces with irrigation systems now had their own hydraulic research laboratories, the need was felt for a central station for the whole of India with better facilities than the provinces could provide. This would be available not only to the irrigation departments but also to the Railway Board, port authorities and any other public bodies who might require advice in its field. The Bombay Government, at Inglis's suggestion, offered the research station at Poona (Khadakwasla) for this purpose. It would be immensely attractive to Inglis to be the first director of the central research station, with much more scope than he had and he was sure that he was best suited for the post, but there were two snags. One was that he was approaching the age of retirement according to the service rules, 55 years, and the other was that the Punjab Irrigation Research Institute was a serious rival to Poona. Apart from the question of the central station Inglis feared that if it was not selected and he himself left on retirement, the Bombay Government might decide to close down the station at Poona or greatly reduce its size. He prepared for battle. He felt that as the Punjab had more irrigation than any other province the Central Board of Irrigation (C.B.I.) might favour the Punjab institute, especially when reports appeared in the Press that the latter was likely to be selected. He listed the arguments in favour of Poona and the arguments which might be put forward in favour of the Punjab and the questions he might be asked so that he would have his answers ready. He saw Lord Brabourne,

Governor of Bombay, and obtained his support. He wrote to a friend: 'Realising that I could hope for little from the C. B. I., who were in any case barking up the wrong tree, the G. of I. [Government of India] being unwilling to finance irrigation research, I saw the Hon'ble Members for I & L [Irrigation and Labour], Home, Railways and finally the Viceroy, and put up the case for a River Research Station at Khadakwasla. This received a very favourable reception. Nevertheless, the G. of I. having once handed over the question to the C. B. I., it will be very difficult to get this through in the teeth of their opposition. If it does go through it will be purely a personal victory against big odds...The whole trouble, which the G. of I. may realise, is that the question is not being considered on its merits.'

In the end, his efforts were rewarded. Despite a recommendation by the C. B. I. for the creation of a new research station at Delhi; thus side-stepping the rival claims of Poona and the Punjab, the Poona Station was selected to be the new Central Irrigation and Hydrodynamic Research Station, with Inglis as its first director, and he was given an extension of service beyond the normal retiring age. This meant the end of his work on irrigation management and land drainage, control of which was retained by the Bombay Government. Inglis was now to concentrate on hydraulic research.

The research station at Poona occupied at this stage about 3 hectares of land. During the war years further development was restricted but it has since been greatly enlarged. In the eight years of Inglis's directorship, investigations were carried out on many problems with models while in other cases advice was given without model tests. The investigations were classed as 'specific' if they were required in connection with actual problems referred to the Station, or 'basic' if they were concerned with research carried out on general matters or on the technique of model testing. The cost of specific investigations was charged to those requiring them while the cost of the basic work had to be borne by the annual grant to the Station.

As examples of the work done there were specific investigations regarding irrigation barrages, river

training at railway bridges, bank protection against scour and water supply intakes. Basic studies were done on flow in alluvial channels, sediment control, depth of scour in rivers, river meanders and the use of spurs in river training, also the technique of reproducing the behaviour of rivers in models. One of the specific investigations concerned the flood problems in Orissa, referred to in more detail later. Another was concerned with bank erosion in the navigable channel of the Hooghly, serving the port of Calcutta, especially important during the war. This involved the use of a tidal model, the first of its kind at Poona. Because of the difficulty in obtaining special equipment from abroad at that time, the tidal control and recording mechanisms were made of components hand made locally, controlled by clock movements taken from alarm clocks, but by trial and error they worked.

Inglis was called in to advise on problems in many parts of India, including the Indian States. In the single year 1944 no less than 54 enquiries were received and, during the war, he was in touch with the Army G. H. Q., advising on problems connected with river crossings. A particularly interesting mission was his visit to Nepal in 1941 to report on the westerly movement of the Kosi river which had changed its course laterally more than 80 km in 50 years, devastating the country overrun. He travelled in remote country rarely seen by Europeans and (unusually) his wife accompanied him.

The extensions of service eventually came to an end and he left India in 1945 on leave prior to retirement, rewarded with a knighthood for his services to India. After 39 years of service, mostly spent on irrigation and hydraulic research, he must have felt at this point a great break with his life's work. In his farewell speech to his staff he said: '... My parting advice is therefore: Don't hide mistakes and be absolutely honest with yourselves in your work...seek ever to make your thoughts and statements more precise and your work more accurate...Especially I would counsel you to view every investigation in its physical aspect. It is not sufficient to obtain a mathematical curve which fits a series of experimental points. You must also understand the physical significance of this curve and reduce the problem to its simplest equilibrium form...'

Mention must be made here of D. V. Joglekar who had served with Inglis for 21 years. For most of this time he was effectively his personal assistant and Inglis relied on him in all his work on the hydraulics side, and later, following K. K. Framji, D. V. Joglekar became Director.

Sir Claude's arrival in England 'on retirement' was the beginning of a new round of activity. He was commissioned by the Government of India to write a report summarizing the aspects of his work at the Poona research station of the kind not contained in textbooks or easily traced elsewhere. With the aid of a secretary and the papers he had brought with him he was able to prepare the report in London and it was published in 1949 in two volumes. Entitled *The behaviour and control of rivers and canals with the aid of models*, it contained detailed accounts of many of the investigations he had carried out and the underlying principles of his work relating especially to alluvial channels and the effects of sediment load and fluctuating discharges.

Inglis was now an independent consulting engineer and his services were still in demand. In 1946 he visited Calcutta to advise the Port Commissioners on the effects of changes in the channels of the Hooghly, and in 1947 he went to Abadan to advise the Anglo-Iranian Oil Company on changes taking place in the Shattal-Arab. In 1948 he advised the Chittagong Port Trust on the training of the Karnafuli river.

Hydraulics Research in the U. K.

While he was engaged in this work, the Institution of Civil Engineers approached the Department of Scientific and Industrial Research on the need for a hydraulics research station in the U. K. to deal with such problems as coastal erosion, flood protection and the silting and scouring of rivers, estuaries and harbours. These were essentially 'loose boundary' problems as distinct from the solid boundary hydraulics which was much more predictable. A committee was set up which endorsed the proposal for a research station and recommended the formation of a Hydraulics Research Board and the appointment of a Director of Hydraulic Research. The Board was formed and in March 1947 Sir Claude Inglis, then aged 64 years, was appointed the first Director of Research.

Some hydraulic work was in progress at the National Physical Laboratory and the staff concerned were immediately placed under Sir Claude's direction but the most important and urgent need was a research establishment with adequate facilities. The choice of a suitable site was far from easy; essential requirements were sufficient area of gently sloping land, adequate water supply and electric power. Inglis also considered it most desirable for the new station to be within easy reach of London because of the number of visits expected from clients, the engineering profession and overseas visitors. But there were political complications; the Government of the day were following a policy of dispersion of Government institutions to please local interests and provide employment in remote districts. It was considered at high level that a site in Central Wales or Scotland would be appropriate for a self-contained research station. This did not suit Inglis; once again he prepared for battle; he marshalled his arguments; he convinced the Hydraulics Research Board; he enlisted the aid of prominent civil engineers and called on influential persons who might induce the Government to change its mind. Once again, as in the cases of Poona effluent, land drainage and irrigation management and sugar factories in the Bombay Deccan and the establishment of the Central Irrigation and Hydrodynamic Research Station at Poona, he got his way. The location of the new Hydraulics Research Station was approved at a site he had selected at Howbery Park, Wallingford, Berkshire. This was an estate of some 45 hectares with a large house which was to be used for offices. It adjoined the Thames river from which ample water could be pumped, or clear water could be drawn from tube wells. It was readily accessible from London. Work began on the construction of tanks, flumes and wave basins and in 1951 the headquarters of the organization was formally transferred to the new station.

It was intended that the facilities should be the most modern and the best that could be provided. Inglis and some of his new staff visited laboratories in Europe to take note of current developments and the layout of the new station, its buildings, pipework, equipment and instrumentation were carefully planned. One requirement was the main hall which, in its first stage, was 92 m × 61 m with a roof of big span to allow unobstructed floor space for large models. Water was

stored in tanks at near roof level for supply to the various models. Two wave basins for coastal works were provided in the open, while smaller models could be accommodated in temporary buildings. Wood and metal workshops, instrument room and stores were also provided; in fact these were built in advance of the main hall, which was then continued on from them. The area of the grounds would permit considerable future extension. By 1955 the first stage of development was virtually complete and by the following year the main hall was almost fully occupied by models being built or in operation.

Britain and British engineers have much to thank Inglis for. 'But for his unremitting efforts it is doubtful', in the words of his successor as Director, Fergus Allen, 'we should have a Hydraulic Research Station of the size, sophistication and international standing that attaches to the Institution at Wallingford. But for his determination and his judicious blend of pugnacity and charm the research establishment which might ultimately have emerged from the mists of bureaucratic lack of conviction would have been a much more trivial place than the laboratory we have—and to which it is hoped British hydraulic engineers are willing to point with a certain pride.'

Enquiries and requests for advice flowed in. Investigations were carried out on the Forth and Wyre estuaries and on a spillway and tunnel at Fassideri near Athens. Following the disastrous storm surge in 1953, survey teams were sent to inspect the damage on the East coast and a small model of the Thames was used for a preliminary study of the problems concerned with flood protection in London and on the estuary. The effect of a surge-reducing barrage was tested on behalf of the Waverley Committee, the model thus being the forerunner of a larger model built to assist in the study of the same problem some 13 years later. Work was started on a large tidal model of the Thames built at Victoria Dock for the Port of London Authority and an investigation was begun into land reclamation in the Wash. One of the larger models in the main hall was of the tidal reaches of the river Trent in connection with flooding and the Station was also concerned with a flood relief scheme for Shrewsbury. Some of the work was from overseas. A model was made of Lyttleton

harbour, New Zealand, one of Karnafuli river and port at Chittagong and another of Tema harbour on the Gold Coast.

Many visitors came from home and abroad. In November 1956, The Queen visited the Station and was taken around by Sir Claude to see the models and equipment. In the same year investigations were started on the river Mersey estuary; this was a combined field and model study of siltation and channel movements. Other specific studies were in progress, too numerous to mention, while basic work included the standardization and calibration of the Crump weir, now widely used in stream gauging, air-regulated siphons, channel meandering, the effect of groynes in coast protection and movements of ships at moorings. New instruments and equipment were developed to meet the needs of the work, including a miniature velocity meter, wave and tide generators and recorders and electronic control of models. A 10 m boat was acquired and equipped for coastal surveys and new techniques were devised to indicate movement of bed material by the use of radio-active and fluorescent tracers.

These were achievements of the team of specialists, ever growing in number and competence, under Inglis's direction. At Poona, Inglis had always acknowledged the contributions made by his staff, but he himself had played a major part in everything done at the Station and carefully edited all reports. At Wallingford, although at first he may have been able to give personal attention in some detail to much of the work in progress, in spite of his occupation with the equipping of the Station, as the work grew in amount and scope its sheer volume must have precluded his remaining in such close touch and control. Moreover, the problems concerning waves and coastal defence were new to him. Nevertheless, he continued to direct work personally and generally took the decisions. His personal involvement is evident from papers published of which he was co-author with members of his staff: see Bibliography, items 1954-68. Some of the staff may not have liked his occasional blunt criticism, others may have wished for more freedom in their work, but all respected his ability and found his impact stimulating. The senior staff increased in number from nine in December 1951 to thirty in December 1957. On his retirement in March 1958, at the age of 75

years, the Hydraulics Research Board in their Annual Report wrote about him: 'He was already an international figure in hydraulics when, in 1947, he was appointed the first director and given the task of creating the Hydraulics Research Station. He selected the site and devised the layout of the present Station which will permanently benefit from his genius and foresight. For ten years he devoted himself to building up the Station and training the staff, so laying a sound and wide foundation for the development of a major research establishment of international standing.' Some years later when a new survey vessel was commissioned, it was named 'Sir Claude Inglis'.

Contributions to Engineering

Inglis's contributions to engineering were mostly in the field of irrigation canals and river training and the use of hydraulic models in connection with these. In northern India vast areas of crops are irrigated by water diverted from the large rivers which traverse the flat alluvial plains and conveyed in canals dug in the sandy soil. Because of the long dry season and uncertain rains, the food supply is dependent on irrigation water. The canals are therefore a vital life line of the people, and with the growth of the population the irrigated area is continually being increased by the construction of new canals. The early diversion works were simple weirs but later gated barrages were built for better control of water flow and the sediment it carried. A constant trouble in the canals was the entry of sediment from the rivers, depositing and reducing their capacity; it was therefore required to design the canals so that they would be non-silting but also non-scouring, a knife-edge condition difficult to achieve. Inglis spent much time studying the flow of water and movement of sediment in alluvial channels and developed an intuitive approach. He was particularly impressed by a paper by Gerald Lacey presented at the Institution of Civil Engineers in 1930*. His strong support for Lacey against criticism in published discussion on this and subsequent papers on the same subject led to cooperation between the two over a period of many years, during which they exchanged ideas and advanced their

theories regarding alluvial channels. The Lacey 'regime theory', as it was known, was a development of Lindley's theorem that the dimensions of a channel free to shape its own boundaries in alluvial material were uniquely determined by the water discharge and sediment load. By correlating data of velocity, depth, width, slope and bed material of numerous channels presumed to be stable or 'in regime', Lacey produced a group of equations showing that these parameters were all related. The equations when transposed in terms of discharge, Q , and sediment factor, f , showed that the width of a channel in regime was proportional to $Q^{1/2}$, depth to $(Q/f)^{1/3}$, mean velocity to $Q^{1/6}/f^{1/3}$ and slope to $f^{5/3}/Q^{1/6}$. The factor f was a function only of transported and boundary material, being greater the coarser the material, Lacey held that his equations depicted laws of Nature and applied in some respects to alluvial rivers and this led to some controversy, but they have since been accepted as the basis of design of unlined irrigation canals throughout India and Pakistan and have been used in many other countries.

Inglis considered the Lacey theory to be a breakthrough in the understanding of alluvial channels and saw their potential in problems of river control and in the design of hydraulic models with sand beds. The maintenance of irrigation barrages and bridges on northern Indian rivers required constant vigilance. When the rivers rise in flood there may be bank erosion which threatens to breach the canal or railway line, or the main stream may change position away from the canal intakes, or training works may be washed away. The effect of training works is not known in advance. Inglis used hydraulic models of rivers to enable alternative schemes of training works to be tested before construction and even to indicate the future tendency of changes in river course. It followed from the Lacey equations that small channels were relatively narrower and deeper than large channels in the same bed material, as in Nature. Also, experience had shown that hydraulic models of open channels should be vertically exaggerated, i. e. the vertical scale made larger than the horizontal scale, for practical reasons and to increase

* Lacey, G. : 'Stable channels in alluvium',
Proc. Instn Civ. Engrs, Lond. 229, 1930.

the Reynolds number. The Lacey equations provided the means of calculation of all scale ratios, once the linear scale had been selected. Moreover, where the bed material was the same in model as in prototype, the velocity scale was proportional to the square root of the depth scale, which also satisfied the requirement of equal Froude number. In practice, Inglis found difficulty in that the model channels tended to become too wide by bank erosion, owing, he believed, to the material forming the banks being artificially laid without cohesion as in natural rivers, and he devoted much effort both at Poona and Wallingford in experiments to overcome this trouble and determine new rules to apply to models.

Inglis had studied the development and effects of curvature in rivers, resulting in meandering where rivers were to form and erode their banks in alluvial materials. He noted that larger rivers tended to form longer meander curves and it occurred to him that meander length might be proportional to river width and hence to the square root of the discharge. He collected data of river meanders and carried out tests in channels and was able to correlate meander length with river width and discharge. The discharge of a river, however, varies over wide range between low flows in the dry season to high flows when in flood. He therefore introduced the concept of 'dominant discharge.' Lacey had shown how the dimensions of uniform regime channels were related to their discharges. Inglis believed that for any particular river a discharge could be found representative of the dimensions of the channel, i. e. its width, depth, slope and meander length. This he termed the 'dominant discharge', which he estimated approximately to bank full discharge. In his own words: '... it will be assumed that there is a dominant discharge and its associated [sediment] charge and gradient to which a channel returns annually. At this discharge equilibrium is most closely approached and the tendency to change is least. This condition may be regarded as the integrated effect of all varying conditions over a long period of time.'

This concept facilitated the application of the Lacey equations to rivers. When confronted with a river problem, Inglis would study the historical surveys and available data of water level and discharge to enable

him to diagnose what was happening and why. By use of the dominant discharge an immediate comparison could be made with the stable condition as indicated by the Lacey equations. This reasoning led Inglis to examine the effects of deviations of channels from regime, often due to excess sediment load and complicated by historical variations in discharge and load. Whereas Lacey had used the sediment factor f which appeared in many of his regime equations, Inglis demonstrated that in a given case f calculated by the different equations might be found to have different values and these could be used to evaluate deviations from regime stability. He also produced expressions to introduce sediment load into the Lacey equations.

Various means had been tried to reduce the entry of sediment, particularly the coarser bed load, from rivers into the canals, for example the provision of high regulator sills, deep sluices and divide walls. These were generally effective to some degree but none was completely successful. Inglis made use of his knowledge of meanders and sediment movement in a different approach. Where possible he preferred to enlist the forces of Nature rather than oppose them, and he used the differential movement between surface and bed curved flow to separate the flow carrying a heavy concentration of coarse sediment near the bed from the relatively clear water above. Bed flow is deflected across the channel away from a concave bank, so if the canal intake is located there it will draw more clear water and less sediment. This principle had been used for many years in locating the heads of inundation canals drawing supplies through cuts in the river banks, which could be moved from year to year to suit the movement of river meanders, but with the increasing use of barrages and large perennial canals the locations of the intakes were fixed. Inglis's solution, where conditions were suitable, was to create artificial curvature of flow for use as described. The best known example is the approach channel at Sukkur barrage on the Indus river, Sind. The barrage is 1400 m long; seven canals draw supplies, four on the left bank which is gently concave and three on the right bank. The flow from a rocky gorge upstream is directed slightly towards the left bank and, because of the curvature, the canals there drew less sediment than those on the right. Two of the

right bank canals silted heavily between 1932 when the barrage was first operated and 1938, despite control provided by the divide wall and gate operation.

Following intensive model tests at Poona, Inglis recommended the construction of a curved approach channel near the right bank upstream of the barrage and leading to it, with a second channel taking off from the first on the concave bank and leading to the right bank canals. When the river carried surplus flow, as in floods, flow could be passed through the approach channel, the canals drawing surface water while the rest of the flow in the channel was discharged through the barrage. At times of low river flows when less sediment is carried, the barrage gates would be closed and the approach channel flow would be reduced to that drawn by the canals. The control was thus flexible to meet varying river flows. The approach channel was 1500 m long with discharge capacity of 1300 m³/s. The right bank canals drew up to 500 m³/s. The scheme was adopted and constructed in 1939-41. Surveys of the three canals in 1941 showed that the silted bed levels had already begun to fall and their discharge capacities continued to improve.

Many of the railway bridges across alluvial rivers, which had been satisfactory when built, began to give trouble after some years when the rivers changed their courses or angle of approach. Often armoured guide banks were provided to maintain a straight approach or spurs were built to deflect the flow towards the bridge. The spurs were armoured banks projecting into the river and were uncertain in their effect; sometimes they failed in their object while others were washed away in the floods. Inglis had observed that some spurs deflected the flow while others attracted and held it, according to their location in relation to the meander. He showed how 'repelling' and 'attracting' spurs could be used to control the river and where they should be located to be effective. Inglis's advice was often sought and in many cases model tests were carried out at Poona; in other cases he felt he was able to

advise without model tests. Two examples are of particular interest.

The Hardinge bridge spanned the river Ganges north of Calcutta, carrying the main railway line to Assam. It was built in 1911 in what was considered to be a reasonably stable reach, the river being held by two outcrops of clay upstream, though there had been swings of the main course from bank to bank during the previous century. The training works consisted of upstream and downstream guide banks and three independent banks upstream known as the Damukdia, Sara and Raita banks, respectively about 2, 5 and 11 km upstream of the bridge. The river at the bridge was 1 $\frac{3}{4}$ km wide. These banks were armoured with loose quarried stone. In September 1933, soon after the completion of the Damukdia bank which was built after the others, a breach occurred in the right guide bank near its head during a high flood. The bridge was saved only by prompt action, filling the breach with a large volume of stone.

At the request of a special committee set up to advise the railway authorities, Inglis carried out model tests at Poona and succeeded in reproducing the conditions at the toe of the right guide bank which he maintained had led to the failure. In his view these conditions were directly due to the existence of the Sara and Damukdia banks upstream and would be relieved if they were removed. This view was strongly disputed by the bridge designer, Sir Robert Gales, in a paper he presented to the Institution of Civil Engineers* but Inglis in the discussion pressed his point, and was supported by W.L.C. Trench, a member of the committee. In the event, Inglis's recommendations were accepted to the extent that the protective armour from the Sara bank was removed, so allowing it to erode and relieve the attack on the guide bank, which was later extended to be continuous with the Damukdia bank.

The other example of Inglis's river training work relates to his proposals for saving the railway bridge at the Rupnarain river. The East India Railway and the

* Gales, Sir R. R.: The principles of river-training for railway bridges, and their application to the case of the Hardinge bridge over the Lower Ganges at Sara, J. Instn Civ. Engrs 10, 136, 1938.

Grand Trunk road to Calcutta had been cut by the disastrous breach of the Damodar; repairs could not be undertaken and as the Burma campaign was in progress, the position was critical. The Bengal--Nagpur line, the only remaining communication to Calcutta, was threatened with being cut off by the Rupnarain river. The left bank loop of the Rupnarain river had eroded to within 1500 ft of the railway at its nearest point, and accelerated erosion was then taking place with grave danger to the approach to the bridge. It was at this stage that Inglis was called in to advise how the erosion could be halted in such a way that the work could be completed within five months before the break of the monsoon. With the aid of only a small rigid bed model constructed for another purpose (to see whether the unusual tidal conditions could be explained) Inglis recommended that a 'repelling groyne' should be constructed, first extending out 800 ft and later further extended, against opposition of the railway engineers to 1400 ft. This groyne proved even more successful than had been expected, and within three months of the break of the monsoon the threat to the bridge was completely averted.

An example of Inglis's application of his knowledge of rivers carrying sediment is found in his work in connection with the flood problems of Orissa. He was a member of a committee set up to study the problems and advise on their solution in the period 1938--42. James Shaw, then Executive Engineer and later Chief Engineer Orissa, writes: 'Sir Claude found the Orissa delta flood problems of special interest as presenting a large combination of big rivers with many different aspects to consider. The three largest rivers had maximum flood discharges of 45,000, 18,000 and 14,000 m³/s respectively and the largest river was over 1½ km wide between embankments in places.

' A large programme of hydrodynamic and land study was undertaken and a model experiment was set up at Poona to prove the distribution of separate river discharges at the head of the Mahanadi delta and the possible effects of the proposed methods of control. This study benefited Orissa but was also of value to Sir Claude in his general studies of river meandering, silt burden and transport and the effect of double banking deltaic rivers. From the beginning Sir Claude emphasized the fact that the problem was not so much

the disposal of excess water as the disposal of sand and silt since these so greatly affected the capacity of the channels. No easy solution was found from comparison of old river data as there were so many fluctuating factors such as sequence of flooding, occurrence of breaches, construction of embankments and flood escapes, and altering of offtake conditions at bifurcations. On the whole, however, there was no proof of a general rise in river bed levels in the last 80 years during which many flood embankments were constructed. This, together with Sir Claude's knowledge of recent advances in river hydrodynamics, helped to determine the policy and programme of the Orissa Advisory Flood Committee. This policy was to conserve and improve the main rivers by restricting the number of branches where at all possible; the extension of double embanking combined with adequate interior drainage; prevention of breaches; spilling of flow in excess of a predetermined figure on the land by selected high level flood escapes taking no coarse silt; and the maintenance of clear river mouths into the sea. As a general policy it was also recommended that there should be strict forestry control in the river catchments to prevent denudation with its ill effects on flooding and that...the construction in the future of flood detention reservoirs in the catchment areas was considered desirable'. Inglis had observed that, in general, large channels had a greater sediment-carrying capacity than small channels per unit of discharge, so more sediment would be carried by a given flow in the delta if the channels were combined into a few large channels than if they were allowed to divide into numerous small channels. Hence the policy of restricting the number of branches, illustrating an important principle in Inglis's methods of river control in deltaic conditions.

Although Inglis had been a pioneer in the use of large models with mobile sand beds and gained much experience over a long period on their design and operation, his conclusions and recommendations in any particular case of river training depended more on his personal judgement and feeling of what was happening, and what would occur if certain action was taken, than on the actual results in the model. In this respect his approach differed from that of those engaged in pure

research and from that of hydraulic laboratories where reliance may be placed more on the reproduction as far as possible of the prototype river. In his presidential address to the Engineering Sections of the 28th Indian Science Congress at Benares in 1941 entitled 'Hydrodynamic models as an aid to engineering skill' he classed hydraulic models in four main types: (I) geometrically similar models which give geometrically similar results; (II) geometrically similar models which do not give geometrically similar results; (III) models with a mobile bed in which flow pattern is the dominant factor; (IV) vertically exaggerated models: (a) rigid, (b) semi-rigid, (c) mobile. After giving examples of each, he ended: 'The general conclusion is that in competent hands a very wide range of experiments with large models gives results of high qualitative accuracy and may also give quantitative accuracy; but in the case of river models, the data available are generally meagre, and though the gaps in data can be filled to a large extent by an officer with wide field experience, so that model can be made to reproduce what has previously occurred in the prototype under known conditions of discharge and silt charge, the problems which generally have to be tackled are of immediate urgency, the discharge data being inadequate and the silt charge data nil, and we are asked "What will happen if nothing is done?" Satisfactory answers depend to a marked extent on an intimate knowledge of the engineering side of the problems under consideration combined with a flair for diagnosis. Mobile river models are in fact a valuable aid to engineering skill, which however they can never replace.'

In the words of Gerald Lacey, 'Claude's great gift was his flair for interpreting river behaviour. We might almost say that he studied river psychology. He treated these alluvial rivers as if they were alive, not rigid and dead. He asked himself the question "What would I do if I were the river?" and almost invariably got the answer right.'

Retirement

In his retirement Sir Claude reverted to private work as consultant and for a few years he and his wife stayed on in Wallingford where he kept in touch with progress at the Hydraulics Research Station. In 1963 they

moved to a house at Henfield, Sussex, where they would be near nieces who were living in that district. Sir Claude's sight was deteriorating owing to cataract in both eyes and one eye was operated on. Tragically this was unsuccessful and led to loss of sight in that eye. The surgeon advised that there was considerable risk that an operation on the other eye would also be unsuccessful so this was deferred. Even so, he carried on his activities with zest, aided by his wife and by his secretary. The procedure was for his secretary to read incoming correspondence and any technical literature he wished to study into a tape recorder. He would later play this back and dictate letters into a second recorder while a third recorder was used as a memory and for his notes.

He continued to advise a firm of consulting engineers in London on the Hooghly. He kept in touch with the Chittagong Port Trust on problems with which he had first been consulted in 1948. This correspondence continued until December 1970 when it came to a sudden end owing to internal strife in East Pakistan. He was also consulted by a British company operating tea estates in West Bengal, India. He had first been called in to advise on this work in 1952 after debris from land slides in the hills was washed down rivers by heavy floods, filling the channels and causing damage to the adjoining tea estates. A programme of river training works was then carried out and, though his advice was not always followed, Inglis was consulted from time to time. He was sent reports on the rivers and training works and gave further advice on action to be taken. This involved much correspondence which continued until the latest report was received in February 1974, when he wrote asking for a set of new maps then being prepared to be sent to him. Many of his letters contained explanations of his diagnosis and proposals and descriptions of what should be done. It is remarkable that a man of his age and failing sight, unable to visit the scene, should be able to visualize what was taking place and offer detailed advice by correspondence.

Throughout his retirement he kept himself aware of development in his field by reading, or later having read to him, published literature and he carried on correspondence with friends and contacts in the

profession. Mrs. Cynthia Smith his secretary writes : To me his amazing quality was his lively interest in new developments in his field and his efforts to comprehend techniques such as mathematical models which have never been part of his experience.'

Miss Marie Lindley, the first lady member elected to the Council of the Institution of Civil Engineers, also writes : ' My own contact with Sir Claude arose from fact that he was a contemporary and friend of my father in India and Lady Inglis was my godmother. Sir Claude and Gerald Lacey took up and extended my father's original work on the regime of canals and Sir Claude frequently drew attention in his writing to that original work. When Sir Claude retired and I myself returned to work in England, I used frequently to spend weekends at Henfield enjoying discussion of problems which he was currently studying. He used to "talk out" ideas for his contributions with me in a way which he was unable to do with his non-engineer helpers. He retained a very active interest in his engineering and in sport, in spite of increasing isolation caused by his decreasing mobility, in a rural area. He always welcomed visitors and would soon have them deep in engineering discussion. His work, when I knew him, was concerned with understanding and interpreting natural phenomena and identifying the real causes and effects in the rivers and canals which he was considering. He was very concerned with the misinterpretations which he saw others making, particularly where an opportunity was being missed of making nature do most of the work.'

During his retirement Inglis became interested in theories regarding the ancient civilization Mohenjo Daro in the Indus valley, Sind, where there is evidence that irrigation was practised some 4000-5000 years ago. He wrote in November 1966 : '... I have been dealing with the reason for the sudden extinction of the town of Mohenjo Daro of the Harappan civilization (B. C. 3800 to 3200)' and later ' I am getting more and more involved in the Mohenjo Daro problem, because three books by people with different ideas have just been published, and though the ideas expressed therein are not the true explanation, and can be refuted, establishing the correct explanation presents great difficulties,

as it depends on the positions and behaviour of several rivers 4000 years ago.' Again in 1970 he referred to a paper written by a friend who had been in the Indian Civil Service in Sind, H. T. Lambrick, which refuted ' the archaeologist's theory that an enormous lake was formed by a tectonic upheaval, which had led to the formation of a barrier across the Indus valley. We consider the true explanation, based on the position of the Indus 2000 years ago, is that the river some 4000 years ago moved many miles to the east, away from Mohenjo Daro, so that cultivation in its vicinity was no longer possible.'

No biography of Sir Claude would be complete without mention of his wife, Vera, whom he married in 1912. She had great charm and sincerity. She and Claude did much for the Poona Library and she kept in touch with the latest books and with the affairs of the day. She had a practical outlook and devoted much time to local charities and organizations and was the recipient of the Kaiser-I-Hind medal. She had a subtle sense of humour and must have exerted a good modifying influence at times on her husband. She died suddenly in November 1972 which must have been a sad blow to Sir Claude but he showed remarkable resilience and his interests were soon as keen as before. In June 1974 he decided to have the cataract operation on his second eye - a courageous decision at the age of 91 but characteristic of the man. The operation was successful but his general health suffered and he died in August 1974. They are survived by one son, Brian St John Inglis, writer and broadcaster.

We are greatly indebted for the help given to us in the preparation of the memoir by Brian Inglis and by P. Ackers, F. H. Allen, T. Blench, J. S. Burgess, H. R. A. Dedow, D. R P. Farleigh, K. K. Framji, D. V. Joglekar, F. J. T. Kestner, G. Lacey, G. H. Lean, Miss and M. Lindley, J. S. Reid, R. C. H. Russell, J. Shaw, Mrs. Cynthia Smith.

Awards And Honours

Claude Inglis was made a Companion of the Indian Empire in 1936 and was knighted in 1945. He was elected Fellow of the Royal Society in 1953. In 1957 the co-author, F. H. Allen, of his joint paper on the River Thames received the Telford Gold Medal of the

Institution of Civil Engineers, Sir Claude being then a Member of Council. The James Alfred Ewing Gold Medal was awarded to Sir Claude by the Institution of Civil Engineers and the Royal Society in 1958. He was member of Council of the Institution of Civil Engineers

1947-52, a member of the Smeatonian Society of Civil Engineers and of many international associations connected with hydraulic research, navigation, irrigation and drainage.

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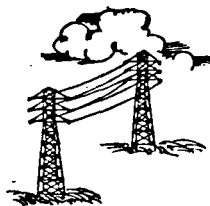
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Acknowledgement

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D. V. Joglekar

(July 19, 1891 – Dec. 12, 1975)

A. S. APTE *

With the demise of Shri Digambar Vasudeo Joglekar, an important era in the history of the Central Water & Power Research Station (CWPRS) has come to an end. Joining, in 1922, what CWPRS then was, the Special Irrigation Division of the Public Works Department of the Bombay provincial government, as a young assistant to the late Sir Claude Inglis, Joglekar rose to be its director during the period 1948–1957. The tenure of his directorship was extended over a period of five years after he had attained the normal age of superannuation in 1952. After his retirement from CWPRS, it was but natural that the engineering profession wanted to put to use his rich experience. This led him to accept the post of adviser to the Central Board of Irrigation and Power in which post he worked during ten years 1958–1967. His work, in this assignment, was the co-ordination of research studies of a fundamental nature undertaken at all the hydraulic research stations in the country.

To most people CWPRS and Joglekar were, for a long time, almost synonymous, such was his identity with the institution he had helped rear from its early days with exceptional loyalty, devotion and singleness of purpose. His loyalty to Sir Claude Inglis, his mentor and guru, over the long period 1922–45, was proverbial. After retirement from India Sir Claude, whose career is reviewed in an excellent article appearing elsewhere in this volume, set up the British Hydraulics Research Station and directed it over the first eleven years. ‘ I

wish I had Joglekar here to assist me ’, bemoaned Sir Claude frequently to his Indian visitors at Wallingford.

Early Years with Inglis

Joglekar obtained his Bachelor of Engineering from the Poona Engineering College in 1921 with a first class, a distinction rare in those days. He must have been an industrious and methodical worker during his student days, a quality which he retained throughout his working life. Soon after graduation he joined the Public Works Department of the Bombay Presidency, as it was then called, comprising Sind, Gujarat, western Maharashtra and northern Karnataka. This is how he describes the early days of his long apprenticeship with Sir Claude Inglis, initially at Hadapsar (a suburb of Poona), where he had his first taste of hydraulic experiments; then for a few years at Kopergaon, in the newly developed sugarcane region, for improvement of water-logged lands; and finally at Khadakwasla, which was to be his permanent place of work.

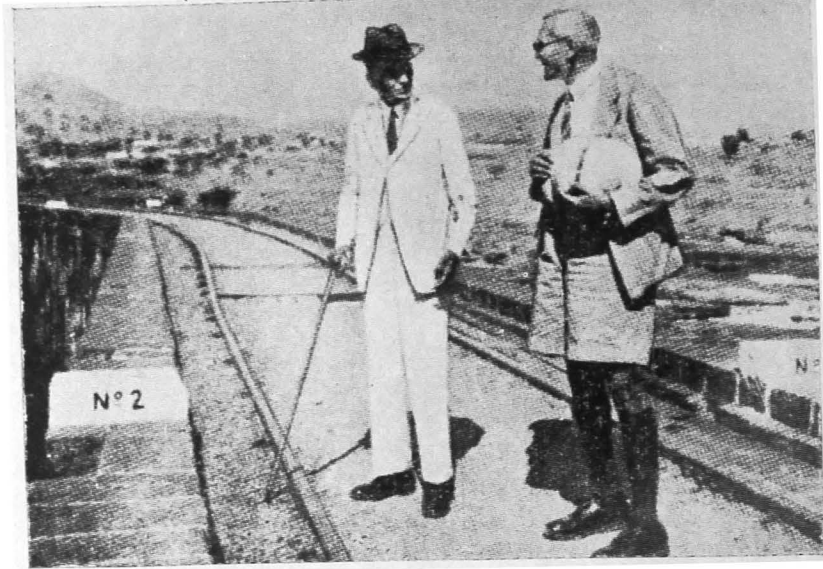
“ When I entered the service I was attached to the Special Irrigation Division. Since the subject of hydraulics was not being taught in the college at that time, I was naturally not feeling interested in this subject. One year I worked in the Special Irrigation Division which was under Sir Claude (then Ex. Engineer). The work comprised mostly improving water-logged and salt-affected areas due to salt efflorescence. Work was also being conducted in the

* Chief Research Officer, CWPRS Pune.

In the Footsteps of the 'Guru'



Dr. D. V. JOGLEKAR
(19-7-1897 to 12-12-1975)



Dr. D. V. Joglekar with Sir M. Visvesvaraya
(1949)



Dr. D. V. Joglekar with Shri Jawaharlal Nehru
(1955)

effluent farm at Hadapsar about 8 miles from Poona to the east. It was a small distributary, where we wanted to determine water contents of the sewage to be given to crops such as sugarcane, vegetables etc., and this was done by pumping up effluent from Poona City flowing upto the head distributary 5, where a proper mixture was done and then distributed. In addition to this work, I was also looking after the various small hydraulic research models where some experiments were done in 1922.

“ In this area we constructed some large scale models of Tando Mastikhan 8 ft (canal) fall, a 500 cfs saddle syphon, etc., for experimental purpose. After seeing my work at distributary 5, I was then transferred to Kopergaon sub-division in Ahmednagar district in the Bombay State. At Kopergaon, lots of areas had been affected due to water-logging and salt efflorescence. I also worked in preparing block areas of the Godavari right and left bank canals. My report was circulated to all the irrigation sub-divisions as guidance on how to write an Annual Report. After working there for about 3 years, I came back as in-charge of distributary no. 5 of Mutha right bank canal. We had to shift to Khadakwasla dam where there were unique advantages for hydraulic research, namely ample water supply and high head. On the right bank of the canal, we accordingly built a small research station which (area) later on was used as a demonstration area. In 1933 the whole station on distributary no. 5 was shifted to Khadakwasla.”

It was not an easy period, for Sir Claude was a hard task-master, and his confidence was not such as could be gained easily. Over the years, however, Joglekar succeeded in building a close relationship and an understanding with his director, and the number of technical papers, listed at the end of this article, as well as at the end of Sir Claude's obituary, testify to the fruitfulness of the relationship.

In 1927, Inglis had this to say: ‘ Mr. Joglekar having got block work of the Godavari carried through was transferred to distributary no. 5 at Hadapsar. His output of work had been excellent’. And ten years later, in 1937: ‘ It is a great pleasure to work with Mr. Joglekar. His actual fault was that he worked harder

than his physique justified. He has done excellent work as was his wont. His three months absence made us feel how invaluable he was.’

The nascent science of hydraulic research in India was closely related to the problems arising out of the irrigation works initiated by the British administration. The problems pertained mostly to canal designs and structures such as off-takes, sills, falls, silt control devices, measuring flumes and sluices; seepage through canals, barrage piers, gates, bunds and other protective measures. To this, later, were added hydrological studies. An account of these studies, and the important motivating ideas and results will be found in the article cited above; a repetition is hardly necessary.

The year 1937 saw the elevation of the Research Station, administered till then by the provincial government, to the Central Irrigation and Hydrodynamic Research Station under the Government of India. The transformation confirmed the prestige acquired by the Research Station as it was already dealing with problems arising outside Bombay province. It meant that the Station could deal, henceforth, with more problems from all over the country. Major studies pertaining to river control, port development, navigability of the Hooghly and the like opened a wider field, with Joglekar acquainting himself with a number of hydraulic phenomena. The hydraulic scale model, especially with loose boundaries, remained the major tool. Of this period of Joglekar's work, Inglis had this to say in 1948 :

“ His long experience of model work, irrigation and land drainage and the technical work connected therewith, statistics, physics, hydrodynamics etc. rendered him highly qualified for a wide range of technical and practical work. The scope of his investigations was ever widening as well as his experience. He had specially worked on problems of model scales and river models with sand on bed. His work consisted of : Sukkur barrage, Sone at Dehri, Sarda at Banbassa, Ganges at Hardinge bridge, fall on Montgomeri-Packpatten link Jamuna at Delhi, all these with sandy bed and not rigid bed models which sometimes gave wrong solution; Jamshedpur syphon spillway, Gibb module, Quetta-Durani outfall, etc. ”

Directorship

Joglekar's long period of an exacting, but no less exciting, apprenticeship ended with the retirement of Inglis in 1945. This was followed by a brief and brilliant interregnum of Shri K. K. Framji's directorship during 1945-48. During these years were laid the foundations of a major reorganisation of CWPRS, in which Joglekar was deeply involved. Joglekar succeeded Shri Framji as director and realized what must have been his cherished ambition of heading an organisation which he had striven so long to nurse. A sea change had, however, occurred in the environment] in which CWINRS (Central Waterpower, Irrigation and Navigation Research Station), as CWPRS was at that time called, found itself. It was a very welcome change; the years immediately following the country's accession to independence were years of hope, of planning and of endeavour. There was a veritable burst of activities on CWPRS, studies, projects, problems arising out of the early years of national reconstruction. CWPRS, already a well-oiled machine, had embarked itself on a period of rapid expansion. Many new scientific and engineering divisions were added : Soil mechanics, ports and harbour, photo-elasticity, ship hydro-dynamics, mathematics, physics and chemistry to answer the new tasks. What grew essentially, in the first phase 1916-1945 as a function of the energies of a single man of exceptional drive and flair, as was Inglis, could and did no longer hold; the Research Station had outgrown that stage.

Indeed, it was Joglekar's good fortune to have come to assume the reins of CWPRS at this juncture. He was assisted by a rapidly increasing team of young earnest colleagues; the output of CWPRS work grew *pari passu*. A narration of Joglekar's work and achievements would be essentially that of CWPRS. Joglekar obviously enjoyed the work, with the stream of important clients and persons visiting Khadakwasla; no less impressive and meaningful was the nature and number of problems. The type of work, referred to CWPRS before and after 1947, would bring out the entirely new character of responsibilities, CWPRS had to shoulder. Canal structures, flood control bridge protection and the like, these were the modest spectrum of CWPRS' activities during the British regime. River valley development became the key phrase in the post-1947 years,

with equal emphasis on maritime communication : establishment of new ports, improvement of existing ones and coastal protection. One can illustrate this transformation of CWPRS by listing the following studies during Joglekar's tenure :

- Spillways, outlets and energy dissipators for Koyna dam; Chambal valley development work consisting of the Gandhi Sagar dam, Kota barrage, Rana Pratap Sagar and Kota dams; Hirakud dam.
- testing of flood control works on the rivers Kosi, Brahmaputra (at Dibrugarh), Mahanadi and Narmada.
- development of ports and navigational facilities at Bombay, Kandla, Madras, Cochin, Mangalore and Paradip.
- coastal protection works; study of sediment movement in tidal and non-tidal streams, sediment in reservoirs.
- testing of a considerable number of structures; barrages; weirs, sluices, energy dissipating devices, regulators.
- foundation studies, in-situ and in the laboratory.
- the difficult and as yet intractable problem of navigation in the Hooghly.

CWPRS' Metamorphosis

A wholly new range of techniques were evolved in response to the new type of incoming works : fluorescent tracers, photo-elasticity, mathematical modelling, rock mechanics, earthquake measurement, etc. Confronted with these varied and numerous demands CWPRS and Joglekar grew together, as will be apparent from the many articles he wrote as well as from the thick tomes of CWPRS' annual reports of that period. Both gained experience and confidence in the diverse problems of hydraulic designs, a process which is continuing unabated to this day, twenty years later. During Joglekar's tenure, CWPRS grew manifold in terms of men, material resources and facilities as a consequence of its evolving activities.

An important aspect of work in CWPRS during Joglekar's regime was the continuous monitoring of data for effecting concordance between prototype and model observations. The state of observational facilities, none too happy at the moment, was more so twenty

years ago. A beginning was then made in respect of certain studies, an important example of which is the Hooghly estuary where, over a decade or so, levels and velocities were observed and compared with similar observations on several models set up at CWPRS. A fairly complete picture of the behaviour of the river was thereby possible, leading to an increased understanding of the causes of deterioration of the river over the years and also the seasonal changes in navigable depths on bars and crossings.

A close study of model-prototype conformity in hydraulic structures, especially in spillways and sluices, began to be made. The years after 1947 saw the planning and construction of a series of medium and high dams which gave rise to problems of high velocity flows. Joglekar succeeded in creating an awareness of examining the conformity of phenomena in model and nature. Special sessions on model-prototype conformity began to form a part of the meetings of the Central Board of Irrigation and Power, and considerable effort was devoted at research stations all over the country to methods of improving model techniques as also to finding out those aspects which model studies failed to reproduce. Joglekar's efforts are reflected in the publications of numerous symposia discussing this theme.

With the construction of dams, a large number of issues, hitherto viewed from a distance, were brought into focus; an example is provided by the problem of siltation of reservoirs created by the dams. Fundamental work done at Khadakwasla helped reveal siltation patterns. The trend was followed by a number of State laboratories; as a consequence of these studies, it became possible to evolve new ideas for conducting prototype studies of reservoir siltation.

As two major instances of model studies, without recourse to which it would have been impossible to undertake relevant vital projects, one may cite the Kosi barrage and embankments, and the structures for protecting the Dibrugarh town against ravages of the Brahmaputra river. The success of both these works, urgently necessary for protecting life and property on a massive scale, was a matter of pride and satisfaction to Joglekar. Studies for the construction of levees and other protection works at Delhi to contain the shifting channels of the Yamuna is another important case.

One may not, however, fail to mention a setback in these years of hectic activity. Fundamental research in river and canal processes, initiated and developed with such loving care by Inglis, to which Joglekar also had devoted many years of hard work, was relegated to the background. One might console oneself with the reflection that the growth of 'specific' work another 'fundamental' studies, a dilemma experienced by Inglis; it only grew more intense in later days.

Spokesman

Joglekar published a large number of papers always on the theme 'role of the hydraulic model in engineering research'. The experimental material, generated at CWPRS, was not slow to draw upon. Soon after his retirement, a manual on 'River Behaviour, Control and Training', prepared under his direction, was published; the book has come to be widely regarded useful and has run in two editions. In 1965, he wrote a treatise on 'Irrigation Research in India'. His paper 'Use of hydraulic models in river training, flood control and other engineering works', published in 1959 in the Journal of the Institution of Engineers, won for him a gold medal. He avidly propagated his message, the utility of the scale model, both in print and by word of mouth.

He used to dictate at a fast rate, with a ready command of facts, but had no leisure nor the penchant to revise his drafts. He liked to lecture, which he did to many audiences, be they engineers or laymen; he spoke clearly, without embellishment as was typical of him. He toured widely on site inspection visits or for attending various committee meetings. He availed of the many occasions, which presented themselves through his visits at many centres, to popularize CWPRS and its activities. He explained the working of CWPRS to its many visitors; Joglekar took round the station more Presidents and Prime Ministers than, perhaps, the head of any other organisation in the country. If Pune found itself on the itinerary of a foreign dignitary visiting the country, CWPRS was the one place he would visit, and Joglekar would be his guide.

He went abroad as India's delegate, to attend congresses of the International Association of Hydraulic

Research : Grenoble (1949), The Hague (1955) and Montreal (1959). He visited a number of laboratories in Europe, the U. K., Canada and the U. S. A., dams in France and engineering fabricators of hydraulic instruments and equipment.

Joglekar was called upon to advise on many matters of national importance and worked, on numerous committees; expert committee on Hooghly and improvements of its head water supply; Brahmaputra and Ganga river committees; coal mining and sand stowing committees; Kuttanad (Kerala) development scheme; National Harbour Board; Board of Engineering Research. He was IAHR's Vice-president during 1962-63.

Person

Joglekar died at the age of 78; his was a happy life full of satisfying work and fulfilment. Recognition came soon enough : the British government of those days awarded him the titles of Rao Saheb (1938) and Rao Bahadur (1943). His own government accorded him the Padma Shree in 1955. In 1964 he was awarded the D. Sc. degree of the University of Poona on the basis of a collection of his technical articles submitted for the degree.

The key to his happiness lay in the simplicity of his

mental structure, an unassuming disposition and sound health. He was modest in the demands he made on life; and the gods smiled on him. He moved easily among his juniors; later, he learnt to do so among his seniors in age, experience or position. Not known for insistence, nor for 'fighting', as was the wont of his guru, Sir Claude Inglis, he had no difficulty in working out a view handed down to him. Naturally he had no occasion to make enemies; nor was his circle of friends large. His habits were, likewise, simple; an occasional movie was his only recreation; a few pinches of tobacco and snuff and listening to the radio were his forms of relaxation.

Joglekar was born in a family of modest means. His father worked in the forest service. Joglekar was the second among four sons, all of whom have had remarkably successful professional careers as lawyer, doctor and engineers. The youngest of the four brothers, Shri K. V. Joglekar, has recently retired as a chief engineer with the Maharashtra state government.

In his retirement, Joglekar built a house in Pune at the foot of the Parvati Hill, which he appropriately named 'Jal-Shakti', water-power. He is survived by his wife Smt. Indirabai Joglekar (nee Bodas). three sons and a daughter.

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The following abbreviations are used :

TP : Technical Paper of the Public Works Department, Govt. of Bombay (prior to 1937).

IP-CBIP : 'Irrigation & Power' Journal of Central Board of Irrigation & Power, New Delhi.

JIE : Journal of the Institution of Engineers (India).

IAHR : International Association of Hydraulic Research (Congress transactions).

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Directors of the Research Station



Shri K. K. Framji
(1945 - 1948)



Sir. C. C. Inglis
(1916 - 1945)



Dr. D. V. Joglekar
(1948 - 1957)



Shri M. G. Hiranandani
(1957 ~ 1962)



Shri. S. C. Desai
(1962 - 1963)



Shri. C. V. Gole
(1963 – 1974)



Shri. P. C. Saxena
(Since 1974)



Shri. Y. K. Murthy
Chairman, Central Water Commission



Shri. C. C. Patel
Secretary, Department of Irrigation,
Ministry of Agriculture & Irrigation



Shri. A. N. Harkauli
Member, Disigns and Research, Central Water Commission

In Retrospect

Introduction

The Central Water & Power Research Station (CWPRS) was founded in 1916 as the Special Irrigation Research Division of the then Bombay Presidency under the able stewardship of Sir Claude Inglis. The mandate of this Research Division was *to modify irrigation practice to meet agricultural requirements and alter the agricultural methods to meet irrigation limitations*. The Research Station began with problems of irrigation, river training and sediment control.

It is necessary to look back at these humble beginnings in the context of the science of hydraulics of that era. The art of hydraulics in the form of river training, water storage and harbour engineering had been in vogue for over two millenia. On the other hand the mechanics of theoretical hydrodynamics had been developed over the previous two or three centuries. It was recognised however, that the practical engineer operating in field conditions was unable to grasp the microscopic natural phenomena that were taking place while he attempted to control the rivers and train them towards a definite objective. On the other hand it was also well recognised that the advances of theoretical hydrodynamics bore little resemblance to reality. The science of small scale models therefore came into being at the end of the 19th century with the work of Osborne Reynolds, and Saint Venant. The theory of dynamic similitude which governs the relations between small scale models and their large scale prototypes was formalised in a paper presented to the Royal Society in 1904 by Buckingham. The

bringing together of theoretical hydrodynamics and the explanation of pressure drag was brought out by Ludwig Prandtl through his concepts of the boundary layer. The foundations of hydraulic research based on scientific principles had thus been laid.

Hydraulic laboratories at the turn of the century could be divided into two categories, viz. (1) Laboratories for academic instructions and (2) Laboratories where engineers of eminence carried out their researches in universities.

The German laboratories at Karlsruhe, Dresden Bremen and Hamburg were in the forefront. The state-owned hydraulic laboratory was yet to come. The CWPRS was, therefore, one of the first government owned laboratories set up specifically for the purpose of providing engineering solutions to specific projects. Other institutions of eminence were yet to follow; the Waterways Experiment Station, Vicksburg was established in 1929, the Hydraulic Research Station at Wallingford in 1944 and the Laboratoire National D'Hydraulique, Chatou, France in 1946.

Pioneering Work During 1916-1928

Sir Mokshagundam Visvesvaraya and Mr. Henry Fitzgerald Beale were the pioneers of irrigation research in the Deccan. It was at the instance of Mr. Beale that Sir (then Mr.) Claude Inglis was brought in 1911 as Executive Engineer to Godavari Canals Division from Jamrao Canal Division in Sind, to study how the North Indian methods of irrigation could be adopted in the

Deccan. On the basis of his work on Godavari, Mutha and Nira Canals, he reported in 1915 that there were major difficulties in introducing North Indian irrigation practices in the Deccan because of vagaries of monsoon, water requirements of the sugarcane crop and the geology. Accordingly the newly created Special Irrigation Division, the nucleus of the present CWPRS, confined its activities, in the early stages, to local problems of land drainage, reclamation, soil classification and improvement of land damaged by water logging or sodiumisation.

In 1918 an expert from England had advised that effluent from the Pune sewage should not be used on the land but should be chlorinated and discharged into the river. This problem of sewage and sullage of Pune City was examined by the Special Irrigation Research Division and as a result of these studies, it was proposed to pump the sewage in the distributary No. 5 of Mutha Right Bank Canal for use directly in the fields instead of letting it out into Mutha river after treatment. This scheme proved to be profitable to the farmers and caused considerable savings to the Government. During this period studies were also carried out with a view to evolving best type of outlet for the Deccan conditions to give a constant discharge irrespective of water levels in both the canal and the distributary. The performance of the rigid module patented by Mr. A. S. Gibb of the Punjab was found satisfactory, and it was adopted on the upper outlet of the distributaries of Nira Left Bank Canal.

In 1920 this nucleus of hydraulic research was renamed as HYDRODYNAMIC RESEARCH STATION and was located at Hadapsar along the distributary No. 5 of Mutha Right Bank Canal about 11 km. east of Pune.

The maximum available discharge at Hadapsar was $0.23 \text{ m}^3/\text{s}$. In order to meet the growing demand of large scale model experiments, a large quantity of perennial water supply was required. Hence in 1925, the Station was partially shifted to its present site at Khadakwasla about 18 km. from Pune, where a large supply of water free of sediment was available with ample head and with very little variation in the water temperature throughout the year.

Some of the important problems studied during 1920 to 1929 were as follows :-

- (i) Irrigation : Seepage losses in Deccan Canals; Constant Discharge Modules and Semi-modules for irrigation; River gauging and rain gauging in the Bombay Deccan; Effluent irrigation; Relationship between maximum floods and size of catchments.
- (ii) Irriculture : Agricultural development on the Deccan canals; Irrigation from river and storage.
- (iii) Soil Physics : Soil and sub-soil surveys in the Deccan canal area; Chemical analysis of soil, water and effluent; Change in composition of effluent.
- (iv) Drainage and Reclamation : Land drainage of Deccan canal area comprising planning, execution and maintenance; Reclamation and soil improvement in drained area; Hydroisobaths on Godavari and Pravara canals.
- (v) Hydrodynamic Research : Lindley type standing wave flume; Crump type standing wave flume; Effect of design of barrage sill on coefficient of discharge; Determination of the coefficient of discharge of Lake Fife waste weir gates by model experiments; Factors affecting design and efficiency of siphon spillway; Calibration of standing wave orifice outlets.

Work During 1929-1947

The work prior to 1928 was mainly of local nature and was confined to local problems of irrigation, land drainage of the Deccan canal area, soil improvement and design of standing wave flumes. In 1929 the Research Station passed through an important phase of research when it successfully tackled the problem of design of Sukkur Barrage. In 1936-37 the Research Station crossed the frontiers of the then Bombay presidency and started working on problems of other provinces also. The first major problem outside the Bombay province was the protection of Hardinge Bridge over the river Ganga.

The important specific works completed during this period were : Lloyd Barrage at Sukkur (1929); Bifurcation of the North Western Perennial Canal at the head of the Warah Branch (1929); Radial gates on the Jamrao Canal (1931); Silt exclusion from canals (1933); Bridge over Krishna at Udgaon (1934); Head sluices of the Nira Left Bank Canal (1935); Protection of Hardinge Bridge over the Ganga (1936-37); Training of Yamuna river at Delhi Gate pumping station (1937); Training of the Watrak river to prevent the town of Kaira from being damaged by scour (1937); proposed Bengal Assam railway bridge at Amingaon on the Brahmaputra (1937); Training of the Rupnarain river (1943-44). One of the important models studied during 1933 was full scale siphon spillway model discharging $15\text{m}^3/\text{s}$.

One of the achievements in this period was the control of sand in canals by preventive methods of drawing off supplies from the outside of a curve natural or artificial. In other words, the Research Station was the first in the field in taking advantage of favourable curvature of flow in a river. A notable instance is that of the improvement of the Right Bank Canals of Sukkur Barrage (Sind), the discharging capacity of which was reduced considerably as a result of silting. Exhaustive model tests were carried out and an approach channel 1500 m. long imposing suitable concave curvature to exclude sand from the canals was recommended. This was constructed in 1941 and sand was satisfactorily excluded, and the canals soon regained their discharging capacity.

In 1930 Shri C. C. Inglis proposed a formula for Maximum flood Discharge, $Q_{max} = 7000 A/\sqrt{A+4}$, to help the engineer in deciding the spillway capacity (where Q_{max} is in cusecs and A is the catchment in sq. miles). This formula, when applied to fan shaped catchments, gives the discharge which might occur only once in a thousand years; but it can as well be approximated to fairly frequent maximum flood discharges in other types of catchments, which are small in area and are subject to intense rainfall in most years. A paper entitled "A critical study of runoff and floods of catchments in the Bombay Presidency" was published subsequently covering the above aspects.

Though hydraulic research was in its infancy at that time, remarkable success was achieved during the period 1929 to 1947 on some other problems such as the training of the Rupnarain river, which brought immediate recognition from the Indian Railways. During the floods of 1942, Bengal was virtually cut off from the rest of the country, owing to rapid shift in the course of the river Rupnarain. The river training measures suggested by the Research Station were so successful in bringing the river back to its old course flowing under the railway bridge, that the Railways decided to contribute Rs. 25,000 per annum as a token of appreciation of the excellent work of the Research Station with a request to continue to advise the Railways on their variegated problems.

In addition to the specific problems, significant basic research was also carried out in this period. This included the dissipation of energy downstream of falls, meandering of rivers, scale effects on the distribution of pressure and velocities in siphon spillways, effect of curvature of weir crests on discharges and the development of a 'regime concept' as applied to canals and rivers. In 1946, based on the experiments conducted in the Research Station, Inglis introduced a set of new regime equations for 'medium sand' range, in which the charge and weighted mean diameter of the bed-mix in movement, was taken into account along with the slope and dimensions of earlier regime equations. In this context a new dimensionless number called "Inglis Number", was developed and the same has been incorporated in what are known as Inglis Lacey equations.

Growth of the Station During 1947-76

With the advent of independence the activities of the Research Station increased to cope with the demands of the planned development of the country. Accordingly the Research Station was reorganised and expanded in 1947 and the new research divisions that were created were : (1) River and Canal Hydraulics (2) Navigation (3) Concrete and Materials of Construction (4) Soils and Soil Mechanics (5) Mathematics (6) Statistics (7) Physics and (8) Chemistry.

For this purpose, the Government of India sanctioned a capital expenditure of Rs. 1.5 million for buildings.

and equipment; a recurring expenditure of Rs. 0.65 million was also approved for establishment and contingent charges.

A Photoelastic Laboratory was set up in 1953 for taking up complicated structural problems with the aid of perspex models. A well equipped experimental tank, with an electrically operated navigation carriage (a gift from the UNESCO) was also commissioned in the same year for calibrating current meters and testing ship designs. An Instrumentation Division was formed in 1958 for developing special instrumentation required for hydraulic research particularly for measuring basic hydraulic parameters. The High Head Structures Division was also set up to study the problems related to hydropower structures. The Geophysics Division was created in 1959. An 'A class' weather bureau was established in 1959 in the campus at Khadakwasla to provide continuous record of basic weather characters. The first Refresher Course in Hydraulics was offered during 1959 mainly for the benefit of field engineers, teacher and research workers. This activity of holding courses continued from year to year and was later extended to specific fields also, viz. Bridge Engineering, Coastal Engineering, Dredging, Digital Data Acquisition, Environmental Engineering, Hydrometeorology etc.

The launching of a new project for fully equipped Cavitation Laboratory in the CWPRS came as a significant landmark of the year 1960. The United Nations' special fund allocated a grant of \$ 491,000 for technical and financial assistance for this purpose. Publication of a new series of Technical Memoranda covering the important studies carried out by the Research Station was started during the same year.

With the failure of Panshet dam, breach of Khadakwasla dam and the subsequent catastrophe in Pune in July 1961, the CWPRS suffered losses in no small measure. About 1.6 hectares of its old area near the dam got completely washed away and the gravity water supply, the life-line of CWPRS, was severely damaged. Quick steps were taken to construct new supply line.

To provide multi-disciplinary approach to various problems referred to CWPRS five new divisions

were set up in 1963, viz. (1) Cavitation (2) Earthquake Engineering (3) Model Engineering (4) Rock Mechanics and (5) Hydraulic Analysis and Prototype Testing.

During 1964, the construction of the office-cum-laboratory building at Khadakwasla was completed and the Physics, Geophysics, Earthquake Engineering, Chemistry, Mathematics, Statistics and Soils and Concrete laboratories, hitherto located at Pune, started shifting to Khadakwasla. The shifting was completed in the year 1965 and since then all the connected facilities of the Research Station were available at Khadakwasla.

CWPRS completed fifty years of an eventful period in the year 1966 and celebrated its Golden Jubilee in January 1966. The inaugural function was presided over by Dr. K. L. Rao, the then Union Minister for Irrigation and Power. In 1970 CWPRS was recognised as the Regional Laboratory for ESCAP countries by the United Nations. During 1970-71 Gates and Valves Division was added to supplement the High Head Structures Division. Later Bridge Engineering Division was formed as a separate entity to tackle the problems of road and railway bridges. The facility of a new Rating Tank was added to Ship Hydrodynamics Division with a view to reducing the work load of current meter calibration on Ship Model Testing Tank. A separate division was created for solving problems in Maritime Structures. The activities of Cavitation Research Centre were further extended by establishing a new Calibration Division.

The UNDP aided project 'Coastal Engineering Research Centre and Development of Hydraulic Instrumentation' started functioning in July 1972. In the same year the Research Station entered into contract with the Port of Singapore Authority for the construction and operation of the tidal model and based on the model investigations for rendering advice on various development proposals of the port.

Some of the outstanding studies conducted in the post independence era were : Protection of Dibrugarh town against the ravages of the Brahmaputra; Design of Trisuli Barrage in Nepal; Development of a satellite port to Bombay at Nhava Sheva; Use of epoxy resin for the strengthening of Koyna Dam; Flood protection

measures for the Kosi river; Foundation studies for the Farakka Barrage Project; Studies for the design of filling system of the navigation lock at Haldia; Cavitation studies for the Kalinadi Francis turbine models; Development of a number of hydraulic instruments for laboratory and field use. Starting with Bombay Port in 1959, a number of radio active tracer studies were conducted in association with Bhabha Atomic Research Centre Bombay at other ports viz. Calcutta, Cochin, Karwar, Mangalore; Bhavnagar, Mormugao, Kakinada and Visakhapatnam. The Geophysics division also used radio isotopes for many of its projects. These are but a few instances of the works carried out by the Research Station. As a consequence, however, savings of millions of rupees had been effected in the project outlays, besides ensuring their safety and operational efficiency.

The year 1950 has left a significant mark in the life of the Research Station, since for the first time the Research Station was approached to solve the problems from outside the country. The problem was of sand exclusion from Ye U canal taking off from the Kabo headworks across the Mu River (Burma) and was successfully solved at the Research Station. The small beginning then made has steadily grown in recent years; the benefits of the expertise developed by the Research Station over the years have been extended to other developing countries in Asia and Africa, e. g. Afghanistan, Tanzania, Iraq, Philippines, Singapore and Libya, as a part of the national endeavour to usher in a new era of international co-operation.

CWPRS Today

The Research Station at present occupies an area of 180 hectares. It is one of the unique research organisations in the country having more than 30 divisions under one roof, dealing with different disciplines and specialised subjects in the field of engineering and science and engaging about 1600 persons in the research effort.

The work of CWPRS now covers development of navigation, communication, irrigation and flood control. The major part of its research activities pertains to planning, investigation, execution, operation and maintenance of river valley and coastal engineering projects besides design of hydraulic instruments and testing of hydraulic

machinery and ship designs. Recently, the Research Station has embarked on the design of cooling water systems for fossil and nuclear energy plants and engineering problems of environment. Besides keeping abreast of the latest developments in these disciplines, it evolves modern techniques of measurements, data acquisition and analysis with a view to improving the design of various engineering projects.

The CWPRS library has a collection of over 60,000 books and bound journals and subscribes to 375 journals including 20 journals in foreign languages (other than English). The Annual Research Memoirs and the self-contained Technical Memoranda separately issued from time to time, provide the results of research work being carried out. CWPRS has been recognised by three universities in the country for post-graduate work and it has 12 research guides approved by different universities for Master's and Doctorate degrees. CWPRS is a leading engineering research organisation in the country having major activity in the field of applied research and field investigations besides facilities for connected basic research. Training facilities in all the disciplines in which CWPRS is engaged, are offered to persons deputed or sponsored by various national and international organisations in the country and abroad.

There is a central workshop having a well equipped machine shop and sections for carpentry, plastic moulding, fitting, smithy and sheet metal work. Compact precision workshops equipped with special machine tools cater to the specialized urgent needs of works relating to instrumentation, ship model testing, structural model engineering, multitest water tunnel, soil and rock mechanics. An independent photography section also exists in the campus.

The annual capital input in the Research Station rose from Rs. 6 million to about Rs. 16 million in the last decade, while the staff increased from about 950 to 1600. Out of 1600 about 1000 are on regular establishment, of which about 35% are engineers and scientists. The Research Station has contributed in its humble way to the planned economic development of the nation by conducting research for practically all the major engineering projects undertaken during the various five year

plans. At present there are about 400 specific problems in hand costing about Rs. 20 million covering different engineering problems encountered in various parts of the country. The Ship Testing Tank alone saves \$ 50,000 in foreign exchange per annum by way of testing 10 to 12 ship models and rating 1000 current meters per year.

A Co-operative Credit Society is run for the benefit of the members of the staff. A mutual benefit fund, and a benevolent fund have been created for immediate assistance in the event of sickness and death. The Recreation Club organizes group activities in sports, excursions, magazine clubs, social gatherings and cultural programmes. Canteens provide snacks and lunches. Transportation facilities are provided to the staff between Pune and Khadakwasla. A residential colony and a hostel are planned for construction near the campus. A residential flat in the central place in the city of Pune has been converted into a Guest House to accommodate the visitors to the Research Station. There is also another small Guest House located in the campus at Khadakwasla.

Looking Ahead

Over the past 60 years the CWPRS has built facilities to conduct research in diverse fields. By virtue of its vast experience and expertise, CWPRS is in a position to provide guidance and advice on the various engineering projects, that would come up in the future development plans of the country.

CWPRS has not only advised on various national engineering projects, but it has also provided expertise to many developing countries of Asia and Africa. Since CWPRS has now been recognised by UN as a regional laboratory for the ESCAP region, it can play a greater role in rendering technical advice and guidance to the developing countries in the days to come.

The UNDP has provided assistance to CWPRS in no small measure. In the past two decades the UNDP has contributed about 2 million dollars in completing three major projects at CWPRS, viz. the Cavitation Research Centre, Coastal Engineering Research Centre and Development of Hydraulic Instrumentation. Extension of the last two on-going projects and setting up of two new UNDP projects viz. Applied Earth Sciences and Hydromechanics divisions have been accepted in principle by the UNDP. The assistance in these four projects will be of the order of 2.56 million dollars. The Documentation Centre is likely come up soon with the assistance of the UNDP. In view of the needs of the country two new projects viz. Tidal Power Generation and Hydraulic Structures Division have been proposed for UN aid and are under consideration. The total UNDP grants during the fifth plan period may go upto 8 million dollars.

The CWPRS is already working on certain problems of environmental engineering such as effluent mechanics and aspects of dispersion of effluents in coastal and riverine waters. It is proposed to start work on vitally needed new disciplines such as biomechanics and development of new sources of energy. In addition, a new ship testing tank with ship manoeuvring basin and setting up of a marine pilots training centre are under consideration for inclusion in the facilities at the Research Station.

The Central Water & Power Research Station has thus risen from an humble beginning made in 1916 to its present status as one of the premier research institutions in the country. It has grown over the years in size, strength, experience and expertise. While rejoicing in its past, it dedicates itself on the occasion of its Diamond Jubilee to the cause of research and service carrying with it the wishes of its innumerable friends.

changes in the name of the research station

1916

Special Irrigation Division, P.W.D. Bombay Presidency.

■

1928

Hydrodynamic Research Station

■ ■

1937

Central Irrigation and Hydrodynamic Research Station

■ ■ ■

1944

Indian Waterways Experiment Station

■ ■ ■ ■

1947

Central Waterways, Irrigation and Navigation Research Station

■ ■ ■ ■ ■

1949

Central Water Power, Irrigation & Navigation Research Station

■ ■ ■ ■ ■ ■

1951

Central Water and Power Research Station

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**SOME SALIENT DETAILS OF
CENTRAL WATER & POWER RESEARCH STATION PUNE
AS IN 1976**

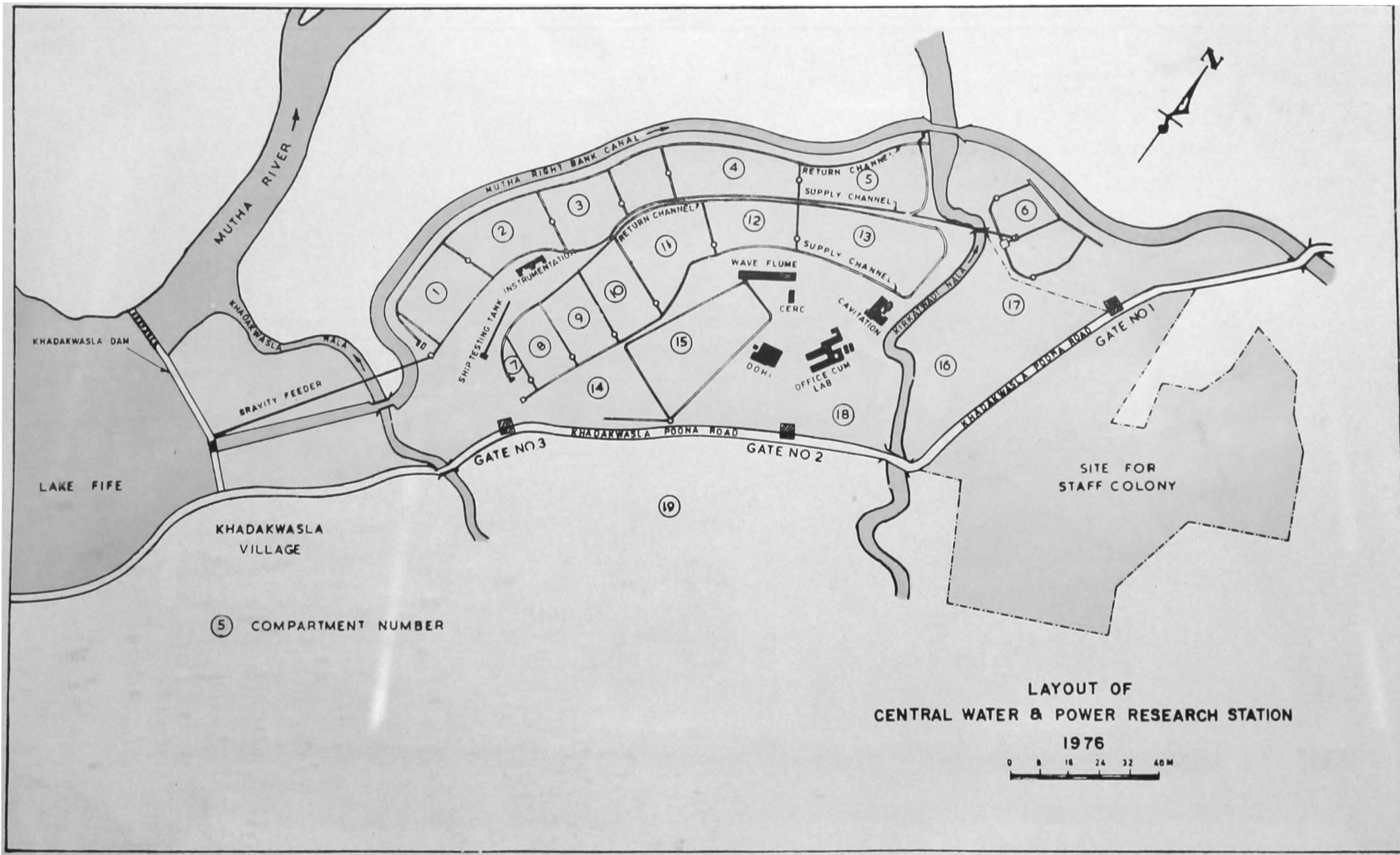
1. Area occupied		180 hectares
2. Water supply for models	Pumped supply	15.1 m ³ /s
	Gravity Supply	7.1 m ³ /s
3. Power	Connected load	2825 KVA
	Annual consumption	1.17 m. KWH
4. Personnel	Research Personnel	502
	Other technical services	88
	Craftsmen and Group D staff	310
	Administrative and Accounts	119
	Work-charged staff	<u>575</u>
		1594
5. Annual Research Expenditure		Rs. 16 million
6. Problems under Investigation		400
7. Divisions :		

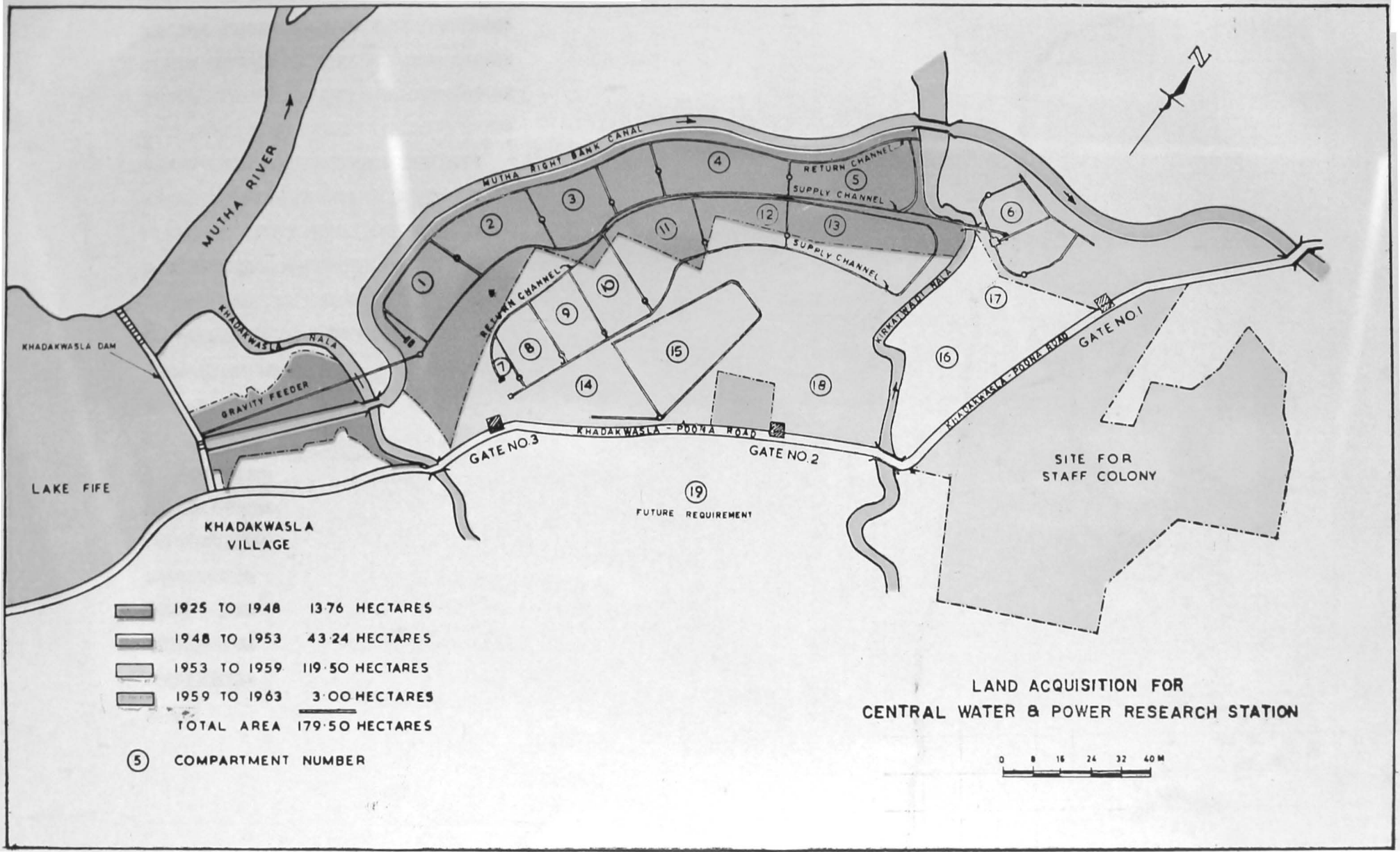
(a) Research Divisions :

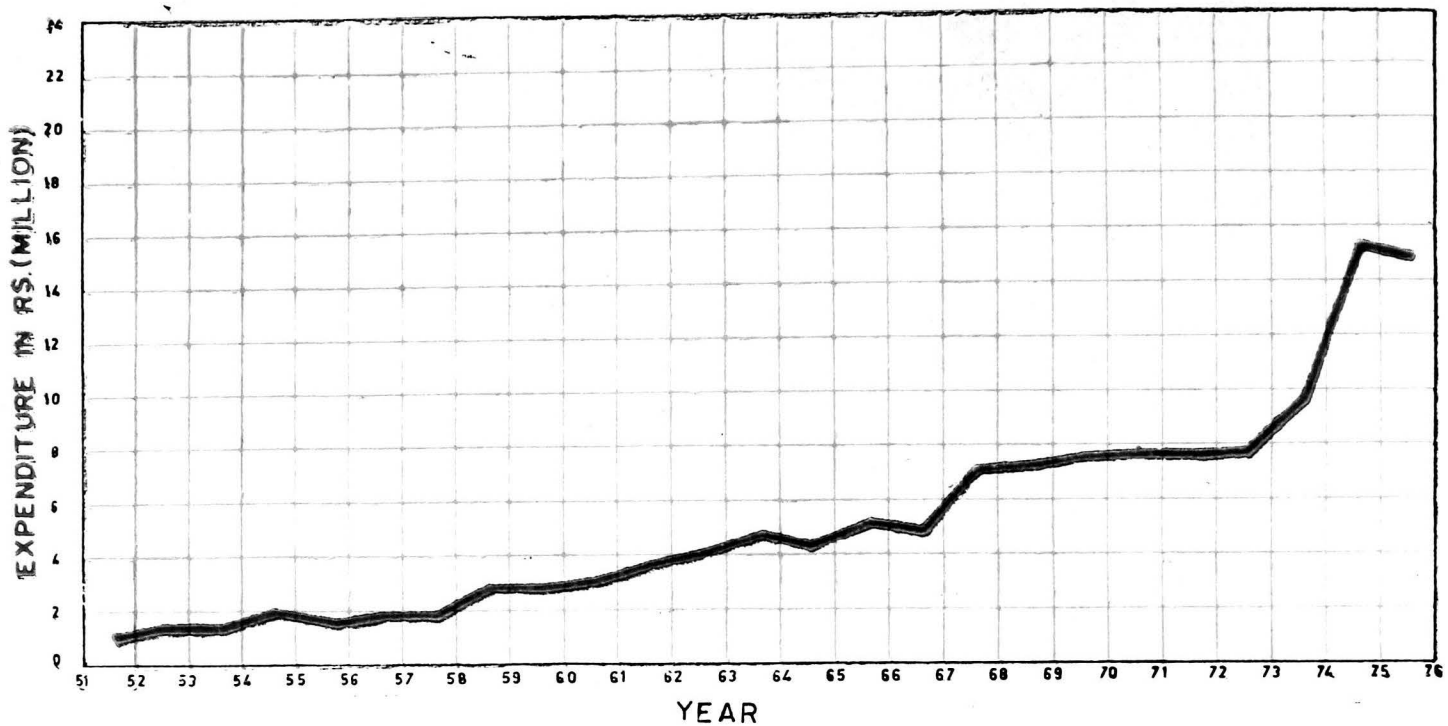
1. Flood Control	11. Rating Tank	22. Earthquake Engineering Research
2. Bridge Engineering	12. Ship Hydrodynamics	23. Instrumentation
3. Central Cell	13. Ports & Harbours	24. Hydraulic Instrumentation Centre
4. River & Canals	14. Maritime Structures	25. Computer
5. Hydraulic Analysis & Prototype Testing	15. Tidal Hydraulics	26. Mathematics
6. Watershed Studies	16. Coastal Engineering	27. Physics
7. High Head Structures	17. Photoelastic	28. Chemistry
8. Gates and Valves	18. Model Engineering	29. Statistics
9. Cavitation	19. Soil & Concrete	30. Technical Co-ordination
10. Calibration	20. Rock Mechanics	
	21. Geophysics	

(b) Service Divisions :

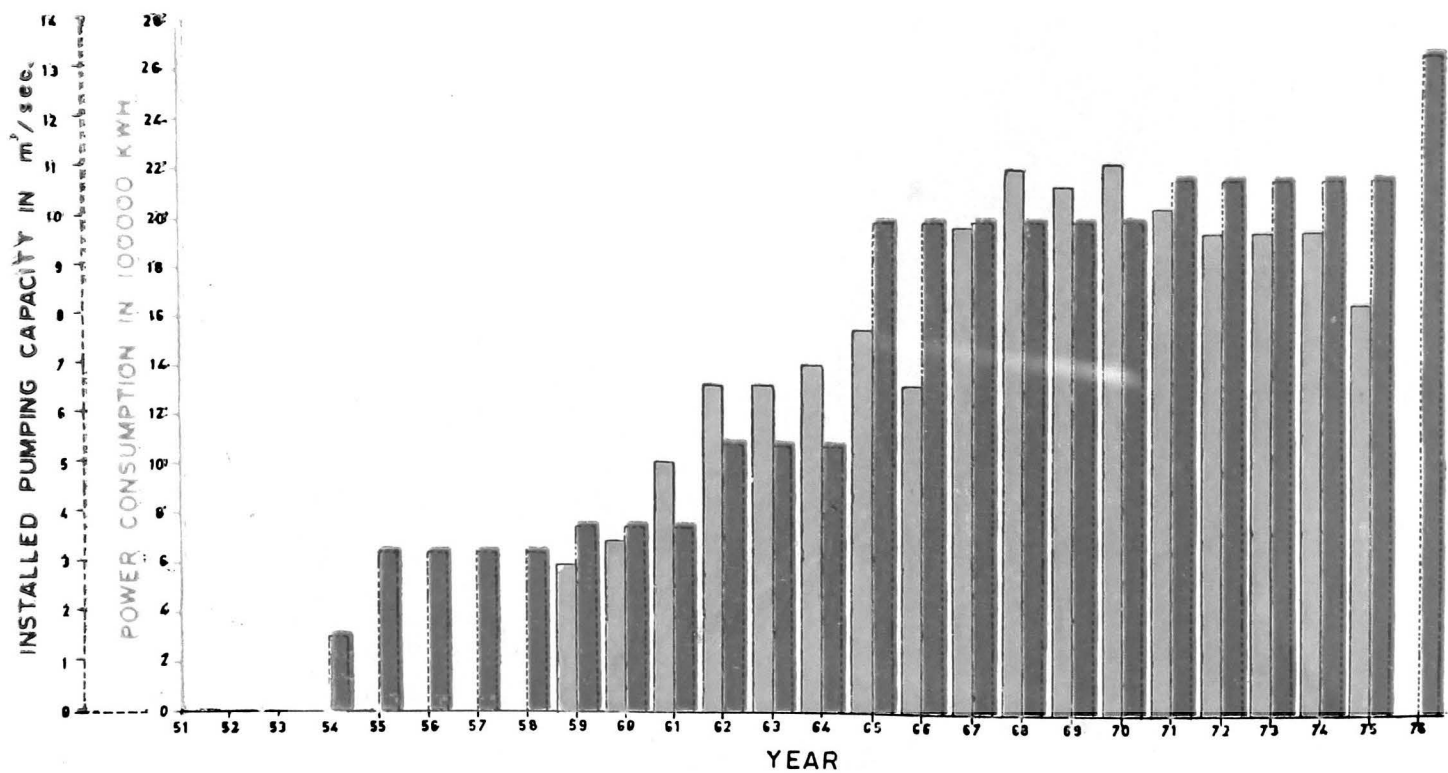
1. Workshop	3. Executive & Accounts	5. Library
2. Electrical Sub-division	4. Civil Sub-division	6. Administration







EXPENDITURE OF CWPRS 1951-52 TO 1975-76



UTILIZATION OF PUMPING CAPACITY AND POWER AT CWPRS

In The Footsteps Of The 'Guru' – Development Of CWPRS Research 1945–1948

K. K. FRAMJI *

This great occasion may rightly be deemed the Sir Claude Inglis Commemoration. The Station was born in 1916 as the new Special Irrigation Division (Bombay) then inaugurated to deal with soil classification, land drainage, block system of sugarcane irrigation, water-logging, land drainage and reclamation, and sewage irrigation, and research in connection therewith, and Claude Inglis was put in charge. He continued to work on the Indian continent problems – the Hooghly, river training for tea estates in West Bengal, the irrigation practices in the Mohenjo Daro civilisation (BC 3800 to 3200), etc.,— until his death in August 1974, despite his total loss of one eye and failing sight in the other. The way he got over his physical handicap is a true reflection of his indomitable spirit and character as well as of his irrepressible interest in his life work until the very end : his niece (or Secretary) would read any technical material he wished to study into a tape recorder, and he would play this back and dictate his immediate reflexions, while a third recorder was used as a memory and for his own notes and reports. Undaunted by his feeble vision – and that in one eye only ! – he would unremittingly pour over plans and drawings with a specially manufactured, high-power magnifying glass and sketch out his own scheme for a draughtsman to elaborate, which he would check and finalise with unsparing precision.

As the author has had occasion recently to recall for ' the Biographical Memoirs of Fellows of the Royal Society ', a key to Sir Claude Inglis' career and achievements lay in his character :

' He was a man of strong character and honesty of purpose and one indefatigable in his pursuits which reflected unlimited reserves of energy. He expected of his associates no more and no less than what he demonstrated by his own example. He was impatient to achieve progress in his mission of determining rational approaches to hydrodynamic problems and he spared neither himself nor his associates in the work for the benefit of India. It is said that scarcely anyone walked into his room without saying a prayer, but scarcely anyone came out of his room without the happy realization that he had learnt something worthwhile... His parting advice at the time of his retirement is characteristic of his own practice throughout his career : " Don 't hide mistakes and be *absolutely honest* " '.

Thus, both by virtue of Inglis' high principles of character and his great achievements in hydrodynamic research he filled the role of the ideal ' guru ' in the true Indian tradition in whose footsteps his esoteric successors could follow dedicatedly. Amongst them must be

* Secretary General, International Commission on Irrigation and Drainage, New Delhi
Director, CWPRS Pune 1945–48.

mentioned Rao Bahadur Joglekar who had served Inglis for over 20 years (and the station for over 35 years) and whom Sir. Claude Inglis came to trust and respect and depend upon—but not before a long and fiery testing period through which Joglekar emerged unscathed and successful. In these 20 years of devoted service Joglekar learnt and assimilated a lot of Inglis' work and himself grew later, when no longer in the shadow of the master, to a man of stature in the field of hydraulic research. The author was not so fortunate as Joglekar to bask directly under the electrifying aura attending the 'guru' but none the less by the attraction of his work and character he was drawn irresistibly to emulate Inglis and become a most devoted 'chela'. Why the author should have been chosen out of a galaxy of Indian talent to succeed Inglis as Director was only clear much later, because the only brief contacts then were at and after the memorable Research and Board meetings of the Central Board of Irrigation, where he was fortunate to meet and exchange ideas with other stalwarts besides Inglis, such as Bench, Bose, Edgecombe, Gulhati, Khosla, Kirkpatrick, Lacey, Malhotra and Montague. It was much later that the author learnt that Inglis had no use of researchers who had no field experience.

Inglis' achievements in hydraulic research were due to his capacity for original thinking coupled with intuition and insight into the physical processes encountered in his problems. His mode of approach to research was characteristically confirmatory. He had to have a "hunch" first, reflect over the problem and conceive the broad frame of the solution. The experiments were the means to prove or disprove the hunch, but he generally was right. Not all are, however, blessed with these powers of insight and intuition. The author followed a dual approach—the confirmatory one where his field experience gave him the strength of his convictions, and the deterministic one where the physical processes were complex and beyond human knowledge and insight at the time. The Director continued to be called upon to advise on problems in many parts of India, and the number of problems on which the author gave advice without the aid of models in the period 1945 to 1948 was about fifty which is large by any standard.

None the less, the sword of Damocles was ever hanging over the fate of the Station from the start. When several provinces with growing irrigation systems had set up their own hydraulic laboratories the Bombay Government, at Inglis' suggestion, had offered the Research Station at Pune (Khadakwasla) as a Central Station for the whole of India with facilities for experiments for the Railway Board, the Port Authorities and other Public Departments who might require advice from expert hands. Inglis had to battle hard for it, but his efforts were ultimately rewarded. Despite the recommendation of the CBI for the creation of a new research station at Delhi, thus side-stepping the rival claims of Pune and the Punjab, the Pune Station was selected to be the new Central Irrigation and Hydro-dynamic Research Station in 1937. Again, at the time of the Reorganization Scheme of the CWPRS in 1947 the battle for shifting the major part, if not the whole, of the Station to Delhi was resumed on the ground that research for the on-coming multitudinous River Valley and Hydro-Electric projects and for the conservation and control of the waterways would be at the hub of activities of planning and design of these schemes, if located in Delhi. The author (who had been transferred by that time) had to come in late 1948 to Pune to defend the rightful claims of Khadakwasla with its ideal setting and evident facilities of adequate land for the large scale models and a large supply of absolutely constant discharge of clear, silt-free water at constant temperature *under ample 'head'*—a major consideration for large-head experiments of syphon spillways and high-head gates, etc—and also because research should not be dictated by design and should be free from day to day interference. The battle was fortunately won again and today Khadakwasla ranks amongst the top-most hydraulic Stations of the world.

Inglis' Contributions to Hydraulic Research (-1945)

Mention has already been made of Inglis' early research on irrigation and drainage problems in the Special Irrigation Division in the Bombay Presidency. In hydraulic research over 100 important investigations involving over 2000 experiments—specific investigations as well as basic studies—were carried out in Inglis' time on measuring devices (Gibb's module, Kirkpatrick Semi-module, Inglis' Standing Wave Flume), falls (S. W. F.

Metre Falls), Siphon Spillways (particularly for scale effects), river training, depth of scour and bank and bed protection against scour, water supply intakes, re-distribution of discharges and sediments for flood control of rivers in Orissa, tidal problems and protection works in tidal flows, etc. Some of his principal contributions to hydraulic research by which he will be best remembered are the following :

(i) He was the first Engineer in India to establish that the best sand-excluding device is obtained by availing of Nature's way by locating off-taking channels on the outside of curves, where the high-velocity sand-free water provides natural sand exclusion. (The experiments on the control of sand entering the Lloyd Barrage Canals constituted classical hydraulic model research on the subject as well as yielded immense benefits on the prototype).

(ii) Inglis expounded clearly the factors determining the size and shape of river meanders in relation to dominant (or formative) discharge. (Contrary to popular belief that meanders are caused by excess slope and energy, Inglis established that a channel begins to meander when it is unable to carry its natural bed load with the discharge and slope available. Furthermore, he provided equations relating meander length breadth and belt to river discharge).

(iii) His researches on the application of natural curvature of flow, which is associated with meanders, were extended to river training measures and to determining the location and design of 'repelling' and 'attracting' groynes. (For example, a repelling groyne located at 0.4 of a meander length upstream of the Bengal-Nagpur Railway saved the strategic bridge on Kolaghat from being out-flanked during the war when all other communications between Calcutta and Bombay were cut. On the other hand, a suitably placed attracting groyne at about 0.4 of a meander length upstream was recommended for positioning of the Lower Sind Barrage or, alternatively, at half a meander length downstream of the natural fixed point).

(iv) The Station research on the design of guide bunds and their protective features (e. g. falling aprons) for the safety of large river bridges is noteworthy. (For example, for the Hardinge Bridge Inglis' research led to the startling suggestions of removing the protecting stone from the Sara Protection Bund, letting the bund be eroded and thereby saving the Hardinge Bridge.)

(v) While Inglis acclaimed the Lacey theory to be a breakthrough in the understanding of alluvial channels and paid high tribute to the *original* Lacey equations – the width of a channel in regime being proportionate to $Q^{1/3}$, depth to $(Q/f)^{1/3}$, mean velocity to $Q^{1/6}/f^{1/3}$ and slope to $f^{5/3}Q^{1/6}$ in terms of discharge Q and sediment factor f – he (Inglis) demonstrated the f values can only be equal at 'regime' and are otherwise different due to divergence from the regime balance between discharge, grade and load, and the difference is not explainable in terms of good or bad maintenance, i. e., 'shock'. Inglis established that these differences in the f values were measures of divergence from regime. This was itself a major achievement, but Inglis' greatest contribution was his persistent emphasis that sediment load was as significant a factor as sediment grade in design of channels in alluvium, and his producing equations introducing X , the sediment load, and V_s , the terminal velocity of the sediment (representing sediment grade), into the Lacey equations adding a new dimensionless number $\frac{(XV_s)^{1/4}}{(\sqrt{g})^{1/3}}$ which Lacey has called

'Inglis number' into the regime theory.

In the Footsteps of the 'Guru' (1945-1948)

The aftermath of the Inglis' era was a period of review, consolidation and reorganization. In short, the answer to the question "where do we go from here?" exercised the author.

Amongst his first major tasks was to assist Sir Claude Inglis who on retirement had been commissioned to write a report summarising the aspects of the special work done at the Pune Research Station not done elsewhere. The wholehearted co-operation and assistance

of the Station under the direction of the author enabled Sir Claude Inglis to publish the report entitled 'The behaviour and control of rivers and canals with the aid of models (in 2 volumes)' within two years. This publication is veritably a mine of information on the various investigations he had carried out and his contributions to engineering and science, notably the effects of sediment load and fluctuating discharges in alluvial channels and river training and the proper scales and uses of large-scale hydraulic models as an aid to the solution of the problems. (Sir Claude Inglis, indeed a maestro of model technology, however emphasized 'Mobile river models are in fact a valuable aid to engineering skill, which however they can never replace'). Indeed, this comprehensive review of Sir Claude Inglis' work provided the author with a unique opportunity of making an in-depth study of all that the Station had achieved and what remained to be done.

The author's experience with model experimentation in Sind, and his rather wider opportunities for closer feel and practical observations of the behaviour of the river Indus and some of the other Punjab rivers (in his capacity as joint discharge officer) made him read, re-read and reflect over this magnum opus of Sir Claude Inglis, admiring and learning all the way. In the words of Gerald Lacey: 'Claude's great gift was his flair for interpreting river behaviour. We might almost say that he studied river psychology. He treated these alluvial rivers as if they were alive, not rigid and dead. He asked himself the question "what would I do if I were the river" and almost invariably got the answer right. In his own subsequent work the author, therefore, took to heart Inglis' sound advice:

"Seek over to make your thoughts and statements more precise and your work more accurate Especially I would counsel you to view every investigation in its physical aspect. It is not sufficient to obtain a mathematical curve which fits a series of experimental points. You must also understand the physical significance of this curve and reduce the problem to its simplest equilibrium form"

After Inglis, the Port and Harbour problems set to the Station multiplied in numbers and complexity.

Following success on the measures suggested to reduce the effect of a 'Knuckle' produced by tidal action due to excessive curvature in the Hooghly and for protecting the foreshore of the Anglo-India Jute Mills on the Hooghly, the Station solved important problems such as that of the Sankrail reach near Akra where the river was very wide resulting in divergence of the flood and ebb flow axes and consequential silting along the navigation route, resulting in improved depths by about 1.2 m. and a large saving on the expenditure on dredging by a long repelling spur. The Calcutta Port commissioners thereafter commissioned the Pune Station to retain models of the Hooghly for the solution of their problems. Similarly, the problems of the Cochin Harbour were increasingly referred to the Station. Soon, this wave of dependence on the Station to solve tidal problems of the Ports successfully caught on, and almost every Port now has a model and claims one or more investigations made with success at the Pune Station.

As an example of the consolidation of the original work done by Inglis the application of principles of curvature of flow in rivers to the control of sand entering the canals and of the principles governing the action of 'attracting' and 'repelling' training works, the continuance of the very important experiments on the Lower Sind Barrage design under the direction of the author may be cited. The Station had earlier emphasized that the successful working of a Barrage—particularly in respect of sand exclusion from off takes depended primarily on its positioning. When the natural meander-length of a river is ignored and unnatural distorted curvature is imposed, sand excluders, ejectors and islands are required to reduce the damage by bad positioning of the Barrage. The author had the advantage of the knowledge of the original designs of the Lower Sind Barrage while working in Sind; the author's design had been changed, and the added insight provided by the model helped him to argue with conviction against the proposed change. The design confirmed by the model based on principles of curvature of flow was recommended and adopted and it is understood that the canals were working satisfactorily. This model investigation also provided increased valuable scientific information on the action of attracting pitched islands for controlling rivers; particularly upstream of barrages.

Similarly, past knowledge on river training by impermeable structures such as stone spurs or groynes, e. g. the repelling spur on the Rupnarayan river, was extended to include the effects of permeable tree groynes and pitched islands. Such permeable groynes have relatively low cost-benefit ratios as they do not cause erosion upstream or downstream. The author had designed and built a massive tree groyne on the Indus in Sind and studied its progressively beneficial effects in the prototype, but the model proved to be a valuable aid for determining the position, alignment, optimum length and orientation for best effect (See AR (T) IWES, 1946, pp. 79-85).

Certain shortcomings of the Station were patently evident. There was much to be desired by way of provision and improvements of instrumentation for hydraulic research—an unfortunate chink in the armour of the Station. For example, the increasing references from the ports showed the lack of suitable apparatus for generating tides and waves. Because of the difficulty of obtaining special equipment from abroad at that time, the tidal control and recording mechanisms were made from components hand-made locally, controlled by clock movements taken from alarm clocks, but by trial and error improvisations they worked. Similarly, a rough and ready wavemaking and recording apparatus was indigenously developed and rigged up in connection with the model of the Madras harbour.

So far, research had been mainly confined to waterways, fluvial and tidal river control and hydraulics with important basic research in these fields. On account of the increased and special research demand in connection with the extensive river development projects under investigation and from the Ports and Railways authorities, reorganization and expansion scheme of the Station was sanctioned in May 1947 to incorporate eight specialist sections: (1) River and Canal Hydraulics, (2) Navigation, (3) Concrete and Materials of Construction, (4) Soils and Soil Mechanics, (5) Mathematics, (6) Statistics, (7) Physics and (8) Chemistry. An Instrumentation Section remained its greatest need, and a Ship Testing Tank its second most pressing requirement. These and other important sections were covered in the subsequent re-organizations which soon followed.

Post 1948

The Station as it stands today is well equipped with modern specialised wherewithal for development of instrumentation, ship testing, study of cavitation effects, an analogue, a computer and facilities for computerised control of models, photoelasticity, high head structures, coastal engineering, earthquake engineering and geophysical studies. Thus, the Station is as complete as it may be for solving on 'system' basis any integrated hydro engineering problem. It rightly attracts customers against competition from similar hydraulic research Institutes of developed countries.

Dr. D. V. Joglekar who had longer experience of the Station than any other person has strongly stressed the importance of continuity of personnel in the Station, and to avoid the brain drain of personnel gravitating elsewhere to improve their prospects he had suggested a common cadre of engineers for design and research and promotions by 'the next below rule'. Mr. Hiranandani who followed him as Director, also urged similar action to attract and hold talented officers for the Station. As stated earlier, Sir Claude Inglis, the Father of the Station, whose views above all should be fully respected, had strongly expressed that he had no use for researchers who had no prior field experience. The author shares Sir Claude Inglis' and Dr. Joglekar's views on recruitment, promotions and continuity for how else, for example, can model results be correctly interpreted without adequate prior field experience and continuity of association with models? A Committee is presently going into the staffing problems of the Station. The Committee will doubtless give due consideration to the views of the past Directors with experience of the particular requirements for the Station, which are not necessarily the same as for other scientific institutions. Changes for mere changes sake will unquestionably be eschewed. Hydraulic research is still an art as well as a science—and this has to be carefully borne in mind when determining the staffing pattern of the Station. With the right men following in the footsteps of the 'guru' the Station is equipped today to rise to the highest pinnacles of achievement.

CWPRS—Its Service To The Nation

1957—62

By

M. G. HIRANANDANI *

This Institute, which was started in 1916 by the late Sir Claude Inglis, has developed into a premier Hydraulic Research Institute in the country during sixty years of its existence.

It is indeed a tribute to the genius of Sir Claude, who may be considered the father of hydraulic engineering research in India, and his distinguished colleague the late Dr. D. V. Joglekar, who laid standards of model technique for fluvial and other model experimentation to solve hydraulic engineering problems of the day on which their successors have been able to build.

Expansion of CWPRS

This period deals with the expansion of the existing facilities and development of new disciplines with a view to meeting the increasing needs for research investigations, which were likely to arise due to the implementation of several national projects included in the second Five Year Plan, and for which the Government of India sanctioned an expansion scheme costing Rs. 9.6 million in 1957.

With the dawn of independence and the sanction of Five Year Plans, emphasis shifted from construction of diversion barrages and weirs solely for the purpose of irrigation, to river valley schemes for multipurpose projects, irrigation, generation of hydropower flood control, and navigation along with development of ports and harbours to meet the expanding needs of the agricultural and industrial economy of the country.

Scientific Laboratories

Apart from shifting offices and scientific laboratories dealing with soil and soil mechanics, concrete and materials of construction, mathematics, geophysics and physics, which were located at different places in Pune, these were brought under one wing with a view to obtaining greater coordination and control. The laboratory-cum-office building proposed to be constructed then at Khadakwasla, was meant to house the newly organised units for studies in model engineering, rock mechanics and earthquake engineering along with the already existing photoelastic unit. Investigations in these disciplines were planned in order to keep pace with developments taking place in these fields in laboratories abroad, to enable CWPRS to deal with such problems when they arose.

Hydraulic Research

Indoor Hydraulic Laboratory

To meet with increased demand for model investigations, an area of about 70 hectares was acquired to provide for model basins. To feed this area a new circulation system carrying an extra discharge was designed.

Hydraulic investigations by model tests had so far been carried out in the open. As results of sensitive tests carried out in the open were likely to be vitiated under the influence of wind and rain, it was considered desirable that such tests be performed under a cover. The chief considerations for an indoor hydraulic

* Formerly Director CWPRS Pune (1957-62)

laboratory were therefore its immunity from the effects of meteorological factors, which permit the use of expensive and precise electronic measuring instruments.

An indoor hydraulic laboratory was accordingly planned and designed for the first time, where flume studies could be carried out without interference from outside elemental disturbances. This laboratory would provide facilities for studies on problems of sediment transport, sections of spillways, energy dissipators, testing of floors and aprons, scour around hydraulic structures and stability of breakwaters.

Cavitation Research

Cavitation research was considered as one of the important aspects of the expansion programme. No funds were however provided by the Government of India for this project in the expansion scheme.

Special object of cavitation research with reference to hydraulic structures is to determine the relation between the magnitude of negative pressure and cavitation damage. The activity of the Research Station with regard to the model study of spillways, barrages and sluice-outlets had hitherto been confined to the investigation of general hydraulic performance, pressure distribution and probability of cavitation. Under atmospheric pressure it is almost impossible for negative pressure in the model to reach the vapour pressure of incipient cavitation.

Study of this phenomenon under sub atmospheric pressures for high coefficient weirs, sluice outlets and penstocks could best be made in a multitest water tunnel, which could also be utilised for testing models of hydraulic turbines, pumps and ship propellers for cavitation research.

The Government of India recognised the necessity of this project and the United Nations special fund allocated a grant of \$ 491,000 for technical and financial assistance in the supply and installation of a multitest water tunnel for cavitation research at CWPRS.

This facility has since been installed and has been rendering advice on cavitation problems referred to CWPRS both by public and private sector enterprises.

Earthquake Engineering

With the proposed construction of hydroelectric projects, thermal power plants and other engineering structures in the second Five Year Plan, it was proposed to investigate the effect of earthquake hazards and induced vibrations due to seismological phenomenon on the safety and economic design of such structures. Seismotectonic investigations were considered for the determination of 'Design Seismic Coefficient' and 'Reservoir Seismicity' for the design of earthquake resistant structures.

This branch was also entrusted to undertake studies :

- (i) to determine explosive charges for excavation for new structures.
- (ii) to observe delays in explosions and blasting patterns for economic pull-out of material.
- (iii) to conduct non-destructive studies of construction materials including concrete for estimation of insitu elastic properties, detection of weak zones, honey-combing etc. in massive construction.

A project was launched in 1958 for vibration studies and stability analysis of power houses and machine foundations, to help arrive at definite conclusions for dynamic design of machine foundations under diverse conditions.

Ship Model Testing Tank

A towing tank 154 m × 3.65 m × 2.13 m already existed at Khadakwasla. The main purpose of the tank was to make possible the prediction of power requirements of the size ship and shape of hulls from the tests carried out on a geometrically similar model. Due to initial paucity of work of ship model testing, the tank was also used for calibration of current meters.

In order to promote interest in the greater utilisation of tank facilities by the Hindusthan Shipyard at Visakhapatnam and other shipping interests in the country, the Government of India appointed an Advisory Committee. The Committee was of the opinion that the existing tank was small for requirements of the shipping industry and that the tank be expanded to 304 m × 12.2 m. × 6.1 m. Experience abroad had shown that with

the judicious use of coefficients, scope of experience in a small tank could be considerably enlarged. Since model experiments of ships 154 m long with a speed of 20 knots and displacement of 20,000 tonnes could be performed in the existing facility, it was considered that, pending advice of Dr. E. V. Telfer, a UNESCO Expert, who had been deputed to CWPRS, potentialities of the existing tank should be fully exploited, before going in for a longer size facility.

Dr. Telfer, who trained the personnel in advanced techniques of ship model testing, suggested that the existing tank may be extended by only 76.5 m. This extension has since been carried out and the facility has been extensively used for the purpose for which it was originally intended.

Hydraulic Research

These investigations were mainly confined to ports, harbours and estuaries on one hand and spillways, weirs, barrages, bridges and surge tanks on the other. Some of the important studies undertaken during the period are mentioned below in brief:

Ports, Harbours, Estuaries

Investigations regarding silting of Bombay harbour silting of Balari and Moyapur bars in the river Hooghly; stabilisation of approach channel to Kandla port; silting of Cochin port; development of Paradip port and Karanja harbour; investigation of direction of littoral drift in case of Mangalore port.

Use of Radioactive Tracer Studies

It would not be out of place to highlight here the development of technique of radioactive tracers for the study of sediment movement in the sea, as it was used for the first time in India, in connection with the silting of Bombay harbour. The areas suitable for dumping the dredged material removed from the main navigation channel had already been investigated by the usual model experiments, using the criterion that the material when dumped at the selected sites would not re-enter the main navigation channel to the Bombay harbour. To be sure that the results obtained in the model would correspond to those in the prototype, the technique of radio isotopes for the study of sediment

transport was employed. This technique was developed in collaboration with the then Atomic Energy establishment, Bombay. The details regarding the design equipment irradiation of the material, use of Geiger counters for the study, have been incorporated in a Technical Memorandum issued by the CWPRS entitled 'Use of Radioactive Tracer for the Study of Sediment Movement for Bombay Harbour.'

Study of Sediment Transport by Use of Fluorescent Materials

In certain cases use of radio isotopes was not considered advisable due either to natural limitations or the hazards and the expense involved. A search was therefore made for a simpler and less expensive technique.

Poland had developed a technique for the study of sediment transport by fluorescent materials. To import this material from Poland would have been prohibitive in cost. Research by the National Chemical Laboratory at Pune showed that fluorescent material could be indigenously produced at low cost. This technique was adopted for investigating the movement of sediment at Balari bar on the Hooghly, Versova beach near Bombay and at Mangalore port.

Spillways, Weirs, Barrages

Some of the important investigations carried out on river valley projects were hydraulic research studies for the design of stilling basin for Kadana dam spillway; design of spillways and dissipating devices for Girna and Vir dams; Kohira, Meshwa and Banas dams; Badua spillway chute; model experiments for Sone barrage, Mundali weir on the Mahanadi, Kanu syphon on Chambal right canal, sluice syphon for Koyna dam; railway bridge on the Yamuna near Delhi; training of river Jhelam to protect Mohora Power House; studies for vibration of crest gates on Bhakra dam spillway; surge tank studies for Koyna and Sharavati hydro electric projects.

Surge tank studies for the Koyna hydro electric project were the first model studies of its kind to be carried out at Khadakwasla. Koyna Project Administration had entrusted these tests to be performed

simultaneously both at Neyrpic, Grenoble and at CWPRS. The results obtained at Khadakwasla fully corroborated with those obtained at Neyrpic. Since then surge tank studies of other hydro electric projects have been entrusted to CWPRS.

Experimental Stress Analysis by Photoelastic Method

Photoelastic laboratory, established with the purpose of assessing and advising on design inquiries for complicated structural problems encountered during planning and design of river valley projects has been an important adjunct of the research complex at Khadakwasla. In the absence of such a facility, problems of reinforcements around galleries in dams, river outlets, sluiceways, surge tanks and spillway piers would have had to be referred to a foreign laboratory, involving precious foreign exchange and delay in finalisation of designs.

Few of the important investigations carried out during the period pertained to Gandhisagar dam spillway piers, Nagarjuna sagar trestle bridges, Barapani dam and Sharavati surge tank.

Foundation Investigations and Geophysical and Seismological exploration

In addition to determining the hydraulic and structural efficiency for the problems by hydraulic research and experimental stress analysis by photoelastic methods, the CWPRS was also entrusted to conduct foundation investigations and geophysical and seismological exploration of the projects, some of which are listed below :

Foundations investigations of Kotah barrage; Foundations investigations and geophysical exploration at the sites of Tawa dam, Linganmakki dam and Mettur tunnel scheme; Geophysical investigations at dam sites in East Punjab and Bombay state; Geophysical and seismological investigations for Jal Dhaka hydro electric project and Kopili dam in Assam.

Instrumentation—Application of Electronics to Hydraulic Measurements

With the receipt of increasing number of problems of river training, tidal hydraulics, breakwater, surge tank

and allied studies, precise measurements of velocity, pressure, water level, wave profile, wave generation, bed profile, tide control and regulation were considered essential for correct interpretation of model results.

Instruments required for the measurement of the above parameters, when indented from abroad were either not available, and when so available were at a great cost involving valuable foreign exchange.

Beginning was accordingly made for development, manufacture and testing of a Midget current meter for measurement of velocities in the model, water level recorders, wave profile recorders, bed profile recorders, wave generators, and automatic tide control and regulator equipment. To obtain higher accuracy in measurement recourse was made to electronics. Instrumentation unit (which finally developed into a Division) was organised, and considerable progress registered in development and manufacture of the instruments.

Refresher Courses in Hydraulics and Hydraulic Engineering

A significant event in 1959 was the inauguration of a two week refresher course in hydraulics at the CWPRS. The specialised research potential in personnel and equipment provided at Khadakwasla was utilised for this medium in the interest of country's research engineers and engineering teachers. The proposal was jointly sponsored by the Ministry of Scientific Research and Cultural Affairs and the Ministry of Irrigation and Power of the Government of India. The course, which aimed at producing engineers more enlightened in their approach to their work and responsibility, was attended by a batch of young teachers of engineering colleges and research engineers from different research laboratories in the country.

The second session of the refresher course in Waterways Engineering was conducted for the benefit of rail and road engineers in the country with the concurrence of the Ministry of Railways and the Ministry of Transport and Communication of the Government of India.

It is gratifying to note that the Refresher Courses in hydraulics, started at the CWPRS in 1959, have attained

a new dimension, in which eminent lecturers from all over the country and abroad extend benefit of their knowledge and latest technology to the research workers of CWPRS as well as other participants from various organisations in the country.

Technical Memorandum

In order to publicise the type and quality of hydraulic engineering research carried out at the CWPRS and to participate in the mutual exchange of research publications with other sister institutions in and outside the country, a beginning was made by publishing the first Technical Memorandum. Some of the Technical Memoranda, that were published, were :-

- (i) Use of Radioactive Tracer for the Study of Sediment Movement of Bombay Harbour.
- (ii) Effect of Temperature and Boundary on Current Meter Ratings.
- (iii) Training of Fulta James and Mary Reach of the River Hooghly.
- (iv) Balari Bar and Regime of River Hooghly.
- (v) Development of the Port of Cuddalore - Hydraulic Model Studies.
- (vi) Spillways and Energy Dissipators - Hydraulic Model Investigations.

In Retrospect

After the Author's retirement in 1962, his association with CWPRS continued for another period of 5 years, in his capacity as the Consultant to Orissa Government, to look after the speedy and effective completion of the Five Year Plan projects entrusted to the Station. During this period he had the opportunity to observe that the expansion programme, undertaken earlier, had been brought to successful fruition under the directorship of Shri C. V. Gole and his able associates, both engineers and scientists.

The CWPRS, as constituted today, is a unique institution in the sense that similar problems in hydraulic engineering research, which are investigated by two different organisations in USA viz. Waterways Experiment Station, Vicksburg, Mississippi and the Bureau of Reclamation, Denver, Colorado, are dealt with at one place at Pune, resulting in greater coordination and control and consequent economy in expenditure.

A unit, which started as a small research station in 1916, has developed into a variegated complex of engineering research during sixty years of its existence. It is a national asset, which has been responsible in aiding indirectly the growth of irrigation and power potential, thereby contributing to the economic and industrial development of the nation.

Some Suggestions

Documentation Service and Hydraulic Analysis Branch

An institution of the magnitude and importance such as the CWPRS is incomplete without a library aid of a documentation service and a hydraulic analysis branch. While the former pertains to the translation into English of pamphlets and research papers published in non-English by foreign laboratories and research institutions, the latter deals with the compilation and analysis of all data collected at research institutions, university laboratories and elsewhere, where similar work is done. As the basic data used in the development of design criteria result from many sources, both foreign and domestic, these are analysed and the results published in the form of charts and explanatory sheets, which are circulated to design and research engineers.

Both the above services exist in an impressive manner at Neyrpic, Grenoble (France) and at the Waterways Experiment Station, Vicksburg (USA). Since the CWPRS and the Waterways Experiment Station are very akin to each other in the organisational set up and scope of work, it would promote the interest of hydraulic engineering research in India, if these auxiliary services are also developed at the CWPRS.

It may be mentioned that the author had recommended the set-up of these services to the Government as early as 1959 in his report on his 'Visit to Hydraulic Research Laboratories in United States, United Kingdom and France.'

Tidal Power Studies

CWPRS, as a premier hydraulic research station, has all along been entrusted with the solution of major hydraulic research problems in the country. To maintain a dynamic lead, as it has done in the past, it should be ready to accept new problems and equip itself to meet

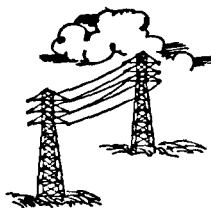
the challenge. One such problem, which may arise shortly, is the exploitation of tidal energy.

Geologists and scientists all over the world have given a warning for conserving dwindling reserves of fossil fuels. Most of the dam sites for generation of cheap hydro-power have already been exploited. Tidal energy development undoubtedly appears at present prohibitively expensive, but this should not preclude the investigation of tidal power studies in the country by CWPRS, which is the only organisation with resources and capabilities for coastal field investigation and physical and mathematical modelling to undertake this work. This will enable it to develop expertise and rise to the occasion, if and when a problem of this kind is referred to it, either in India or any agency from the ESCAP Region for which CWPRS has been recognised as a regional laboratory.

Mathematical Modelling

Present trend of work in hydraulic laboratories all over the world is to develop mathematical modelling with the use of sophisticated equipment such as computers, to provide solution to several engineering problems without having recourse to physical modelling, as the latter involves both time and expense.

Due, however, to limitations of mathematical modelling at present, a judicious compromise is made, while providing solution to the engineering problems. In order to keep pace with the development of this technique in the advanced laboratories abroad, it is desirable to develop expertise in mathematical modelling at the CWPRS and to provide adequate equipment to assist in these studies.



Development of Central Water And Power Research Station 1948-1974

S. C. DESAI *

Introduction

As a close associate of late Padmashri Dr. D. V. Joglekar, Director, CWPRS, 1948-57, and as Director for one year in 1962, I have been approached to contribute an article on the growth, development and impressions on the activities of CWPRS during the period of my association with the Research Station and thereafter. Dr. Joglekar joined the CWPRS in 1922, served the station for 35 years till he retired as Director in 1957; however, his association and benevolent guidance continued upto 1967, when he finally retired as Adviser to the Central Board of Irrigation and power. The author joined the CWPRS in 1940 and served the CWPRS for the entire period upto 1974, except for 4 years, when he was on deputation to the Central Water and Power Commission, New Delhi.

Considering its usefulness to the entire country, the Research Station was taken over by the Government of India in 1937 with Sir Claude Inglis, the father of hydraulic research in India, as its first Director. The Station was made permanent in 1944 in order to ensure the continuance of the work and accumulation of data and experience. Dr. A. N. Khosla, the first Chairman of the Central Water and Power Commission, appointed Dr. Joglekar as Officer on Special Duty in June 1946

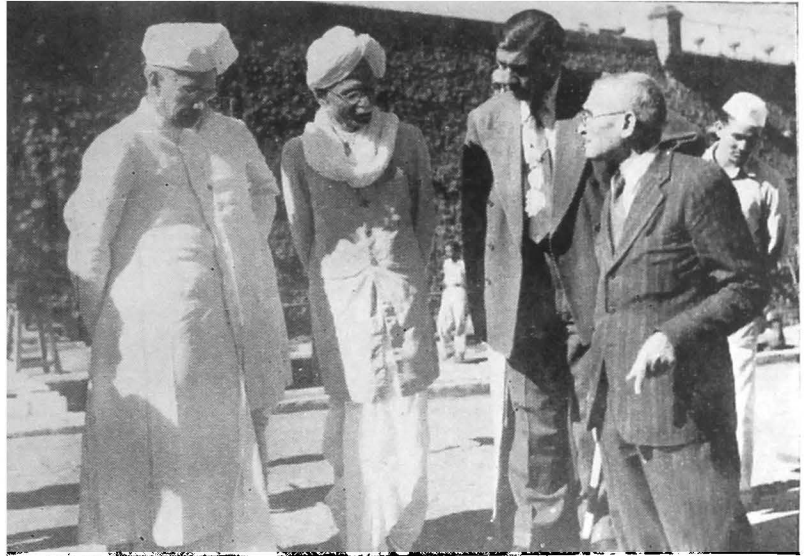
for reorganisation and expansion of CWPRS. Dr. Joglekar took the services of the author, who had then joined the CWPC, for assistance in framing the proposals of reorganisation, which were later sanctioned by the Government of India on 22nd May 1947. Immediately after sanction, Dr. Joglekar took over as Director of CWPRS in 1948. In addition to the then existing 14 hectares, 43 hectares of land was acquired and the work of expansion began as also the recruitment of officers and staff for the eight newly created Research Divisions. The author rejoined the CWPRS as the seniormost Chief Research Officer (Engineering), and was placed in charge of development and expansion of CWPRS and its administration, besides his duties as CRO (Hydraulics). Even before the completion of the 1947 scheme, proposals for a huge expansion scheme of CWPRS in the Second Five Year Plan were framed, and Government accorded their approval immediately. Additional land to the extent of 122 hectares was acquired by 1963, after which there has not been any acquisition to date inspite of the tremendous development that has followed.

With the dawn of independence in 1947, huge river valley projects were taken up for investigation, design and construction, and the CWPRS was called upon to

* Project Manager, Water Research Centre, Baghdad and Resident Representative of WAPCOS, New Delhi. Formerly Director, CWPRS Pune and Adviser to the Government of Gujarat for Hydraulic Research (1975).

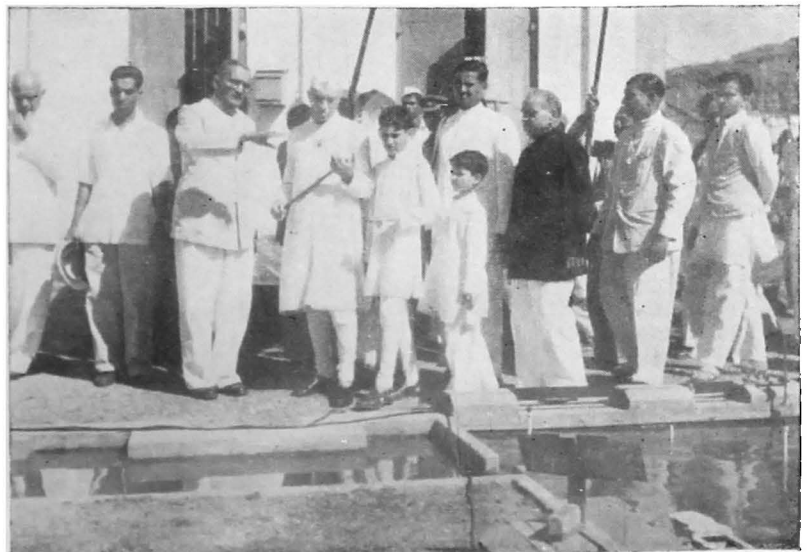
Our Distinguished Visitors

Dr. S. Radhakrishnan
Vice President of India
(10-1-1954)

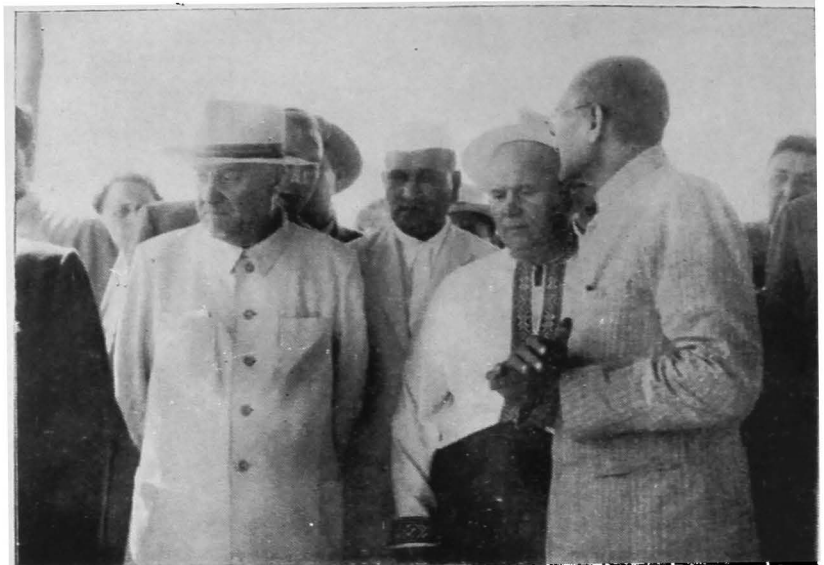


Dr. Rajendra Prasad
President of India
(18-11-1954)

Shri. Jawaharlal Nehru
Prime Minister of India
(4-6-1955)



Mr. N. Bulganin
Prime Minister of U. S. S. R.
and
Mr. N. Khrushchev
First Secretary of Communist Party
of U. S. S. R.
(22-11-1955)



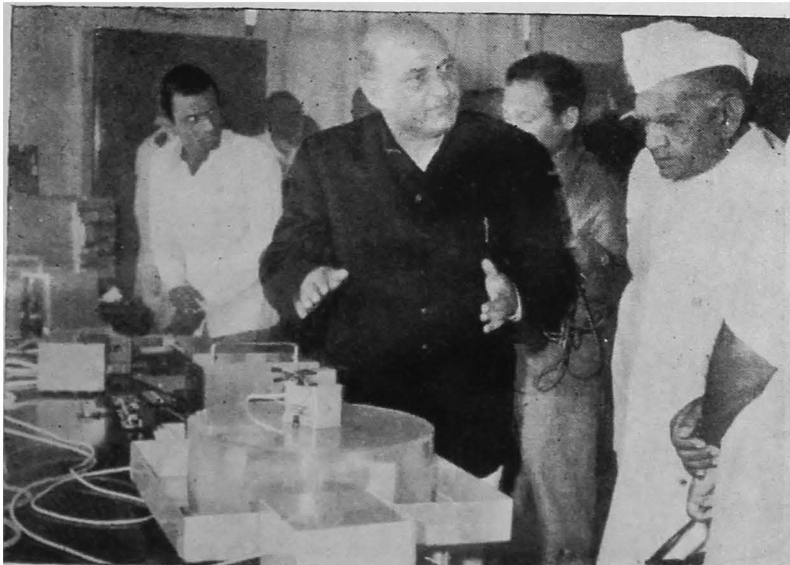
Sir Claude C. Inglis
Director, Hydraulic Research Station,
Wallingford, England
(19-2-1956)

Mr. Chou En-Lai
Prime Minister of
the People's Republic of China
(2-12-1956)

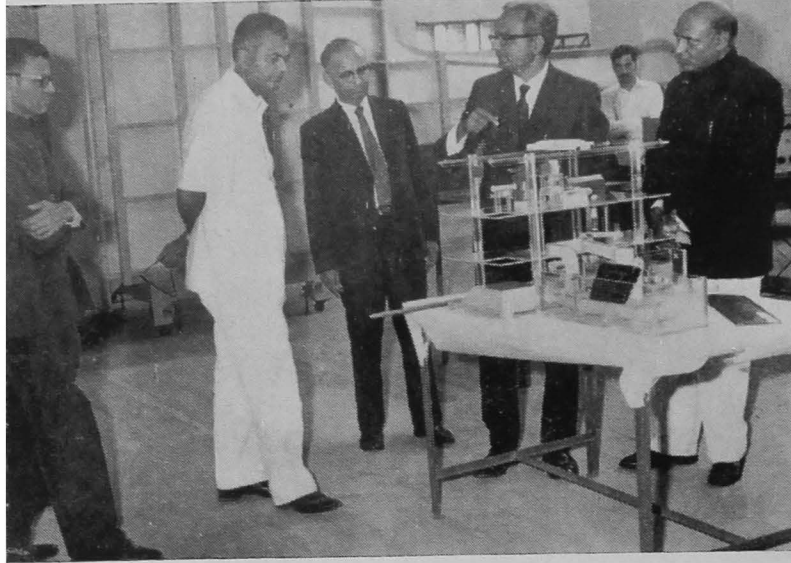




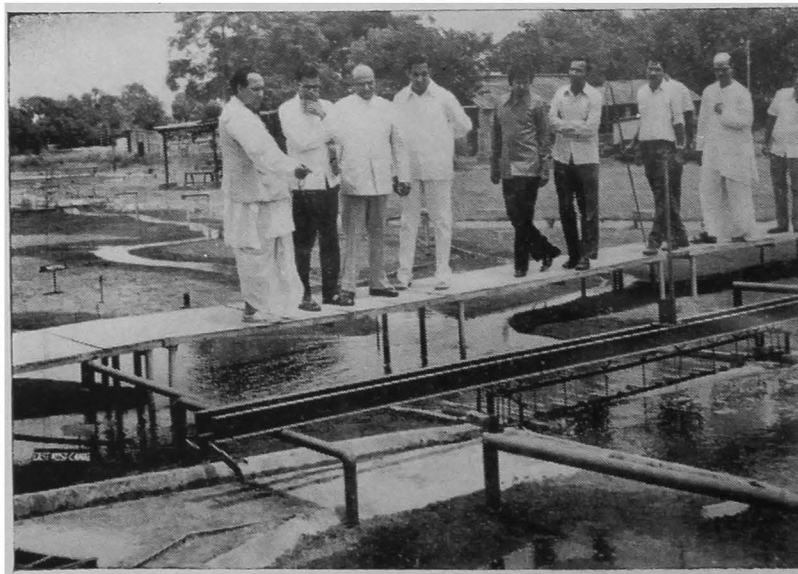
Dr. K. L. Rao and Shri. P. K. Sawant
Inaugural function of the Golden Jubilee of CWPRS
(23-1-1966)



Shri. Fakhruddin Ali Ahmed
President of India
(21-9-1974)



Shri. K. C. Pant
Minister for Irrigation and Power
(21-9-1974)



Shri. K. N. Singh
Dy. Minister for Agriculture and Irrigation
(1-9-1975)

participate and contribute their services for the development of river valley projects and ports and harbours. Some of the important problems of national importance in which CWPRS contributed and research developments that were made, are briefly described in the following paragraphs.

River Valley Projects

Hirakud Dam Project in Orissa was one of the huge river valley projects taken up for construction immediately after independence. The author was deputed to USA for its design in 1948-49. Hydraulic model studies for the spillway and undersluices were conducted in several models at CWPRS and the subsequent prototype behaviour very successfully confirmed the findings of the models. Since then several studies by means of models were conducted for Koyna Dam spillway in Maharashtra, Gandhi Sagar Dam in Rajasthan, Kakrapara weir in Gujarat. The model testing of these structures improved their designs and made them safe, sound and economical.

Flood Control and River Training Works

Since its beginning, the CWPRS is playing a vital role in solving flood control and protection problems. Problem of the Kosi, the river of sorrow of Bihar, and the Brahmaputra in Assam, are outstanding examples of CWPRS' contribution for these problems of national importance.

The river Kosi which joins the Ganga near Kursela bridge runs in sandy alluvial plains. The river had shifted its course by 110 km towards the west during the last 200 years. With an intensive flair for field studies Dr. Joglekar accompanied by the author, undertook a hazardous inspection of the Kosi for 7 days, camping on the river bank in the winter of 1953. The scheme for a barrage and flood embankments prepared by CWPC was extensively tested in different models at CWPRS, and several modifications for location, alignment of guide bunds, and alignment of afflux and flood embankments were made. The recommendations were implemented in the prototype with great success.

Due to landslides, the Brahmaputra brought huge quantities of sand. During 1954 the river eroded about 1/7 of the prosperous tea town of Dibrugarh in Assam. The protection scheme of 5 stone spurs and 13 permeable spurs recommended by CWPRS after conducting model tests was completed in 1955. It was very effective in protecting the town during unprecedented floods of 1956. The late Prime Minister Shri Jawaharlal Nehru paid rich tributes to the engineers for the excellent performance of the protection scheme for Dibrugarh.

In this connection it is worthwhile quoting a remark made in 1956 by late Sir Claude Inglis, who has been recognised as one of the greatest river training experts in the world: "In my considered opinion, the Central Water and Power Research Station has a far clearer grasp of the use of loose boundary models for the solution of river problems than any other Station in the world today." Mr. F. H. Allen, the then Director Designate of Wallingford Hydraulic Research Station, UK, spent sometime in 1956 at CWPRS in acquainting himself with the methods of river training.

Visits of V. I. Ps

It was the visit of late Shri Lal Bahadur Shastri, the then Union Minister of Transport on 1st April, 1954, which heralded the beginning of visits of Union and State ministers, eminent engineers and scientists and other VIPs from all over the world. At the suggestion and request of Lal Bahadur, Gulzarilal Nanda, (the then Union Irrigation Minister), President Rajendra Prasad and Prime Minister Jawaharlal Nehru visited the CWPRS in 1954-55. Their visits were followed by the visits of foreign dignitaries, such as Nikolai Bulganin, Prime Minister of USSR and Nikita Khrushchev, the First Secretary of Communist Party in USSR, Chou En-lai, Prime Minister of the People's Republic of China and scores of other VIPs in period 1954-57. These visits were given wide publicity in national papers throughout the country and in All India Radio news bulletins. This period may be regarded as the golden period of the CWPRS, as the common man came to know about the activities of CWPRS.

Ports, Harbours and Estuaries

Problems of development of ports, harbours and

estuaries began to flow into the CWPRS. It was at the instance of Lal Bahadur that a complicated problem of silting of Bombay harbour was referred by the Bombay Port Trust to CWPRS instead of to a foreign laboratory. Problems of Kandla port development, Kuttanad area development, ports of Madras, Mangalore and Paradip, were referred to CWPRS by the respective port authorities and the Ministry of Transport. One of the most difficult estuarine problems of navigability of the river Hooghly for the port of Calcutta was undertaken by model studies. There is considerable navigation traffic to Calcutta Port through the Hooghly river. To negotiate a distance of 190 km it took 2 to 3 days as there were acute bends and shoals, and ships had to wait for high tides. Hydraulic model studies were conducted to evolve measures to solve navigation difficulties in the river. One of the important problems that was tackled was that of Sankrail reach near Akra 11 km from Calcutta. A 395 m long flood repelling spur constructed at a cost of Rs. 3 million on the recommendations of CWPRS improved the navigable depths and caused reduction in the annual expenditure of dredging on the bars. A feather in the cap of CWPRS!

Allied Research Problems

Quick reconnaissance surveys are necessary for selecting sites of weirs, barrages, dams and other hydraulic structures. With the help of geophysical equipment and trained personnel CWPRS investigated several sites in the country. The photoelastic equipment procured as aid from UN was made use of in determining stresses in complicated engineering structures; such studies in connection with Bhakra Dam gave very useful information for design of its foundations. Soil survey had been carried out to study the suitability of soils for irrigation purposes. Such studies were undertaken for Tapi and Sabarmati basins in Gujarat. Thus a solid foundation was laid for conducting scientific investigations related to river valley and other projects. With great foresight, a ship model testing tank, the first of its kind in southeast Asia was commissioned in 1953 for testing the shapes of ships and incidentally to rate current meters.

Work in 1962

With the retirement of Shri M. G. Hiranandani on

5th January 1962, the author worked as Director CWPRS, for a full year till 4th January 1963. Besides researches on dams, barrages, ports and harbours and allied branches, a fillip was given to testing of prototype structures to study their behaviour, e. g. vibration studies for the sluice gates of Bhakra Dam, prototype studies of volute syphons at Hirebhasgar dam. With the successful completion of radioactive tracer studies in Bombay harbour in 1959-60, similar studies were taken up in Cochin harbour. For the first time in the country radioactive tracer techniques were used for measurement of river discharges. After the failure of the Panshet Dam in 1961, model studies were taken up to determine the causes of failure of the Panshet sluice outlet and Khadakwasla Dam, for the Panshet Inquiry Commission.

For better prospects of the nongazetted staff, a Reorganisation Scheme was submitted to the Government. The UNDP sanctioned the Cavitation Research Centre in 1962 and a new era of development dawned in CWPRS.

Development of CWPRS and its Future—My Impressions UNDP Assistance

Since 1957 shortage of foreign exchange began to be felt, with the result that essential foreign equipment for research, could not be procured. This gave birth to an Instrumentation Cell to develop instruments and equipment indigenously. At the same time a project was put up for UNDP assistance in a big way. The Cavitation Research Centre was sanctioned by the UNDP in 1962. Subsequently a project "Coastal Engineering Research Centre and Development of Hydraulic Instrumentation" was commenced in 1972, and today four additional projects are on the anvil, a rare instance of an institution receiving such a size of aid. When these projects are completed by say 1980, the CWPRS will perhaps be the top institution in the world with latest sophisticated equipment, buildings, more than 100 foreign trained staff and research experts, with continuous experience for more than 20 to 25 years in their field of specialisation.

Continuity of Research Personnel

The late Dr. Joglekar believed in continuity of research

careers and he would not forward application of a good experienced research officer for any outside job. The author was being promoted as Superintending Engineer and posted in Central Water Commission in 1959. Dr. Joglekar succeeded in keeping him in Pune and got a higher post transferred to CWPRS. This incident prompted the Government to separate the cadre of CWPRS from that of CWPC in 1961. This decision though not favoured by many CWPRS engineers, has paid handsome dividends, and CWPRS has now developed an expertise in their field of specialization. This is one of the important aspects which distinguishes the CWPRS from the rest of the State irrigation research institutes where research personnel are transferred every 3 or 4 years.

Administrative Status of CWPRS

CWPRS inspite of its unique position in the international field, its recognition by United Nations as a Regional Laboratory for ESCAP in 1970, still remains a subordinate office of Central Water Commission, New Delhi. A strong case was made for raising the status of the Director to that of a Member in CWPC in 1967 before the Bhagvantam Committee; but it was not supported in spite of the fact that the officers in CWPRS exceeded the officers working under two Members in CWPC both in number and skills. Though there is fortunately, freedom of expressing technical opinion, the growth of CWPRS is stunted by its low position in administration. This has to be remedied by raising the status at least to an attached office, with the status of the Director raised to that of a Member in CWC. This is fully justifiable and long overdue.

CWPRS in International Field

With the recognition of CWPRS as a Regional Laboratory for ESCAP countries in 1970, problems for solution are being received from these countries. The

port of Singapore Authority entrusted CWPRS with the conducting of hydraulic model tests for the development of Singapore Port. They have now entered into an agreement with CWPRS for hydraulic models and allied studies for a period of 20 years.

WAI COS (Water & Power Development Consultancy Services (India) Ltd.), a Government of India undertaking have been engaged as consultants by the Republic of Iraq for establishment of a Water Research Centre in Baghdad, of which the author is the Project Manager. CWPRS is playing a very important role in this Project. It will have perhaps to play a still larger and vital role in operation of the Centre in Baghdad. It would be another feather in the cap of CWPRS in the international field through WAPCOS.

Future of CWPRS

The author had the splendid opportunity of working as the seniormost Dy. Director/Joint Director in CWPRS for 22 years, except in 1962 when he himself was the Director. He was, therefore, extremely fortunate in making a significant contribution in shaping the destiny of CWPRS regarding its development plans including UNDP schemes, research programmes and their direction, setting up the research cadre, additional staff through SIU, service conditions of establishment, labour relations and welfare activities.

With the solid foundation laid during Dr. Joglekar's Directorship in 1948-57, and the superstructure built upto 1974, the CWPRS has a very bright future to continue to serve the entire nation in wider areas and in the international field. This objective will be achieved under the dynamic leadership of Shri P. C. Saxena, the present Director, who has to perform this important task with the aid of a team of research workers whose devotion and dedication is difficult to equal and whose ability and experience can hardly be excelled.

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Central Water And Power Research Station Perspective 1963 To 1974

C. V. GOLE *

Introduction

In the year 1976 the CWPRS is completing sixty years and is celebrating the Diamond Jubilee in a befitting manner. This is a significant landmark in the history of the Station. Apart from the awareness of the background, growth and achievements of the Station during the past years, the present celebrations provide a great opportunity to evaluate, illuminate, and organise the present and future development needs of the Station and harness the capabilities in the very many facets of its activities.

It has been a great privilege to have actively worked in the CWPRS for over thirty years. Late Sir Claude Inglis, Mr. K. K. Framji, the late Dr. D. V. Joglekar and Mr. M. G. Hiranandani, who headed the Station earlier made outstanding contributions in the field of hydraulic research and paved the way for raising the status of the CWPRS to its present level. The writer was most fortunate to have worked with and learnt from these great experts and luminaries in the field of hydraulic engineering and allied research and technology.

It was a memorable moment when the writer became the Director of CWPRS in 1963 and headed the organisation for about 12 years, upto August 1974. It was a challenging assignment, but the impact

made by the traditions, pioneering efforts and strides of the CWPRS in the application of latest techniques to evolve solutions to intricate and complex problems of rivers, hydraulic structures, ports and harbours, under the leadership of the previous Directors together with the team of excellently capable, dedicated, and devoted research engineers, scientists, and workers, created a growing confidence to progressively develop the Station, organise and direct its activities for the primary benefit of our Nation.

With the rapidly increasing challenge of research problems of development projects in the country, the urgent need for an allround expansion of CWPRS was immediately realised and gradually implemented. The Station has now more than 300 highly qualified engineers and scientists with a large complement of technical and professional personnel, and has built up expertise in various fields of hydraulic engineering and other allied aspects.

The Station had 13 Divisions only when the writer took over as Director and the number increased significantly to 30 Divisions during his tenure as Director of the Station.

Early Development

In the early years of its existence, the Research Station, which was located at Hadapsar, near Pune

* Member, (W. R.) Central Water Commission, Ex. Officio
Jt. Secretary to Government of India.
Director, CWPRS, 1963-1974

mainly conducted research in the fields of irrigation, agricultural development of Deccan canals, soil physics, land drainage problems and hydraulic research. Pioneering work was undertaken by the Research Station in the pre-independence period between 1930 and 1947. Notable amongst these are the studies for silt exclusion from Canals at Sukkur Barrage and protection of Hardinge bridge (now in Bangla Desh) and bridge at Kolaghat in West Bengal across the Ganga and the Rupnarain rivers respectively. During the post-independence period, the Government of India established the Central Water and Power Commission. Within the Commission, the activities of the Research Station increased manifold. In 1947 the Research Station was reorganised by the great engineer and statesman Dr. A. N. Khosla, and its activities expanded to cater to various needs of river valley projects, ship-building industry, ports and harbours and inland navigation.

The important role played by the Research Station in the post-independence period in research and advice on river valley projects, flood control schemes, ports and harbours has earned the CWPRS wide recognition, and has effected great economies by ensuring proper design with efficient working.

The Period 1963-1974

During this period, the Research Station had to develop its potential both in magnitude and scope. This was the period when there was an enormous increase in major hydraulic structures, water resource development, ports and harbours, which in turn focussed the need for diversification of research activities and functions of the CWPRS. All these were organised and the Research Station rose to the occasion admirably. To attain the much needed self-sufficiency in basic technology and know-how, the engineers and scientists were trained for specialisation both in India and abroad.

To reduce our dependence on imported equipment and instruments needed for research, the writer initiated the stepping up of indigenous development of these instruments. For this a new Instrumentation Cell was created. This has already paid dividends. However, to accelerate the progress, a UNDP scheme was motivated.

Under this scheme, which started in 1972, a mini-computer, equipments for data acquisition and logging systems were obtained and eminent experts in the field of hydraulic instrumentation were invited to give guidance and training to our engineers and scientists in our endeavour to develop necessary instruments locally. A number of officers of the Station were also provided with excellent training in the best laboratories abroad.

A Coastal Engineering Research Centre was established in 1972 with a view to develop a strong base to take up the intricate and complex problems posed in its domain. These problems essentially comprise of the study of natural phenomena such as waves, tides and ocean currents in connection with the problems associated with the development of navigation channels, design of harbours, coastal protection works, sewage disposal, cooling water intakes and outfalls and offshore drilling platforms. It calls for interdisciplinary approach involving fluid mechanics, hydraulic engineering, hydrology, geology, geomorphology, soil mechanics, instrumentation, electronics, mathematics etc. Intensive research has, therefore, been initiated in the Coastal Engineering Research Centre to study various problems of waves, tides, littoral drift and beach processes.

As cavitation had caused serious damage to turbines and pumps in some major hydro-power projects and also in high head gates, research and development facility of multitest water tunnel was provided. Since 1967 the work has been progressing. This is particularly important as water turbines, pumps, valves are manufactured by BHEL and high-head gates by Triveni structurals and Tungabhadra Workshop.

Cavitation Research Centre, Coastal Engineering Research Centre and the Hydraulic Instrumentation Centre were set up with the UNDP assistance, which provided expertise, training and equipment.

An Earthquake Engineering Research Division was established in 1963 for intensive Earth Sciences Research along with Hydraulic Research. The Division has made encouraging progress. The application of earth sciences to solve engineering problems has developed into a sophisticated and specialised branch of scientific research. A project was initiated to strengthen this Division with

the assistance of UNDP whose contribution would be around 0.74 million dollars. As the hydraulic structures have to sustain vibration and seismic forces, research findings would greatly help in many water utilisation projects in planning, design, construction, maintenance and operation, and finally in the overall costs of the projects.

A large-scale mass transfer of water to serve arid and semiarid areas, would need high head pumps. A new hydrodynamics laboratory was considered essential to carry out research and study of development problems for all types of pumps, water hammer, and transport of solids in pipe lines and provide calibration facilities for flow meters. This scheme is now coming up with UNDP assistance.

Some Additional Activities

The conservation and control of water for irrigation, power and navigation require the construction of dams, tunnels, power houses, navigation locks, quays and wharves. These structures are subjected not only to heavy water pressures and forces due to self weight but also subjected to wind and wave action, temperature changes, shrinkage, and earthquakes. The routine methods of analysis are inadequate for the design of these structures, which have complicated profiles and non-uniform and unsymmetrical foundations. These problems were required to be referred to foreign laboratories earlier. Research studies of large scale structural models were introduced. It is also proposed to develop new techniques such as Moire fringes and brittle coating in stress analysis. Models are designed to approach the prototype in greater detail, reproducing the elastic and plastic properties and discontinuities. As a result of detailed studies carried out with these facilities, substantial economy in cost as well as safety of the huge structures would be ensured.

Discipline of Rock Mechanics was established to study the effects of heterogeneity, gneissosity, schistosity, cleavage etc. and rocks from shear zone and fault zone. With planned research it is possible to improve stiffness and strength of rocks and to replace thumb rules by formulae based on theoretical and experimental results. The feasibility of using thermosetting and thermoplastic

synthetic resins for grouting the structures was also being examined at the Research Station. All the above developments proved extremely useful in Koyna dam which was damaged due to earthquakes of 1967.

To remove the pressure on the Ship Model Testing Tank, a separate tank was established to meet the increasing demand for calibration of current meters.

Field measurements for in-situ efficiency studies of turbines in hydropower projects were organised.

Another important activity initiated at the Research Station was establishment of Hydraulic Analysis and Prototype Testing Division to fill up the long felt need to establish design criteria and cultivate deep understanding of limitations of hydraulic model techniques.

The Status of CWPRS

The occasion of the Golden Jubilee Celebrations of the CWPRS in 1966 with symposia on "Model and Prototype Conformity" and "Modern Trends in Hydraulic Engineering Research" was graced by some of the eminent experts and engineers from abroad who attended the I. C. I. D. conference held in Jan. 1966 in India. The Station had the admiration and appreciation of all these experts.

On the basis of achievements and potential of the CWPRS the station was recognised in 1970 as the Regional Laboratory to serve the needs of ESCAP countries. Other UN Agencies have also recognised the achievements of CWPRS.

Some Contributions

A new approach for tackling the hydraulic research problems at the Station was introduced. Solutions were characterised by blending experimental results with mathematical and analytical approach, after examining in addition, various other aspects such as ease of construction, availability of construction materials. This approach has been very much appreciated by the World Bank and other authorities. This impressive approach was responsible in securing a long term contract for studying various problems of development and improvement of Singapore Port which ranks as the fourth largest port in the world.

After extensive in depth studies and on the basis of decades of most valuable experience, the Research Station prepared a manual on River Behaviour, Control and Training under the guidance of the late Dr. D. V. Joglekar. The writer was intimately associated with the task of preparing the manual which provided him with the unique opportunity to analyse the various aspects of river behaviour.

Among the important problems of development of ports, dispensing with long breakwaters for the new port of Mangalore by taking advantage of attenuation of waves in the approach channel was another important contribution. The scheme was executed on the basis of this layout and prototype observations have shown very good conformity between model and the prototype. This layout had resulted in substantial savings in the construction cost almost to the extent of about Rs. 100 million. A study on Inland Delta building activity of the Kosi presented to the American Society of Civil Engineers in March 1966 has been considered an outstanding contribution by the American Society of Civil Engineers. In this paper, predictions on scientific basis were made about the behaviour of the Kosi river. This study has helped substantially in planning river training works for the protection of the embankments.

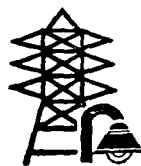
Another notable contribution was regarding dispensing with lock system in the proposed new satellite harbour at Nhava Sheva.

During these 12 years, the station had great opportunities to study a large number of problems connected with river valley projects, development and improvement of ports and harbours, hydraulic engineering problems etc. and make significant contributions to ensure efficient, economical and effective performance of very many development projects. These contributions are too numerous to be covered in this brief narrative.

Looking Ahead

Research is an evolutionary process and has a great role to play in the changing needs and pattern of water and power development, hydraulic engineering, coastal engineering etc. Significant research studies have been made and are also being made by the CWPRS. I am confident that the Station with its highly competent, capable and specialised research experts and staff will reach new heights of prosperity in the future.

I wish the Diamond Jubilee Celebrations a grand success.



The Road Ahead

P. C. SAXENA *

The Central Water and Power Research Station (CWPRS) at Pune, which began in a humble way in 1916 as a part of the Special Irrigation Research Division of the then Bombay Presidency, has today become one of the largest institutions of its kind in the world and the premier engineering research institution in the country. The pioneering work of the Station on design of barrages and development of loose-boundary model techniques in its early days is well known.

The growth and development of the CWPRS has been inextricably coupled with the development of the nation through the various five year plans. This is evident from a casual examination of the projects on which the advice of the Research Station has been sought from time to time. Immediately after independence the country had to face some major problems due to devastating floods of rivers such as the Kosi and the Brahmaputra. The Research Station acquitted itself creditably by providing the necessary solutions. The flood protection work at Dibrugarh is a notable example. The everchanging Kosi known as the "river of sorrow" has been a subject of considerable study at the Station, which has helped in controlling its fury and ensuring safety to the large number of people living along its course.

The first and second Five Year Plans laid stress on developing the agricultural economy of the country,

which in turn called for construction of multi-purpose river valley projects and understandably the Research Station's activities were concentrated on many of these interesting problems. This has enabled development of new designs for energy dissipating devices as well as new techniques of modelling.

With the increasing use of water borne transport, the Research Station has undertaken investigations to evolve economic designs for vessels both inland as well as sea-worthy. The Ship Model Testing Tank, which was conceived in the late forties and opened in 1955, was the only one then available in the country. With the diversification of the activities of the Station from routine and conventional studies, the need for augmenting the instrumentation facilities for making sophisticated measurements on the models was also felt and the Research Station did not lag behind in providing the necessary start in this direction.

The rapid expansion of international trade, particularly of bulk cargoes such as iron ore, oil and fertilizers, led to the development of a number of ports and harbours throughout the country. It was only natural that CWPRS should be called upon to lend its expertise in this field as well. Beginning with the Hooghly, Kandla and Cochin harbour models, the Research Station has been intimately associated with the development of all the major ports in the country and practically all the

* Director, Central Water and Power Research Station Pune.

· fishing harbours. Several problems require a multi-disciplinary approach involving different groups and indeed, the existence of a large number of disciplines under one roof is one of the unique features of the Station.

One of the major objectives at the CWPRS has been to develop a level of technology, which is comparable to that existing anywhere in the world, to enable the solution of complicated problems encountered. The Station has been able to accomplish this in several areas, some of which are :

- (i) flood control and training of alluvial rivers,
- (ii) providing layout and development plans for major ports, navigation locks etc.,
- (iii) design of hydropower structures and appurtenances,
- (iv) cavitation studies for efficient design of turbines, pumps and gates/valves,
- (v) instrumentation – both for laboratory and field use,
- (vi) structural design of complex elements relating to river valley structures,
- (vii) geophysical exploration and foundation engineering.

The industrialisation of the country during the Fifth Plan requires that the generation of power be increased from 18 million kw to 35 million kw by the end of the Fifth Plan. Though India possesses a large amount of hydro potential, it has not been possible to tap all these sources owing to various reasons. This naturally led to greater emphasis being placed on thermal power. Today India is setting up super-thermal power stations. This calls for intricate studies on the pattern of disposal of hot water from the condensers and prevention of recirculation towards the intake. Since the availability of cooling water is abundant along the coasts/estuaries/ rivers, such power stations are generally located along these regions, where in addition to the meteorological factors, the hydro-dynamic aspects of the flow also play a significant role in determining the recirculation. Today the Research Station has been entrusted with studies relating to a number of thermal power stations. With the necessity for speedy completion of these studies

and the technical requirement of measurement of a large number of parameters concurrently at several locations in these models, the demands on instrumentation and data acquisition have also been enhanced considerably. The assistance of the UNDP has made it possible to meet this requirement by the provision of a computer based data acquisition system for on-line work.

One of the consequences of industrial and economic advancement is an increase in the levels of pollution in the media of air, water and land. This problem has assumed alarming proportions in advanced and affluent countries, and large sums of money are spent to combat the effects of pollution. As rightly pointed out some time back by Shri. Subramaniam, Union Minister for Finance, developing countries cannot afford to deny themselves the industrial development plans for fear of pollution, and therefore timely measures to combat the hazards of pollution should go hand in hand with these development plans. The CWPRS has been entrusted with studies relating to dispersal of pollutants by several agencies, because this dispersal follows the laws of hydrodynamics. Such studies have to be conducted not only through physical models but also by other techniques such as mathematical modelling. Besides, it is also essential to obtain adequate information from the field. Though the CWPRS has been involved in such studies for about a decade it is only recently that such problems have been engaging our attention to an increasing extent. During the coming years greater emphasis would have to be placed by CWPRS on equipping itself in terms of men and material to conduct these studies through mathematical modelling and field observations.

It may however be mentioned that the Research Station does not consider itself competent to prescribe standards for effluents before their disposal or in their actual enforcement. Its role is merely to suggest engineering methods for solving the pollution problems and to make industrialisation possible without encroachment on the standards prescribed by competent organizations.

To meet the vast and varying needs of the future, research activity at CWPRS must be planned to build

the edifice of future economic development of country on the foundations of existing knowledge. Our efforts should be therefore diverted to two main directions namely

- (i) up-dating the facilities and expertise which will be called upon to play an increasing role in the future and
- (ii) introduction of new technologies and expertise relating to our field of interest.

In the former category fall the Ship Hydrodynamics, Pump Hydromechanics, Hydraulic Structures Research, Applied Earth Sciences and studies relating to dispersion of pollutants. The second category should provide for new disciplines such as design and testing of off-shore structures, design of breakwaters under random sea wave conditions, development of techniques and equipment for dredging, bio-fluid mechanics of the cardio-vascular and gastro-intestinal systems, design of automatic flood forecasting techniques and creation of digital data system for coastal and hydrological data including modern techniques such as remote sensing and satellite communication, and development of tidal power.

Up-dating and expansion of this order calls for considerable expansion of library and documentation services, placing of adequate emphasis on the development of man-power, employment of latest techniques of R and D management and shedding of a good amount of routine work which the CWPRS is currently doing.

UPDATING THE FACILITIES

Ship Hydrodynamics

The Ship Testing Tank was built two decades back to test the design of ship and calibrate currentmeters. Not only has the tank saved a foreign exchange of the order of Rs. 5-6 crores in terms of test fees in the last two decades, but what is more important it has already developed a technology which can keep India free from the necessity of having to depend on outside help. In view of the limited size of the tank (154 m. long, 3.65 m wide, 2.13 m. deep) ships larger than 10,000-15,000 DWT capacity cannot be tested. The advent of large ships,

particularly for bulk cargo traffic, makes it necessary for India to have a large ship testing tank of its own. This can be achieved at a fraction of the cost it would take to set up the similar facility elsewhere because of the considerable infra-structure such as a marine propeller test section, highly developed instrumentation and digital data system existing at the CWPRS, and the highly experienced staff which has been specially trained in ship hydrodynamics. Furthermore there is a necessity of setting up a multi-purpose wave basin and manoeuvring basin to study the behaviour and manoeuvring characteristics of ships under varying conditions of currents and waves.

Pump Hydromechanics

The pressing needs of agriculture, industry and power generation have resulted in a very sharp increase in the demand for large and special pumps and related equipment. Thermal and nuclear power plants of 2000 MW capacity would be very common and would be served by large size pumps. Long distance pumping of water and oil and transport of ore or coal would also be very common in the near future. Special fluid pumps for use in chemical industries would have to be developed. The gigantic scheme of Ganga-Cauvery link, would involve pumping of ten to twenty thousand million cubic metres of water over very high lifts. Satisfactory functioning of pumps of such large size and special duty equipment depends upon careful designs evolved through experimental research investigations conducted in a laboratory. The CWPRS plans to set up soon a modern laboratory for hydraulic machinery research and thereby attempting to cover the present gap in the country in this field.

Hydraulic Structures Research

Complicated designs due to unusual site conditions, changes in design concepts, necessity of integrating conduit systems of two hydel projects and so on, result in a need for building structural model and for solving these problems by adopting three dimensional photo-elastic techniques. In such cases laws of scaling would also have to be evolved. A proper assessment of a stress distribution under dynamic conditions is needed. In certain cases full scale studies on prototype would be necessary. In addition considerable work would have

to be done to evolve techniques of mathematical modelling using finite element methods and to correlate the results with the physical model. In several cases field observations would be necessary to study static and dynamic response of the structures.

Applied Earth Sciences

As a result of the concerted efforts made in the post-independence era for exploitation of water resources for the needs of irrigation and hydro-power, the convenient sites for dams and other hydraulic structures have already been utilized. Greater innovation is therefore necessary in solving various problems posed by the more difficult sites now left. Recent failures of some of the dams, say in France and Italy, have highlighted the need of a comprehensive study of the behaviour of the rock mass. It is also necessary to ascertain that the design of structures is adequate for stresses caused by forces due to vibrations and earthquakes. Technique must also be evolved to reinforce the existing structures against such stresses. It is time that CWPRS undertakes research and development in these areas. Research would have to be conducted to evolve new techniques, to study new materials and to enter into new fields of investigations such as hydrogeology, isotope hydrology and seismic technology.

Pollution Studies

The quest for improving man's standard of living is ironically coupled with his struggle to survive the pollution generated by the same industrial revolution through which it is sought to improve the standard of living of mankind. The preservation of the environment is, therefore, one of the greatest needs of the day. This effort calls for a multi-disciplinary approach requiring the services of engineers, scientists, public health specialists, biologists etc.

The problems of pollution could arise due to various causes viz. thermal discharges, industrial and municipal effluents, oil pollution etc. Since in all these cases, the major aspect is the dispersion/diffusion of the effluent i.e. the hydraulics of mass and momentum transport, the study naturally falls within the scope and functions of the Research Station.

The super thermal power stations, which are planned

to meet energy needs, would release a large quantum of thermal energy into the environment. The means of safe disposal would vary with each location and detailed layout. The laws of modelling in cases of purely radiative heat loss or purely diffusive heat loss are well established. However in many instances the mechanism of heat loss is not so very distinct. Further the zone of development between the far and near fields from the outfall, is as yet not investigated fully, though it plays a dominant role in the dispersion process. The effects of waves is yet another factor which needs to be understood in the mechanism of heat loss.

Industrial and municipal effluents would find their way into natural water courses in increasing quantities in the years to come. Their proper disposal also calls for studies of the complex hydrodynamic processes.

Yet another area is the containment of oil pollution that arises due to accidental collision of ships or other causes. It is necessary to predict the rate of oil spread both in the mid ocean area as well as near the coastline taking into consideration the different parameters that influence the oil spread.

Air pollution problems can also be studied by applying the laws of fluid flow. It may be mentioned that due to lack of adequate pre-investment studies, the location for a major chemical factory was not permitted in a particular city, which would otherwise have helped the country from the points of view of economy and employment potential.

NEW FACILITIES

As stated earlier development of facilities at the CWPRS has been linked with the development plans of the country. Effort in the fifth and possible sixth Five Year Plan calls for creation of new facilities in the following areas :

Offshore Structures

With the increased activity in the field of offshore oil exploration, studies on offshore structures would gain greater and greater importance in coming years. This calls for sophisticated instrumentation for measurement of random wave forces, vibration and structural

research, added mass of complex body shapes, methods of floating and sinking the platforms taking into consideration the variable foundation conditions encountered.

Random Sea Wave Generation

Though the testing of marine structures and assessment of tranquility conditions in harbours have so far been conducted with monochromatic waves, experience from other laboratories has proved the necessity to simulate the random nature of the seas for realistic design criteria. With this objective in mind work has already been initiated in setting up a random sea wave generating facility at the Research Station, thanks to generous assistance from the UNDP as well as the Government of India. Three dimensional model basins should be provided and equipped with random sea facilities in order to examine the movement of ships in protected harbours.

Dredging Research Studies

The third and fourth Five Year Plans saw a major activity in the field of shipping and transport through the development of several major ports and harbours. The maintenance of these ports is to be undertaken by dredging, which for all the ports put together is roughly of the order of 40 million cubic metres per annum today at an approximate cost of Rs. 10 per cubic metre. Realising the importance of this, the Government has established a Dredging Corporation for taking care of dredging problems of various ports. The economy of dredging operations can be considerably improved through proper research on aspects such as design of dredge pumps, transportation of solid-liquid mixtures over long distances through pipelines, behaviour of different materials such as clay, silt etc. in the hopper as well as in reclamation areas, the pattern of dredging, disposal of dredged material to keep up with the environmental requirements etc. With this objective in mind it is proposed to initiate detailed studies on different aspects of dredging during the forthcoming period.

Bio-Fluidmechanics

The laws of fluid flow are applicable to the blood circulation system in living beings just as to an industrial network or a water supply system. The fruitful

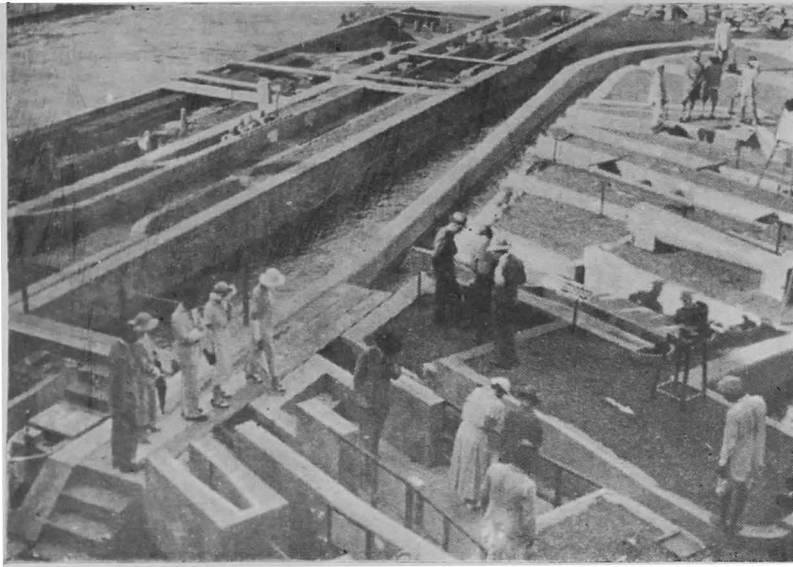
work initiated abroad has proved this possibility adequately. The concept of two phase flow, diffusion and flow through elastic pipes can be very usefully employed for studying the blood circulation and gastro-intestinal systems. To further serve the cause of research, analysis of the body-mechanism is proposed to achieve 'better health through technology'.

Design of Automatic Flood Forecasting System

An automatic flood forecasting system for any river basin has two essential components. First we require a working and proved model of the flood basin, which would accurately predict water levels as a function of time at various points along the river given the necessary inputs in terms of rainfall and river stage in the upstream reach. The second and equally vital component is the availability of accurate hydrometeorological data. Since the essence of the system is in the warning time given to the local population, it is apparent that the modern high speed digital computer is necessary to perform the task of data acquisition from remote sources, analysis of the same and integration with a physical, electronic analogue or mathematical model. The annual loss on account of floods in the country is averaged at nearly Rs. 100 crores, in addition to the toll of human life and consequent misery. It is proposed to set up an automatic flood forecasting system on a pilot basis on Narmada and Tapi catchments. Once the success of this system is established, it would be possible to extend such services to other important river basins. It is also proposed to consider coastal flooding as a result of storm surge which has resulted in disasters of tragic dimensions, such as in the Orissa cyclone of 1971.

Data Acquisition System

The coming era would call for rapid completion of studies involving intricate measurements for which sophisticated equipment would be necessary, besides a computer for the data processing. With the large number of parameters to be measured simultaneously both in the field and in the laboratory the need for providing suitable data acquisition systems and a computer for processing of the data is imperative. It is proposed to augment the existing facility in this regard to cater to the needs of the future.



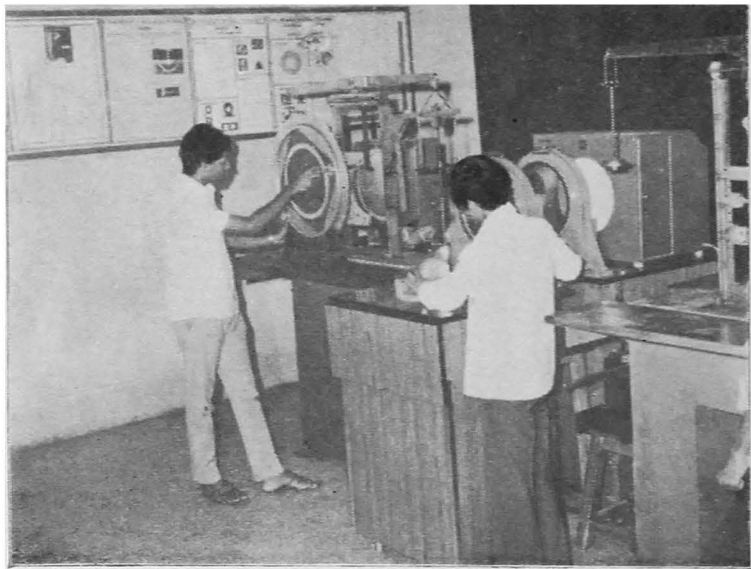
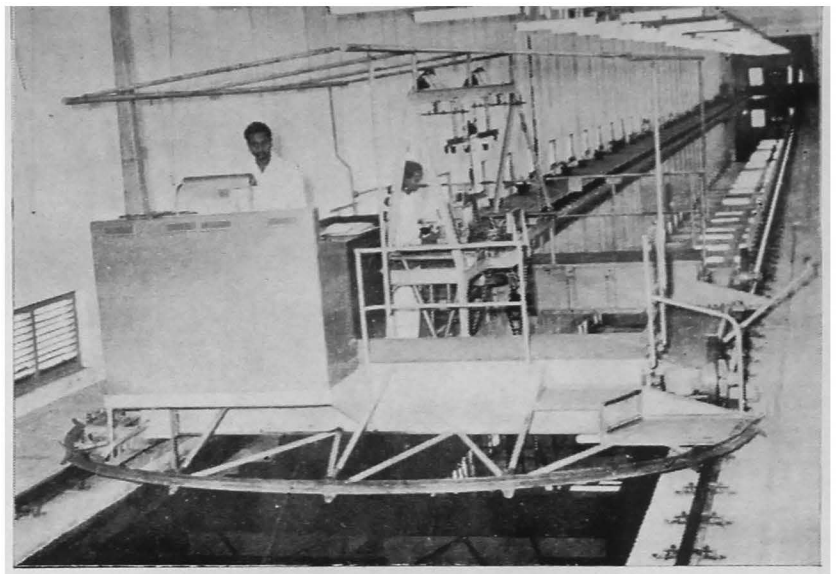
**Models Located Downstream
of Khadakwasla Dam**

**The Breach in the Khadakwasla Dam
(12th July 1961)**



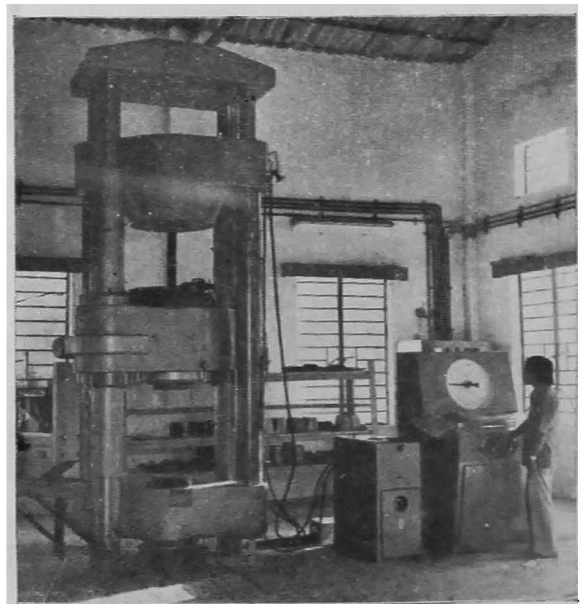
**Damage to the Models
after the Breach**

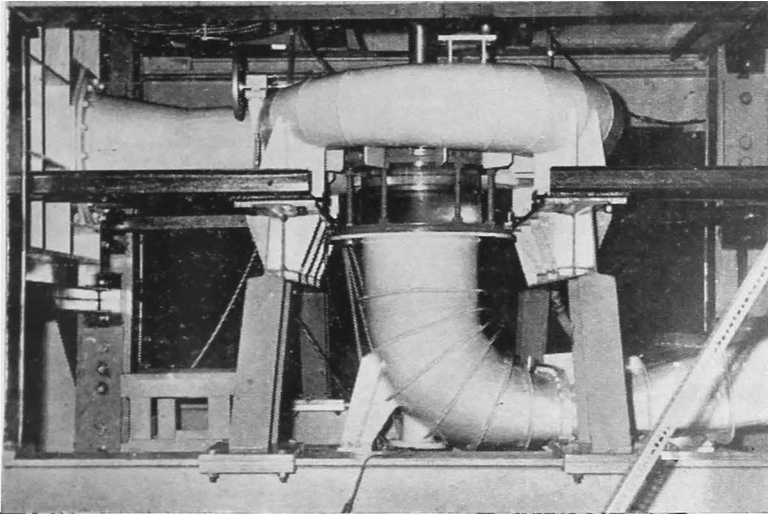
**Ship Testing and Currentmeter
Calibration Tank**



Photoelastic Laboratory

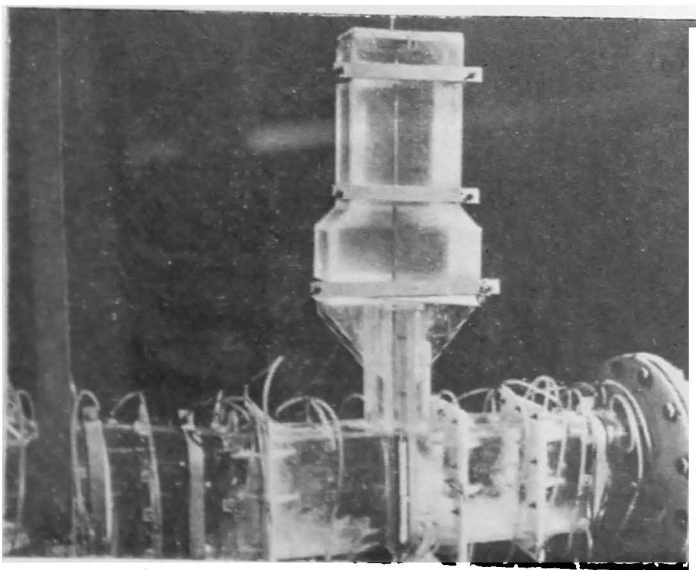
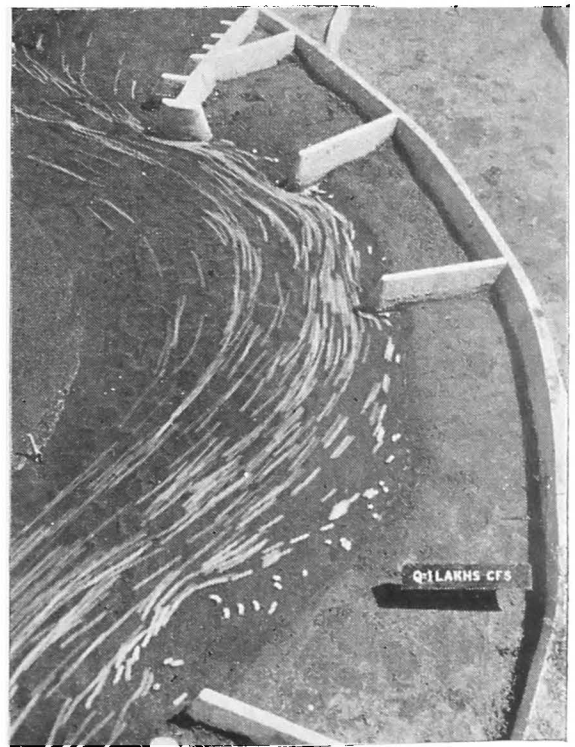
**Universal Testing Machine
300 Tonnes Capacity**



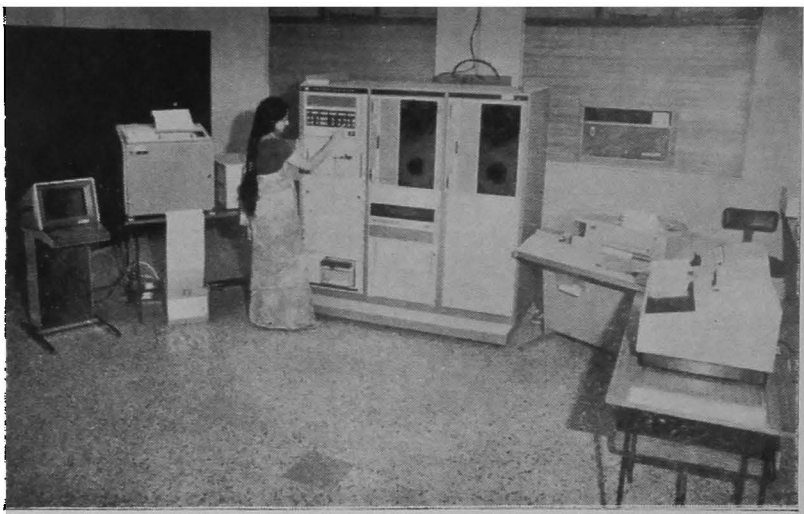


Test Assembly for Francis Turbine model at Cavitation Research Centre.

Flood Control Studies

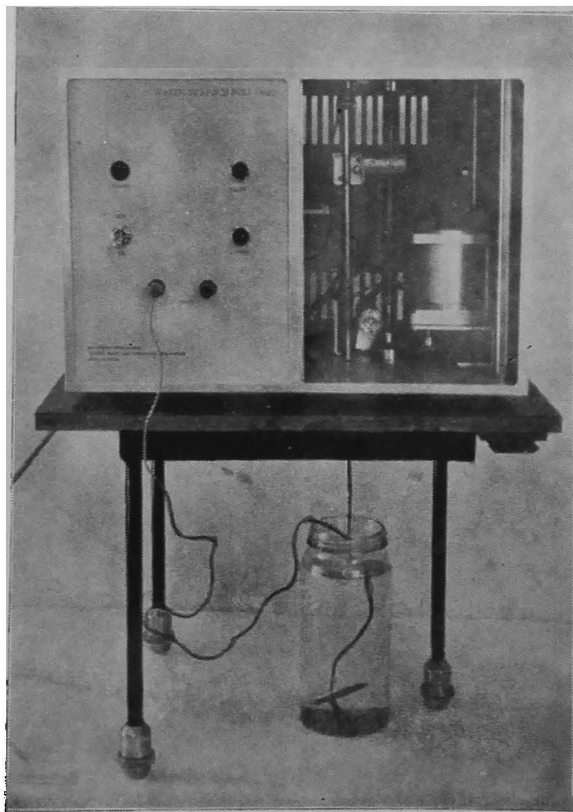


Gates and Valves Studies



HP - 2100 Mini Computer

**Launching of Dutch Wave
Rider Buoy for Coastal
Field Studies**



**Water Level Measuring
Equipment Developed at
Hydraulic Instrumentation
Centre**

Remote Sensing and Satellite Communication

In recent years a new concept in data gathering has been generated by using earth satellites. The satellites can be used to keep selected areas under observation almost continuously. India has entered the space age with the launching of the Aryabhata in 1975, and is proposing to launch another earth satellite called SEO (Satellite for Earth Observations) in early 1978. The primary objective of the SEO mission is "the conduct of earth observation experiments for obtaining scientific information of relevance to the areas of meteorology, hydrology and oceanography using satellite based sensors, evolving the methodology of retrieval and processing of such data using appropriate ground systems and generating user oriented data products for dissemination of such information." With the help of the on-board sensors of TV camera systems and microwave radio meters, it would be possible to generate data products by way of imageries and computer-compatible magnetic tapes. The CWPRS should participate in the mission as a potential user and utilise the techniques of remote sensing for the problems of coastal engineering, hydro-meteorology and flood forecasting. It would be necessary to acquire the equipment required for the interpretation of data and also to train personnel in this area.

Feasibility studies on the Development of Tidal Power

The beginning of the Fifth Five Year Plan can be really called the period of energy crisis. The failure of the monsoons (and thus of hydropower) in some recent years, the increasing problems of transportation of coal and the shooting up of oil prices, have focussed attention on the need to harness other sources of energy. The advantages of utilizing the tides for power generation are evident, being a perennial source, whose potential can be predicted in advance, which is not affected by the vagaries of nature and which causes no pollution. It is interesting to note that the assessment made by Prof. Wilson, UNDP Expert, indicates that the maximum exploitable power through tides can be as much as 40% of the present day installed capacity. Major advances have been made in the construction techniques and design of low head turbines, making tidal power more attractive. With a suitable combination of

the power output from tidal power stations with those of other power plants and multi-purpose planning to utilise the tidal barrier for location of harbours, recreational waterways and access roadways would make the project economically viable. This is a major study involving several disciplines, the expertise for all of which is available at CWPRS. Since the studies will be somewhat time consuming, an early start is necessary to equip ourselves for the future requirements.

Intensive mathematical modelling techniques using a high capacity digital computer would form a major study in this context. As rightly pointed out by Dr. Leendertse, an eminent mathematical modelling expert, the experience gained by CWPRS in undertaking these studies would stand the CWPRS in good stead by equipping its personnel with the necessary expertise to tackle similar problems, that may come up in future both in the country and abroad.

But for the foresight of the late Dr. Homi Bhabha, India would not have seen the pioneering work being carried out by the Atomic Energy Commission today, exemplifying the indigenous knowhow and capability of Indian scientists. His predictions in 1944 that "when nuclear energy has been successfully applied for power production in say a couple of decades from now, India will not have to look abroad for its experts but will find them ready at hand" has been amply borne out by facts. It may be mentioned that it is not too early to plan for tapping of tidal energy. Many other countries are also planning on similar lines.

INFRASTRUCTURE

In addition to new disciplines, thought has to be given to providing the necessary infrastructure as indicated below:

Instrumentation, Data Acquisition and Analysis

The up-dating of facilities in several disciplines and the creation of new areas of research calls for creation of matching facilities in measurements techniques and instrumentation, systems for data acquisition and data analysis and development of new instruments for laboratory and field studies. The CWPRS must therefore initiate development of new types of instruments

for measurement of various engineering and hydro-meteorological parameters in laboratory and field, and employ improved techniques so that the vast volume of data to be obtained by simultaneous measurement at several places can be transmitted to a central base and analysed by modern methods. We must develop systems to record various field parameters which can be installed in remote and temporarily inaccessible sites to record data unattended for brief periods in a computer compatible form.

Instruments based on new techniques and principles such as acoustic and electromagnetic current meters, infra-red sensors, hot wire/hot film sensors and laser based systems for measurement of velocity of water must be developed. Similarly instruments for accurate in situ measurement of salinity, temperature and depth must be developed.

Due emphasis also must be given on development of hydrological instruments as these form the basic data collecting elements for a typical flood forecasting system.

Data acquisition and analysis system must be developed for on-line and real time data acquisition and analysis of data. Such system would include development of serial and parallel techniques for data such as data transmission. Field instruments for collection of data logger using magnetic cassettes, cartridges and floppy discs must be developed.

Documentation Centre

It is important to provide modern documentation and library facilities consistent with the standing of the Research Station. Such facilities form an integral part of practically every laboratory abroad, serving scientists and engineers in their search for the latest information on the subject of their interest, and also in the dissemination of available knowledge.

Man Power Cell

One of the most important pre-requisites for implementing the ambitious programme as outlined above is to give adequate thought to the development of the man-power at CWPRS. While investment in equipment and facilities is important enough, the most

important investment is in our men. The CWPRS should therefore immediately attempt to create a Man Power Development Cell fully equipped to expose the research workers at the CWPRS to the men, material and techniques available in the rest of India. A new entrant to the CWPRS must undergo an intensive in-house training in special fields such as advanced mathematics, fluid mechanics and instrumentation, and have an extensive exposure to laboratories and scientific institutions working in identical fields in the country. Research Staff at senior levels should have facilities to undergo refresher courses. The CWPRS must be a training ground for research workers from all over India in new techniques and methodology. The staff at all levels must actively co-ordinate the laboratory studies with the field conditions.

R & D Management

A proper R & D Management of the Station is essential for optimum results in research. Besides individual efforts, the benefits that accrue from the concepts and ideas of a group of specialists greatly help in execution of the research programmes. With this aim, the concept of a group, wherein discussions on topics of common interests could be undertaken, needs to be introduced. Similarly the inter-disciplinary nature of the work calls for constant interchange of personnel between the different groups and greater participation in each other's activities. The selection and mode of operation of projects can be best done through the participation of the senior officers, whose experience and counsel would play a large part in the success of the programme. Above all, the need to give managerial training to senior officials cannot be underestimated.

Shedding of routine works

With the advance in technology and development of new disciplines, it should be expected that some of the routine disciplines, such as testing of strength of materials, design of concrete mixes, or routine analysis of breakwater design could be taken up by other upcoming laboratories. This policy has been implemented by the CWPRS in the past, and which not only helps in its own development, but also assists sister laboratories to develop themselves.

Inter Institutional Co-ordination

With the multi-disciplinary approach, it is only natural that the Research Station should maintain close co-ordination and contact with various other institutions. With the variety of problems being studied, the CWPRS is in fact already in close contact with institutions such as National Chemical Laboratory, National Institute of Oceanography, Bhabha Atomic Research Centre, I.I.T.s, Indian Institutes of Science, different institutes of technology and sister laboratories in different States. Constant exchange of ideas with these institutions has greatly promoted development of technology. The Central Board of Irrigation and Power and the Ministry of Transport and Shipping do sponsor schemes for basic and/or fundamental research at the CWPRS, providing opportunities of exploring areas related to basic research and at the same time having direct application to the projects. This needs to be further extended in co-operation with laboratories abroad.

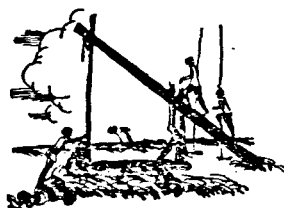
CONCLUDING REMARKS

The Central Water & Power Research Station has come a long way in the last sixty years from a small Irrigation Cell looking at the problems of a State, to the Premier National Institute in the area of water resources and one of the leading laboratories of the world. As one looks to the future a vista of new disciplines appears on the horizon beckoning to the engineers of the future. The expansion of a research institution, which has been so long in existence, is an interactive and iterative process – a process involving examination of not only the scientific and technological efforts

required to move into the new disciplines, but for maximising return from existing investments and achieving self-reliance. It is accordingly necessary for the CWPRS to shed traditional disciplines and move into new areas that belong truly to the future.

We have further to ask ourselves whether the balance between basic and applied research as it exists today is correct. Dealing with problems of engineering, it has been inherent in the organisational set-up, that specific research pertaining to individual projects should claim priority over long-term goals. The allocation of priorities involves a question of delicate balance between short term and long term considerations. The short-term approach is based on current data and understanding: a long term programme of basic and basic-oriented research is aimed not at immediate applications but at keeping fully abreast of developments in international science and technology. It is necessary that we should inculcate among our scientific workers a sense of purpose both towards immediate applied goals as well as towards the future needs of the country, looking as far ahead as the turn of century. A general introspection in this regard would reveal that basic-oriented research would have to be given greater priority, so that the organisation could equip itself to meet the challenges of the future.

The woods of the future are indeed lovely and deep and at this stage it is appropriate to pledge our renewed efforts towards keeping our promises with the future.



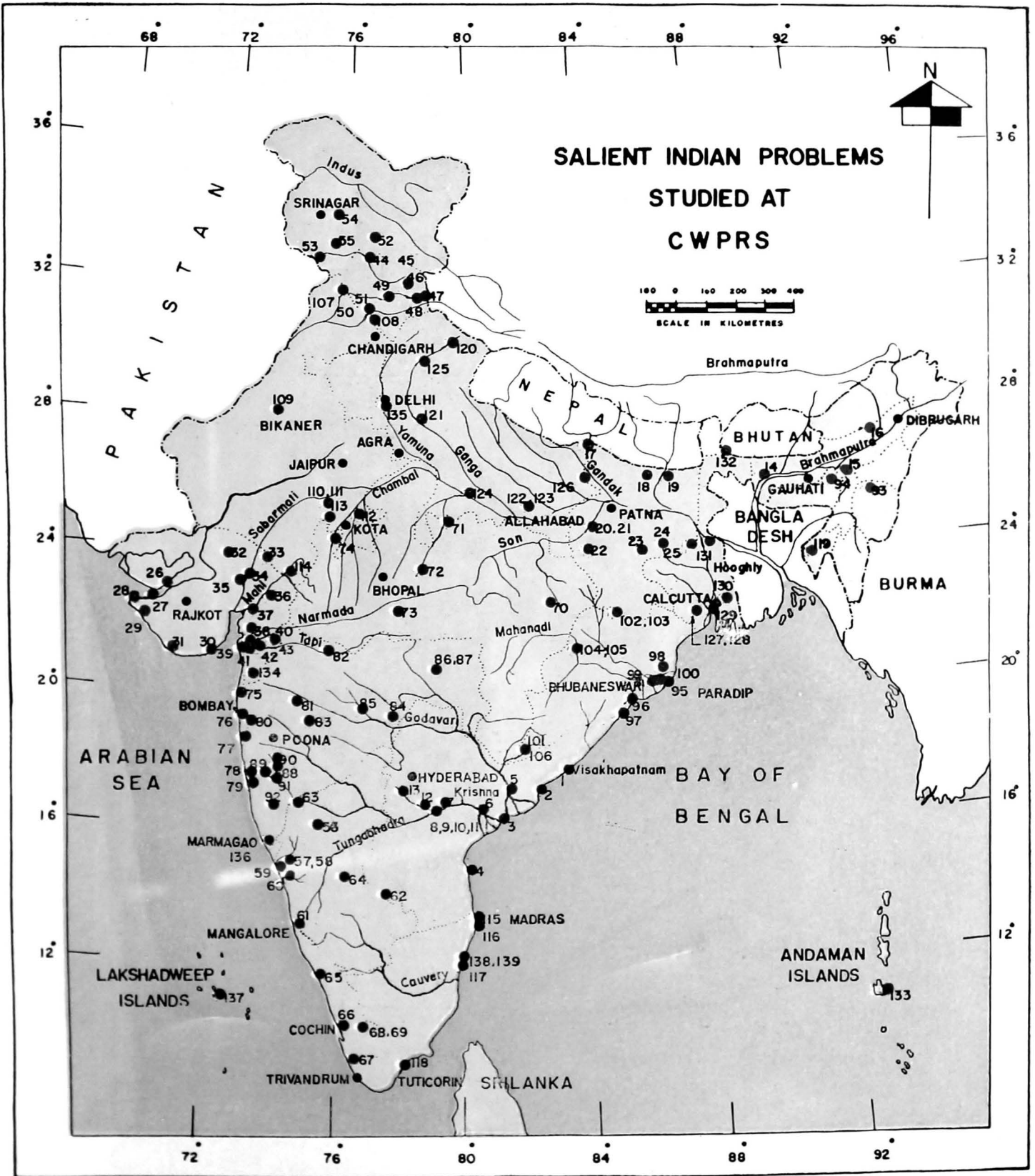
Important Events in the Life of CWPRS

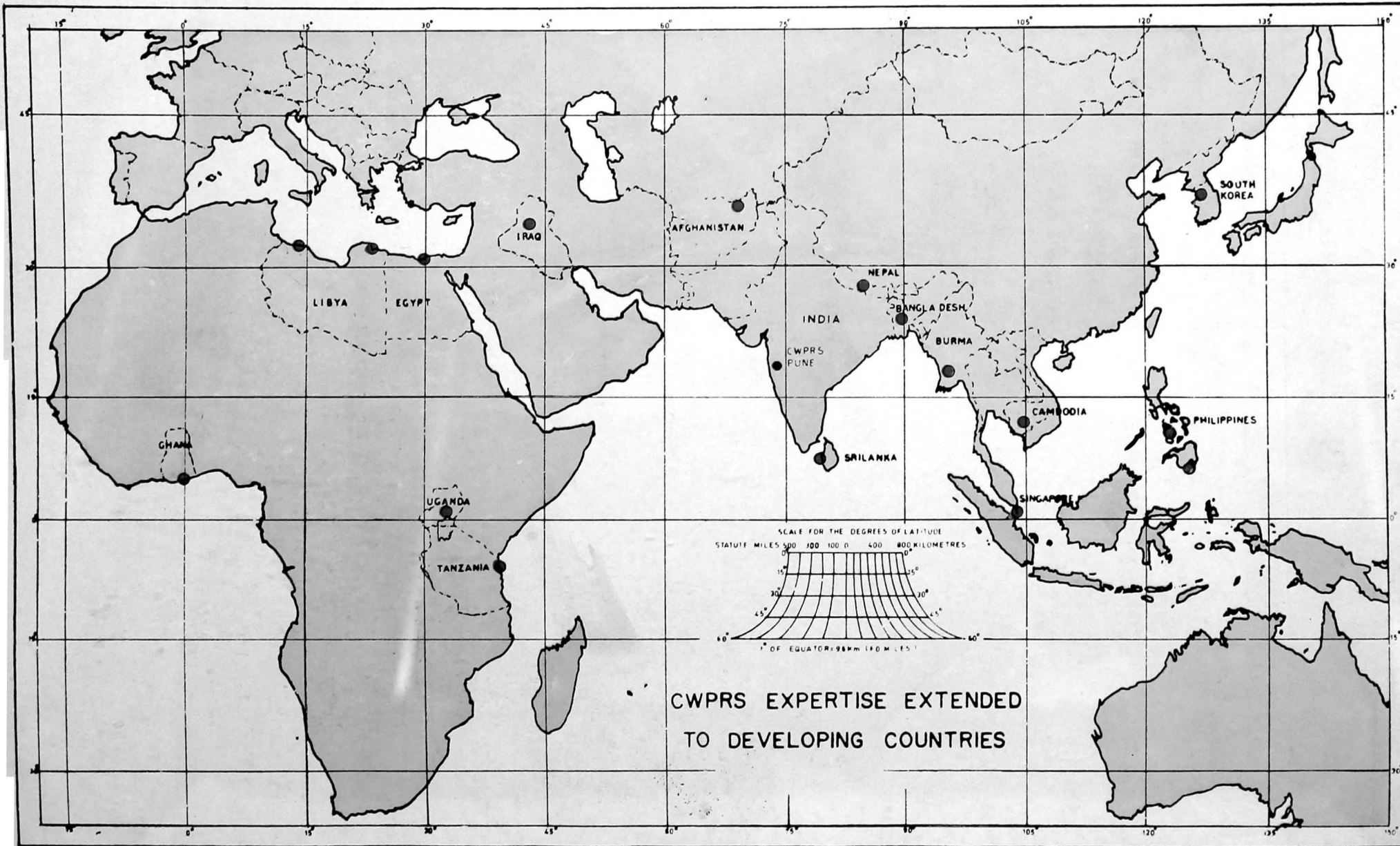
- 1916 Creation of "Special Irrigation Division" within the P. W. D. of the Bombay Presidency.
- 1920 The Special Irrigation Division was located at Hadapsar near Pune.
- 1928 The Research Station was renamed 'Hydrodynamic Research Station'
- 1934 Shifting of the Research Station to Khadakwasla Started in 1925 was completed.
- 1937 The Research Station taken over by the Government of India. Its name changed to 'Central Irrigation and Hydrodynamic Research Station' Problems outside the Bombay Presidency investigated-Studies on Ganga at Hardinge Bridge.
- 1942 The Research Station was made permanent on the recommendations of the CBI.
- 1944 The Research Station was named 'Indian Waterways Experiment Station'
- 1945 Sir Claude Inglis retired as Director of the Research Station and Shri K. K. Framji took over.
- 1947 Re-organization and expansion of the Research Station. Eight new Divisions were created viz. (1) River and Canal Hydraulics, (2) Navigation, (3) Concrete and Materials of Construction, (4) Soils and Soil Mechanics, (5) Mathematics, (6) Statistics, (7) Physics and (8) Chemistry.
- 1948 Shri D. V. Joglekar took over as Director.
- 1950 The Research Station investigated its first problem outside India-viz. Sand Exclusion at Kabo Headworks across Mu river in Burma.
- 1951 The Research Station was named 'Central Water and Power Research Station'
- 1952 Construction of first Wave Flume.
- 1953 Creation of Ship Hydrodynamics Division and Photoelastic Division.
United Nations Aid for Photoelastic Laboratory and Ship Testing Tank.
- 1954 Dr. Rajendra Prasad, the President of India, visited the Research Station (18-11-1954)
Dr. Radhakrishnan, the Vice President of India, visited the Research Station (10-1-1954)
Commissioning of the Internal telephone facility of 25 local lines within the Research Station.
- 1955 Shri Jawaharlal Nehru, the Prime Minister of India, inaugurated the Ship Testing Tank.
- Shri D. V. Joglekar, was awarded 'Padmashree' by the President of India (7th June)
- Visit of Mr. Nikolai Bulganin, the Prime Minister of USSR and Mr. Nikita Khrushchev, the First Secretary of Communist Party of USSR (22-11-1955)
- Commissioning of 11 kv. power supply to the Research Station.
- 1956 Visit of Mr. Chou En-lai, the Prime Minister of People's Republic of China (2-12-56)
Visit of Sir Claude C. Inglis, Director Hydraulic Research Station, Wallingford, UK.
Construction of C, H, and G type quarters at Khadakwasla. Publication of "Manual on River Behaviour, Control and Training" (CBIP publication No. 60)
- 1957 Visit of Dr. A. N. Khosla, Vice-Chancellor of the University of Roorkee (First Chairman of the CWPC, New Delhi)
Shri M. G. Hiranandani, Director-designate, visited various laboratories in USA, UK, and France. Shri D. V. Joglekar retired as the Director of the Research Station. Shri M. G. Hiranandani took over.
- 1958 Setting up of High Head Structures, Instrumentation and Tidal Hydraulics Divisions.
- 1959 Formation of Geophysics Division.
First Refresher Course in Hydraulics was organised.
- 1959 First Radio-active Tracer Studies were carried for Bombay Harbour (March 1959)
Dr. E. V. Telfer, UNESCO Expert, on 4 month's assignment for Ship Model Testing Studies.
- 1960 Launching of a fully-equipped Cavitation Laboratory with the United Nations Aid. First Technical Memorandum on "Use of Radio-Active Tracer Studies for Sediment Movement of Bombay Harbour" published.
Publication of "Stream Gauging Manual"
- 1961 Second Reorganization of CWPRS. Elevation of the post of the Director of the Research Station to Chief Engineer. Breach of Panshet and Khadakwasla dams on 12th July 1961. About $1\frac{1}{2}$ hectares of CWPRS area suffered complete damage.

- 1962 Shri Hiranandani handed over charge as Director to Shri S. C. Desai (4-1-62).
Dr. B. C. Deb went to Egypt as an expert, in Soil Chemistry.
Instrumentation Laboratory Building completed.
Recirculating system for compartment Nos. 7 to 12 completed.
- 1963 Shri C. V. Gole took over charge as Director. King Mahendra of Nepal visited the station. Formation of seven new divisions viz. Earthquake Engineering Research, Rock Mechanics, Model Engineering, Cavitation, Hydraulic Analysis and Prototype Testing, Computer and Central Cell.
- 1964 Completion of laboratory-cum-office building at Khadakwasla.
- 1965 Sixteenth North Zonal Meeting of the CBIP held at the Research Station (March 65).
Central Workshop shifted to its new building.
Shifting of Pune laboratories and Office to Khadakwasla completed. Completion of Cavitation Research Building.
- 1966 CWPRS celebrated Golden Jubilee from 23 to 25th January.
Symposia on 'Model and Prototype Conformity' and 'Modern Trends in Hydraulic Engineering' were organised on this occasion.
Publication of 'Hydraulics of Stable Channel' Post-graduate Diploma course in Dock and Harbour Engineering conducted in May 66.
- 1967 The first refresher course in Coastal Engineering conducted (24-5-67 to 3-6-67).
- 1968 Commissioning of Cavitation Research Centre.
- 1969 Construction of New Wave Flume with diffraction basin.
Extension of Ship Model Testing Tank by 76.5 m.
Visit of Staff Inspection Unit of Ministry of Finance (March to June 69)
- 1970 Formation of five new Divisions viz. Calibration, Gates and Vales, Maritime Structures, Bridge Engineering, and Rating Tank.
UNDP Mission visited CWPRS to survey the proposals submitted by CWPRS for UNDP Aid (28-1-70 to 4-2-70)
- J. C. Lebreton and M. Remillieux visited on behalf of ECAFE to evaluate capabilities of CWPRS (9-4-70 to 10-4-70)
CWPRS was recognised by UN as its regional laboratory for ECAFE region.
Construction of Rating Tank for currentmeters.
- 1971 Formation of Watershed Studies Division.
Launching of UNDP Project of "Coastal Engineering Research Centre and Hydraulic Instrumentation Centre."
Initiation of Studies for the Port of Singapore.
- 1972 Mr. Goh Keng Swee, Defence Minister of Singapore visited the Research Station (27-12-72)
- 1973 Courses in "Coastal Engineering" and "Digital Data Acquisition system" Conducted under the joint auspices of UNDP and Government of India.
- 1974 Shri C. V. Gole handed over charge as Director. Shri P. C. Saxena took over charge as Director. Shri Fakhruddin Ali Ahmed, President of India visited CWPRS (21-9-74)
Building of Coastal Engineering Research Centre completed.
- 1975 Third UNDP/GOI course in "Hydraulic Dredging" conducted from 30-12-74 to 11-1-75
Commissioning of the Mini-computer HP-2100-S
First "Open House Day" organized on 30-10-75.
- 1976 International Courses under the auspices of UNDP/GOI were conducted on:
- (i) Acquisition and Transmission of Hydrological and Oceanographic Data, January 1976.
 - (ii) Magnitudes and Effects of Vibration on Hydraulic Structures including Measurements of Vibrations, Feb. 1976.
 - (iii) Control of Hydraulic Models March, 1976.
 - (iv) Environmental Aspects of Coastal Engineering, May-June 1976.
- Appointment of High Level Review Committee by the Government of India under the Chairmanship of Dr. Swaminathan, Director-General of ICAR to review the organization of CWPRS.
Diamond Jubilee Celebrations of CWPRS (29-11-76 and 30-11-76) and Symposium on "Modelling Techniques in Hydraulic Engineering"

SALIENT INDIAN PROBLEMS STUDIED AT CWPRS

- 1 Visakhapatnam Harbour.
- 2 Kakinada Port.
- 3 Masulipatnam Fisheries Harbour.
- 4 Krishnapatnam Harbour.
- 5 Godavari Anicut.
- 6 Krishna Anicut, Vijaywada.
- 7 Nagarjun Sagar project.
- 8 Srisaïlam Tunnel - Geophysical Studies.
- 9 Srisaïlam Reservoir - Flood routing studies.
- 10 Srisaïlam Tunnel - Photoelastic Studies.
- 11 Srisaïlam Dam - Foundation Investigations.
- 12 Krishna River - Railway Bridge below Almatti Dam.
- 13 Kolsagar Dam project.
- 14 Protection of Dhubri town and Kokilmukha area from river Brahmaputra.
- 15 Weir across river Jamuna.
- 16 River training of Dikrong river.
- 17 Gandak Barrage.
- 18 Road Bridge on river Kamala-Balan.
- 19 Protection to flood embankments on Kosi.
- 20 Sone Barrage electrical analogy investigation.
- 21 Sone Barrage project.
- 22 North Koel Dam project.
- 23 Konar project.
- 24 Tenughat Dam.
- 25 Mayurakshi Reservoir - Wave height recording.
- 26 Kandla Port
- 27 Salaya Harbour - Oil Terminal.
- 28 Okha Port.
- 29 Porbandar Port.
- 30 Pipavav Port.
- 31 Veraval Port.
- 32 Saraswati Barrage.
- 33 Panam Dam project.
- 34 Sabarmati river at Ahmedabad.
- 35 Dharoi Dam project.
- 36 Kadana Dam project.
- 37 Dhuvaran (Thermal power).
- 38 Narmada river at Broach.
- 39 Hajira Port.
- 40 Protection of Rardon town (Surat) against erosion by river Tapi.
- 41 Railway Bridge on river Poorna, at Surat.
- 42 Tapi river flood embankment.
- 43 Tapi basin flood routing.
- 44 Baira Siul Hydel project - Sediment exclusion of Siul weir.
- 45 Baira Siul Hydel project - Under sluice tunnel.
- 46 Shanan Hydel project - Sediment exclusion of Uhl weir.
- 47 Pandoh spillway.
- 48 Dehar surge shaft.
- 49 Beas project (Pandoh Baggi Intake structure).
- 50 Bhakra dam - Photoelastic Studies.
- 51 Bhakra dam - Earthquake Engineering Studies.
- 52 Ravi canal project, Ujh river.
- 53 Salal Hydro electric project.
- 54 Chenani Hydro electric project.
- 55 Ganderbal Hydel channel.
- 56 Hidkal Dam project.
- 57 Kalinadi Hydro electric project.
- 58 Kalinadi Hydro electric project - Geophysical Studies.
- 59 Karwar port.
- 60 Sharawati river.
- 61 Port of New Mangalore.
- 62 Narayanpur Dam.
- 63 Civil Aerodrome, Bijapur.
- 64 Tungabhadra Dam.
- 65 Bepore Harbour.
- 66 Cochin port.
- 67 Neendakara Harbour.
- 68 Iddikki Dam project - Foundation Investigations.
- 69 Iddikki Dam project - Earthquake Engineering Studies.
- 70 Hasdo Barrage on Hasdo river.
- 71 Matalia reservoir - wave height recording.
- 72 Borna Dam project.
- 73 Tawa Dam project.
- 74 Gandhi Sagar Dam.
- 75 Satpati fishing Harbour.
- 76 Bombay Port.
- 77 Murud Janjira Port complex.
- 78 Bhagawati Bundar, Ratnagiri.
- 79 Ratnagiri, Coastal Erosion.





CWPRS EXPERTISE EXTENDED
TO DEVELOPING COUNTRIES

- | | | | |
|-----|--|-----|---|
| 80 | Thana Creek Bridge. | 111 | Chambal cooling water studies. |
| 81 | Bhatsa Dam. | 112 | Kalisindh Weir. |
| 82 | Bhusawal Power House pumping station. | 113 | Jawahar sagar Dam. |
| 83 | Mula Dam. | 114 | Mahibajaj sagar Dam. |
| 84 | Veer Dam-Spillway pier. | 115 | Madras Outer Harbour. |
| 85 | Jayakwadi project. | 116 | Ennore Thermal Power project. |
| 86 | Koradi Thermal Power project. | 117 | Cuddalore Harbour. |
| 87 | Koradi Thermal Power project - Earthquake engineering studies. | 118 | Port of New Tuticorin. |
| 88 | Bhatgar Dam. | 119 | Tripura project. |
| 89 | Koyna Dam. | 120 | Obra Thermal Power Project. |
| 90 | Kolkewadi Dam. | 121 | Narora Atomic Power project, |
| 91 | Protection of Bridge at Karad. | 122 | Scour around bridge pier at Allahabad on Ganga. |
| 92 | Malaprabha Dam project. | 123 | Ganga Bridge at Allahabad. |
| 93 | Manipur river channel. | 124 | Yamuna river - Railway Bridge at Hamirpur. |
| 94 | Kopili river. | 125 | Ramaganga project. |
| 95 | Paradip Port. | 126 | Training of river Gogra. |
| 96 | Chilka Lake. | 127 | Road Bridge on river Rupnarayan near Kolaghat. |
| 97 | Gopalpur Harbour. | 128 | Railway Bridge on Rupnarayan. |
| 98 | Jabra Weir on Brahmani river. | 129 | Hooghly river Calcutta Port. |
| 99 | Weir across Mahanadi at Mundali | 130 | Noamemdi Iron mines Baitarni river. |
| 100 | Studies regarding breach on river Katjuri | 131 | Farakka Barrage. |
| 101 | Balimela Dam. | 132 | Road protection near Sikkim. |
| 102 | Rourkela Dam. | 133 | Hut bay at Little Andaman. |
| 103 | Brahmani river at Rourkela - Silt problem. | 134 | Pipvia Dam project. |
| 104 | Hirakud Dam. | 135 | Training of river Yamuna, Delhi. |
| 105 | Hirakud Dam reservoir-Wave height recording. | 136 | Port of Mormugao. |
| 106 | Balimala Dam. | 137 | Kavaratti Harbour. |
| 107 | Beas dam project. | 138 | Pondicherry Harbour. |
| 108 | Nangal Dam. | 139 | Bridge on river Chunnambar. |
| 109 | Bikaner Lift Irrigation. | | |
| 110 | Rajasthan Atomic Power Project. | | |

**CENTRAL WATER AND POWER RESEARCH STATION
EXPERTISE EXTENDED TO DEVELOPING COUNTRIES**

(A) SPECIFIC PROBLEMS

1. Burma	Kabo Headworks - Mu River	1950
2. Nepal	Trisuli Barrage Project	1962-74
3. Cambodia	Tonle Sap Barrage Project (Mekong River)	1964-65
4. Sri Lanka	Planning of Hydraulic Research Station	1967-69
5. Singapore	Development of various port facilities at Singapore	Since 1971
6. Afghanistan	Khanabad Barrage Project	Since 1974
7. Iraq	Planning of Water Research Centre at Baghdad	Since 1976

(B) EXPERTISE

1. Egypt	UN Expert on behalf of FAO in Soil Chemistry (Dr. B. C. Deb)	1962-63
2. South Korea	UN Expert on behalf of FAO in Soil Chemistry (Dr. B. C. Deb)	1965-69
3. Sri Lanka	Expert on behalf of Colombo Plan for Planning of Hydraulic Research Station for Sri Lanka (Shri S. C. Desai)	1967
	Expert on behalf of Colombo Plan for the Hydraulic Research Station for Sri Lanka (Sri P. M. Damle)	1968-69
4. Singapore	Visit on behalf of Port of Singapore Authority for inspection and advice on port development proposals (Shri C. V. Gole, Dr. Z. S. Tarapore)	1971-73
5. Uganda	UN Assignment on behalf of W. M. O. as Laboratory Technician (Dr. S. P. Chadha)	1971-73
6. Philippines	UNDP Fact Finding Mission on siltation of Pulupandan Port Philippines (Shri C. V. Gole, and Dr. Z. S. Tarapore)	1972
7. Bangla Desh	On behalf of Indo-Bangla Desh Joint River Commission. Inspection and advice on Intake of Ganges Kobadak Project and erosion problem of Sirajganj Town on river Brahmaputra (Shri C. V. Gole, and Shri N. V. Prahlad)	1973
8. Zanzibar	Membership of the Govt. of India team deputed for studying 'Development of Ports of Zanzibar and Pemba and Modernization of Navigational Aids' (Shri C. V. Gole)	1973
9. Iraq	Expert to the Directorate General of Drainage, Govt. of Iraq (Shri K. G. Das)	1973 onwards
10. Libya	Inter-Governmental Technical Co-operative Scheme -Services lent as University Asstt. Professor (Dr. K. N. Katyal)	1973 onwards
11. Philippines	Expert on behalf of WAPCOS* for Mindanao Irrigation Project - Coastal Aspects of Tago River Irrigation Project. (Dr. Z. S. Tarapore)	1976
12. Afghanistan	Expert on behalf of WAPCOS* for Khanabad Irrigation Project. (Dr. S. V. Chitale)	1976
13. Iraq -	Experts on behalf of WAPCOS* for setting up of Water Research Centre at Baghdad (Shri P. C. Saxena, Dr. S. V. Chitale, Shri S. L. Mokhashi)	1976
14. Egypt	UNDP Expert as Consultant (Instrumentation) (Shri P. C. Saxena).	1976

* WAPCOS stands for "Water and Power Development Consultancy Services (India) Ltd." - a semi-Govt. Consultancy Organisation.

Section II

An Appraisal of Irrigation and Water Resources Development in India

Y. K. MURTHY*

Introduction

INDIA is predominantly an agricultural country and over 70% of the population depend on agriculture for livelihood. But the success of agriculture depends on the timely onset of monsoon and its distribution over the crop period. Most of the rainfall in the country is received during the south-west monsoon period of three to four months. There is also considerable variation from region to region, and from year to year, in the onset and withdrawal of monsoon and its distribution. About a third of the country receives a rainfall of less than 75 cm while another 30% of the area receives a rainfall of 75 cm to 100 cm. Only about 31% of the cropped area in the country gets a good rainfall of more than 115 cm. A notable feature of annual variations in the rainfall is that regions with good rainfall like Western Ghats and Assam experience a low variation ranging from 20 to 30%, whereas the low rainfall regions like Peninsular India have to face the consequences of much larger variation of 80% and above. Thus, while irrigation is necessary largely for multiple cropping in high rainfall areas, the low rainfall regions may require irrigation facilities even for an assured single crop. The development of water resources for irrigation has thus been a necessity for assured agriculture, and measures have been taken continuously to develop water resources for this purpose.

While irrigation provides the basic means for increasing agricultural output, power provides sinew for

industrial development and lift irrigation. The country is endowed with a vast potential of hydropower resources and the tapping of this potential has been taken up on a large scale in recent years. Though the development of water resources has been mostly for irrigation (96%) and to a small extent for hydropower, there has been some use for other purposes like domestic and livestock use, industries and cooling water for thermal power generation.

Water Resources and Irrigation Potential

Present estimates indicate that the gross flow (average annual flow) in the rivers is about 178 m. ha. m. The subsequent table indicates the gross flow, utilisable flow and the approximate present utilisation in different river basin groups, as estimated at present.

Owing to limitations of topography, physiography, geology, dependability, present stage of technology etc., less than 40% of the average annual flow is considered utilisable. The limitations are particularly pronounced in the case of Brahmaputra basin and the basins of west flowing rivers south of Tapi. Though these two groups of basins account for almost 43% of the average annual flow in the rivers in the country, they contribute towards less than 8% of the utilisable flow. With the advance of technology, the quantity of utilisable flow is likely to undergo an upward revision.

Preliminary estimates of ground water indicate that its potential is of the order of 27 m. ha. m. With the

* Chairman, Central Water Commission
Ex. Officio Secretary to the Government of India.

(In million hectare metres)

Name	Average annual flow	Utilisable flow	Approximate utilisation (1974)
1. Indus basin	7.7	4.6	3.7
2. Ganga basin	51.0	25.0	8.5
3. Brahmaputra basin (including Barak)	54.0	2.4	0.5
4. Mahanadi and other east flowing rivers upto Godavari	12.3	9.1	2.8
5. Godavari, Krishna and other east flowing southern rivers	22.5	19.0	7.3
6. West flowing rivers south of Tapi	21.8	3.0	1.1
7. Narmada and Tapi	6.2	4.9	0.6
8. West flowing rivers north of Narmada	2.5	2.0	0.5
	<u>178.0</u>	<u>70.0</u>	<u>25.0</u>

advance of technology and development of water resources, ground water potential is also likely to undergo an upward revision. Recently, the National Commission on Agriculture has reported that this may go up to 35 m. ha. m. About 11 m. ha. m. of ground water are estimated to be used presently (1974) for irrigation and about 2 m. ha. m. for other uses.

According to the broad assessments the possible irrigation eventually in the country will be as follows :

Groundwater	35 m. ha.
Small (minor) surface water schemes	15 m. ha.
Major and medium surface water schemes	57 m. ha.
	<u>107 m. ha</u>

This indicates that eventually 50% of the cropped area in the country is likely to get irrigation benefits.

Irrigation Development before Independence

The dependence of the country on agriculture for its major source of livelihood and the unreliable nature of monsoons have been responsible for the development of irrigation works since time immemorial. The early works included inundation canals, tanks and dugwells. Some of the old irrigation works like the Cauvery Anicut (2nd Century A. D.) are still in use with considerable alterations and additions. There was considerable activity for development of irrigation in the medieval and later periods as well. During the early part of the British rule, a number of old irrigation works which had gone into disrepair were restored for efficient operation.

Towards the middle of the last century a number of large irrigation works were taken up in different parts of the country, the most conspicuous of them being the Upper Ganga Canal. At the time of its construction in 1836-54 the canal, taking off from the Ganga at Hardwar, was the largest irrigation canal in the world. The Upper Bari Doab Canal taking off from the Ravi, in the Punjab, and the Krishna and Godavari Delta systems in Andhra Pradesh were also constructed about the same period. Sirhind Canal taking off from the Sutlej in the Punjab, was constructed during the latter half of the nineteenth century and this was the largest irrigation system brought into being at that time.

With the construction of Khadakwasla dam (1869-79) the country entered into the new field of building of comparatively large masonry dams. The Periyar dam in Kerala, which diverts the water of the west-flowing river to adjacent areas in Tamil Nadu, is a product of this period and is a fine example of engineering skill and inter-state co-operation.

During the first quarter of the twentieth century, a number of important irrigation works were taken up in the country, the notable ones being the Tribeni Canal in Bihar, Pravara, Godavari and Nira Canals in Maharashtra, the Sarda Canal in Uttar Pradesh, the Gang (Bikaner) Canal in Rajasthan and the Mahanadi Canals in Madhya Pradesh. The twenties and thirties witnessed the emergence of three major reservoirs in Southern India namely, the Nizamsagar in Andhra Pradesh, the Krishnarajasagar in Karnataka and the Mettur reservoir in Tamil Nadu.

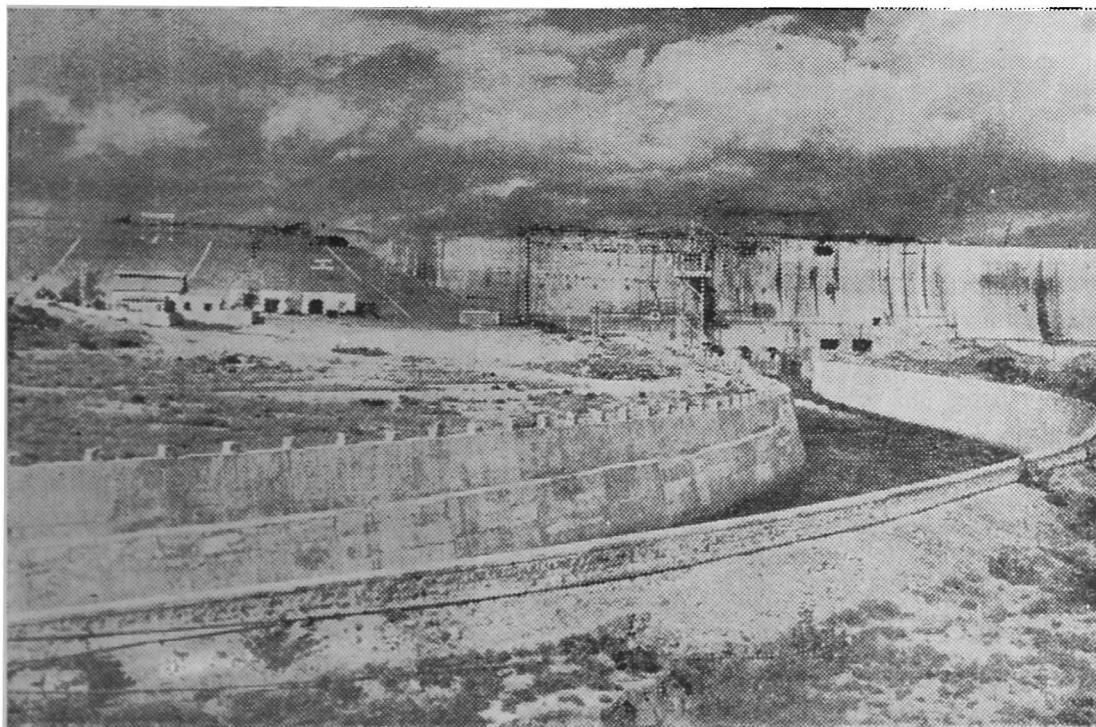
The development of irrigation facilities over the ages, and on a sustained scale during the British period, has resulted in the creation of a large network of irrigation works in many parts of the country. At the time of Independence, irrigation facilities were available to a net area of 19.4 m.ha., which corresponded to a fifth of the net sown area at that time. About a third of the irrigation at that time was from Government Canals, while over a fourth of the area irrigated was by shallow wells. Tanks accounted for another sixth of the irrigated area at that time.

Irrigation Development after Independence

Owing to the Partition at the time of Independence, nearly a third of the irrigated area went over to Pakistan alongwith a population of 18%. In the years

(Bihar), Chambal (Madhya Pradesh and Rajasthan), Matatila (Uttar Pradesh), Lower Bhawani (Tamil Nadu) and Mayurakshi (West Bengal). These schemes were incorporated into the First Five Year Plan which commenced in 1951.

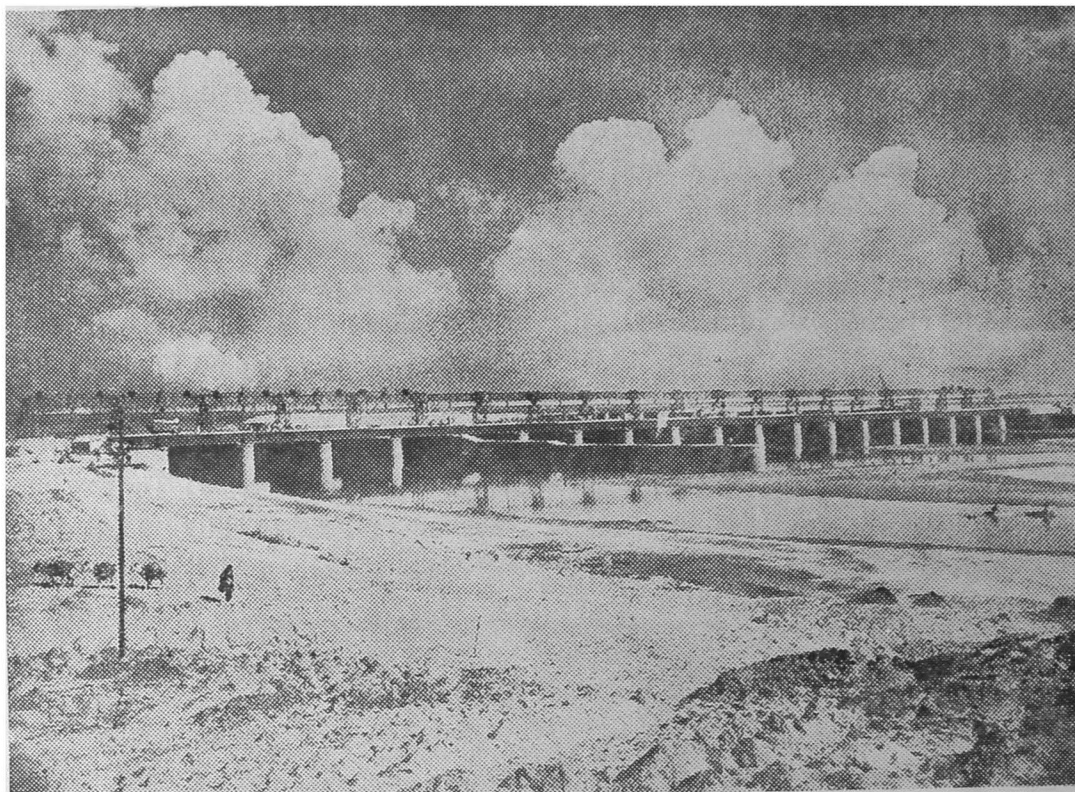
During the Second Five Year Plan, in addition to work on schemes already taken up, a number of new schemes were also launched, which included Rajasthan Canal Stage I (Rajasthan), Gandak (Bihar and Uttar Pradesh), Tawa (Madhya Pradesh), Ramganga (Uttar Pradesh), Parambikulam Aliyar Project (Tamil Nadu), Ukai Project (Gujarat), Mahanadi Delta (Orissa) and Kangsabati (West Bengal). The new important schemes taken up during the Third Five Year Plan included Beas (Punjab, Haryana and Rajasthan), Malaprabha and



The Jawahar Canal taking off from Nagarjunsagar Dam, Andhra Pradesh

immediately preceding Independence development of new irrigation facilities had also been slow owing to the Second World War. The country was facing a severe food shortage soon after Independence and much attention was paid to irrigation to increase agricultural production. A number of new projects were taken up in the late forties and early fifties including Bhakra (Punjab), Tungbhadra (Andhra Pradesh and Karnataka), Hirakud (Orissa), Damodar Valley (Bihar and West Bengal), Nagarjunsagar (Andhra Pradesh), Kosi

Upper Krishna in Karnataka, Pochampad (Andhra Pradesh) and Jayakwadi Stage I (Maharashtra). During the period of Annual Plans that followed (1966-69) the most important project taken up is the Sardar Sahayak in Uttar Pradesh, while the important schemes taken up in the Fourth Plan include Tehri Dam (Uttar Pradesh), Rengali dam (Orissa), Mahi Bajajisagar (Gujarat and Rajasthan) and Rajasthan Canal Stage II (Rajasthan).



A View of Sarda Barrage (Sarda Sahayak Project.)

Since the inception of planned development in 1951, 612 major and medium irrigation projects were taken up for implementation upto the end of the Fourth Plan (1973-74). Out of these, 382 schemes were completed and the balance comprising 75 major and 155 medium schemes spilled over into the Fifth Plan. Upto 1975-76, in all, over 750 major and medium schemes were taken up, out of which over 400 have been completed. Besides the above, a large number of minor schemes (costing less than Rs. 25 lakhs) such as shallow and deep tubewells; dugwells, small diversion schemes and tanks were also taken up. As a result of the massive programme for increasing the irrigation facilities, the irrigation potential which was 22.6 m. ha. in 1951 has risen to about 46 m. ha. in 1974-76 an increase of over 100%. The table on page no. 5 indicates the development of irrigation in the country and the outlay in different plan periods.

The 20 point programme envisages the creation of irrigation potential of 5 m. ha. during the last four years of the Fifth Plan from major and medium irrigation works. This means an average annual addition of 1.15 m. ha. which is two and-a-half times the average rate of

the past years. Concerted efforts are being made to realise this ambitious target, by closely monitoring the progress of important projects and by providing adequate funds of the works.

Some Recent Trends

A distinct feature of development since Independence is the attempt for making irrigation facilities adequate for growing high yielding varieties of crops, and not merely for protective irrigation, as was the case with most of the pre-plan projects. For ensuring water supplies for multiple cropping, there has been progressive increase in the storages created by construction of high dams, for providing irrigation during dry season. During the last twenty-five years, the gross storage of water has increased to 1.47 m. ha. m. from a mere 0.18 m. ha. m. in 1947. Nearly three-fourths of the major irrigation projects taken up after Independence have been based on storages. 150 masonry and concrete dams and 370 earth and rockfill dams were undertaken, out of which 25 are over 60 m in height.

Tubewells have also played a notable role in improving the quality of irrigation supplies. Advancements made in the field of ground water exploitation have

Outlay and Development of Irrigation Potential

Plan	(OUTLAY IN Rs. CRORES)			IRRIGATION POTENTIAL CUMULATIVE MILLION HA		
	Major & Medium Irrigation	**Minor Irrigation	Total	*Major & Medium Irrigation	Minor Irrigation	Gross Total
Pre Plan	—	—	—	9.7	12.9	22.6
First Plan	380*	76	456	12.2	14.06	26.26
Second Plan	380	142	522	14.3	14.79	29.09
Third Plan	576	328	904	16.6	17.01	33.61
Annual Plans (1966-69)	429	326	755	18.1	19.0	37.1
Fourth Plan (1969-74)	1254	513	1767	20.9	23.5	44.4
Total up to end of Fourth Plan	3019	1385	4404	20.9	23.5	44.4
1974-75	387	111	498	21.7	24.3	46.0

* Includes Rs. 80 crores during the pre-plan period.

** Government outlays only.

made it possible to lay deep tubewells, and with the extension of rural electrification on a large scale in recent years, tubewell irrigation, both from shallow and deep tubewells, has shown rapid increase. Tubewells have also paved the way for conjunctive use of surface and ground waters, and supplemental tubewell irrigation has been adopted in some canal systems for achieving flexibility in irrigation supplies.

Another notable development in recent years is taking up construction of sizable lift canals to irrigate areas outside gravity commands. Prior to Independence, irrigation canals were usually of gravity type and extension of irrigation to areas which could not be commanded by gravity was ruled out. The development of our hydropower resources has rendered lift canals economically viable in a number of cases.

The storage dams that have been constructed in recent years reflect the advancements made in the fields of design methods and construction techniques. The Bhakra dam, one of the highest concrete dams in the world, the Hirakud dam, which ranks as the longest high earth dam in the world, and the Srisaillam dam located in a narrow gorge with a huge river diversion problem, are examples of works which have adopted recent design and construction techniques. Design organisations and research institutes, which were earlier

restricted to a few advanced States in the country, have been set up in almost all the States. The combined efforts of the designer, the research engineer and the construction specialist, have been responsible for the successful introduction of latest trends into our engineering structures.

India leads today in the construction of large canals. The Rajasthan Canal (524 cumecs capacity), and the Nagarjunsagar Canals (623 cumecs capacity) are among the largest in the world. About 17,000 km of big canals have been built since 1951. Labour intensive processes are generally preferred for employment generation in canals but a judicious combination of human labour and machinery is inevitable for speedy construction. Rapid strides have also taken place in the fabrication of equipment needed for construction of irrigation projects. Hardly any equipment needs to be imported now, either for constructing major dams or canals. Spillway gates and high head gates are designed and tested by the Engineering Departments and fabricated in Public Sector Undertakings.

The most remarkable feature of our water resources development in recent years is the development of expertise in the country to formulate, plan, design, execute and operate all water resources project indigenously. Foreign assistance to a small extent was

obtained for a few years initially. It is creditable that most of our major projects, which rank among the largest in the world in scope and magnitude, have been handled exclusively by Indian engineers. In fact, we are now in a position to share our rich expertise and experience with other developing nations.

The need for prompt and efficient use of available irrigation facilities has now been well recognised. The activities concerning prompt and efficient use of water involve a number of Departments such as Revenue, Agriculture and Cooperation besides Irrigation. No single Department will be in a position to provide all the facilities to the farmer. Integrated command area agencies have been set up in a number of projects with a view to provide all the inputs, infra structural facilities and agricultural extension services, required for efficient irrigated farming. Efforts are also being made for economising the use of water by proper crop planning and modernisation of the irrigation system.

The Task Ahead

While considerable progress has been achieved since Independence, much more remains to be done for developing further irrigation potential available in our country and for making efficient use of available irrigation supplies. So far as extension of irrigation facilities to new areas is concerned, most of the simpler and easier sites have already been exploited and the future projects will, by and large, involve more complex structures in seismic areas with difficult foundation conditions. We have already a wealth of experience and talent in dealing with these problems, but we have to ensure that we keep ourselves abreast with advancements in technology in more developed countries in the world. Research, design and construction should be closely coordinated, and concerted efforts made to deal with problems which arise.

Mere extension of irrigation facilities to fresh areas by new structures will not be enough to meet the long term irrigation requirements of the country, because

only about a half of the cultivable area can be provided with irrigation facilities by full development of utilisable water resources. The available irrigation supplies should also be used with economy and efficiency, to avoid wastage of irrigation supplies and for stepping up the per unit yields. In the first instance there should be proper selection of crops on considerations of soil suitability and agro-climatic conditions. Adequate drainage facilities will have to be provided to remove excess water from the field and ensure proper crop growth. Rostering of irrigation supplies will have to be done after taking into account the moisture requirements of the crop during different stages of its growth. To avoid wastage of water by irrigation from field to field, adequate field channels will have to be provided and for ensuring even distribution of water over field, land levelling and shaping will have to be done.

There is also need for lining reaches of canals showing excessive loss through seepage. Available ground water facilities will have to be tapped for supplementing canal irrigation. The canal systems will have to be tuned up with reference to location and adequacy of outlets and cross regulators, and efficient maintenance will have to be ensured.

Enough attention has not been given to introduction of advance irrigation techniques. Methods of economising irrigation supplies, such as sprinklers and drip, will have to be increasingly adopted to stretch our available resources, which are limited to cover wider areas.

Our future strategy for development of irrigation will have to be a combination of development of facilities in new areas, and efficient and economic use of water supplies in areas already under irrigation. Most of the measures required for bringing in efficient and economic use of available supplies are capable of yielding large benefits with comparatively small outlays. Schemes envisaging modernisation of existing systems should, therefore, receive due priority in our future plans.

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UNDP Aid to India's Irrigation and Power Sector

Filling in Gaps in Science and Technology

ROGER POLGAR*

IT has been a great privilege for the United Nations to be associated with the irrigation and power development in India. Although the period of such collaboration is quite recent and the contribution which the United Nations system has made to India in the last 20 years or so has been marginal, viewed in the context of crores of rupees invested and the enormous technical manpower mobilised by the Government, it has at least served as a catalyst for quickening the economic and social development in this country. It must be emphasized that the inputs of the United Nations Development Programme (UNDP) and other allied agencies of the UN system have been confined to filling in such crucial gaps in science and technology as have been identified by the Government of India. This is in conformity with the Government's policy of self-reliance and the pre-investment character of UNDP assistance.

Long Tradition

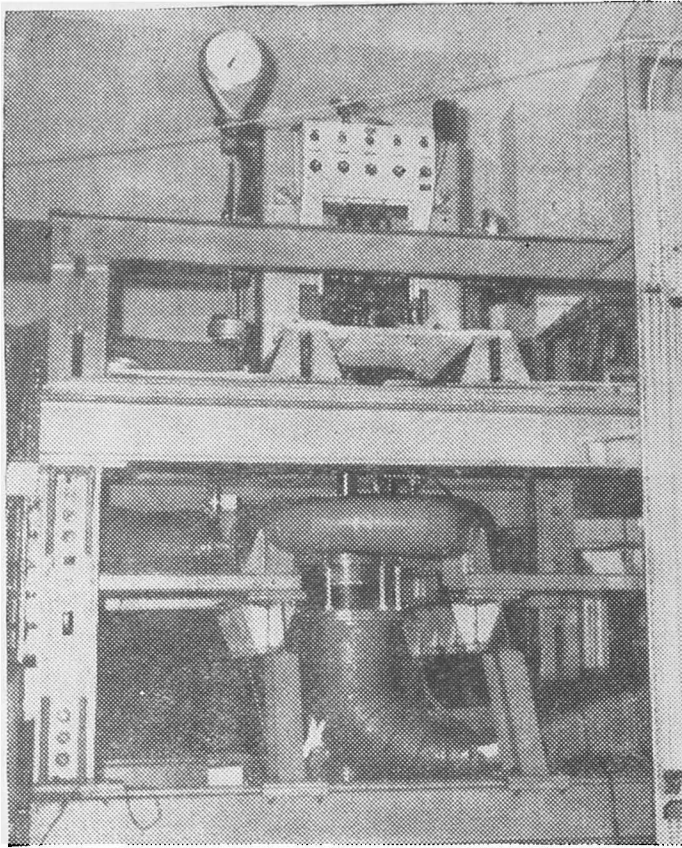
Since the pre-historic days of Mohen-ja-Daro and Harappa, India has demonstrated the engineering skill of its people. History has also subsequently recorded about the magnificent network of dams and canals constructed by Hindu and Moghul emperors in the north and Pandya and Chola kings in the south. With the passage of time, some of these have become merely historic while others have been renovated, reconstructed and even expanded to suit the requirements of changing times. This tradition was maintained during the

period of British rule when construction of canals and power development were second only in importance to the excellent network of railway links developed during the period. But it was only after India became free in 1947 that under the leadership of the first Prime Minister, the late Mr. Jawaharlal Nehru, that huge multi-purpose river valley projects and power development schemes were executed to cope with the growing requirements of a welfare state. In the series of five-year plans, substantial provisions were made for irrigation and power to boost agricultural and industrial production. While on the one hand, development planning had to cope with population growth, India has naturally sought to adopt modern techniques in science and technology to march forward with rest of the world. It is in this context that the United Nations has been called upon to make its due contribution. The contribution has been in the form of expertise, equipment whenever necessary and fellowships to Indian personnel to be trained abroad so that when foreign experts leave, there will be continuity of progress.

Cavitation

By far the largest contribution of the UNDP in the last 15 years has been to the Central Water and Power Research Station (CWPRS) near Pune, which has now been recognised by the Economic Commission for Asia and the Pacific (ESCAP) as a regional centre. Among the projects supported by UNDP and allied executing

* Resident Representative of UNDP in India.



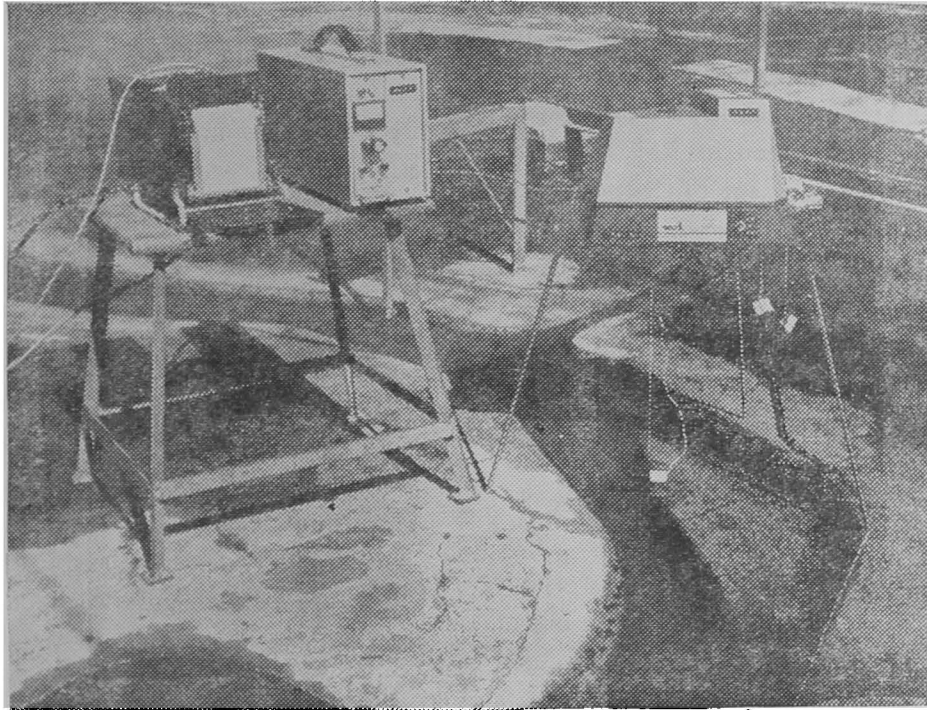
Francis turbine model and D. C. dynamometer assembly on the water tunnel installation of Cavitation Research Centre

agencies are those related to testing of ship models, cavitation research, coastal engineering research and hydraulic instrumentation. When Panshet dam collapsed in 1961 and flooded Pune, Indian engineers became aware of the danger of cavitation to dams and other hydro-electric projects. So high is the destructive power of cavitation that it can cut a hole in a 50 mm. thick solid blade of a ship propeller in a matter of a few hours. In response to a request from the Government of India, UNDP assisted the establishment of a modern Cavitation Research Centre. Equipped with a multi-test water tunnel and other sophisticated machines, the centre is the culmination of nearly 12 years of planning, designing, construction and testing by Indian and international experts. The centre's three-storey-high water tunnel, a major tool for cavitation study, combines the best features of similar water tunnels in laboratories all over the developed world and is designed to test pumps, valves, sluice gates, turbines and marine pro-

pellers. Since the establishment of the centre, considerable foreign exchange has been saved as cavitation-free tests on models are made in India itself. The centre has already carried out tests on models on behalf of Bharat Heavy Electricals, Bhakra-Nangal dam complex and other undertakings. It would be possible to test three models in a year.

Coastal Problems

With a coastline of 4,000 kilometers, India has to tackle many complex coastal problems in order to maintain and improve its position as a major maritime power. These problems include improvement and expansion of existing ports and designing of new ones. In order to attain international standards in coastal engineering research and to develop most economical designs of ports, harbours and shore and offshore structures and to develop instruments and systems for the precise measurement and analysis of all civil engineering parameters in hydraulic models, river valley structures and coastal engineering projects, UNDP has assisted the establishment of a centre within the campus of CWPRS. Sophisticated equipment was supplied for setting up a field measurement facility and a laboratory for the Coastal Engineering Research Centre and a computer based data acquisition system and UHF test instruments for the Hydraulic Instrumentation Centre. Provision exists for recruitment of a dozen international consultants for brief periods and an equal number of fellowships to train abroad Indian engineers and scientists attached to these centres. Additional assistance for these two projects and assistance to Applied Earth Sciences Division and Hydromechanics Division of the Centre is under the consideration of UNDP headquarters, although project documents relating to them have been signed by the Government of India. Three other projects for which the Government of India has requested UNDP support are the Development of coastal Engineering Division at K. E. R. I. Peechi in Kerala, where a large part of the coast is subject to erosion, and for the establishment of a National Institute of Hydrology to conduct advance research in hydrology and to prepare a national water budget for long and short-range water resources planning and its optimal development. The third project involves the establishment of a Documentation Centre in CWPRS.



UNDP Equipment for Water Level Measurements in Hydraulic Models.

Water Grid

In view of the fact that water resources of India are maldistributed in relation to demand for water by a growing population and because large quantities of water go waste into sea, the Government requested UNDP expertise in 1972 to prepare a survey and feasibility study on a national water grid. The project envisaged diversion of surplus monsoon flow in the Ganga river of about 1.23 million hectare metres in the first stage and about 2.47 million hectare metres in the final stage to deficit areas in other parts of the country by a combination of lift and gravity canals over a distance of 3200 kms involving a lift of over 609 m. Mr. Joseph Barnea, until recently Director of UN Resources and Transport Division, led the team which came to the conclusion that the project is feasible and would quicken the tempo of economic development of India. Under the UNDP country programme an additional provision of \$ 1 million of UNDP assistance was made, but in view of the huge cost and complexity of the project, which would take 25 years to complete, the Government decided not to embark on it for the present. But the UNDP's preliminary investigation and

analysis would help the Government to develop the ambitious project whenever resources permit.

Command Area

In what is popularly known as the Command Area Development, UNDP and FAO have collaborated with the Government of India. In six pilot projects in Rajasthan, Madhya Pradesh, Andhra Pradesh and Bihar, a package of agricultural practices was evolved to retrieve large chunks of cultivable land which had gone waste due to water logging, salinity of soil and infestation of weeds. The package, which consisted of proper levelling and lining of land and provision of water courses and drainage, was effectively introduced in the Chambal river command area in Rajasthan and Madhya Pradesh. During its Fifth Year Plan, the Government of India is planning to develop 15 million hectares under Command Area Development. This is one of the outstandingly successful pre-investment projects where UNDP/FAO assistance led to capital investment by the World Bank to supplement internal resources. In Chambal Command Area alone involving the states of Rajasthan and Madhya Pradesh, the World Bank has given loans to the tune of \$ 100 million. More requests are being negotiated.

Groundwater

In the development of groundwater resources for irrigation and drinking purposes, UNDP has been extending financial and technical assistance for the past ten years first in Tamil Nadu, then in Rajasthan and Gujarat and now in the development of Ghaggar basin area covering the Punjab and Haryana. International expertise was provided by UNDP in the fields of hydrogeology, artificial recharge, hydrochemistry, bore-hole geophysics, tracer studies and use of highly sophisticated equipment. The first UNDP-assisted project related to a survey of groundwater resources in the environs of Madras city and in the Cauvery delta area. UNDP experts established that use of groundwater for a third crop in the Cauvery delta was feasible. This pre-investment finding led to the assistance of about \$ 35 million by the World Bank to the Government of Tamil Nadu for minor irrigation and other related activities. In Rajasthan and Gujarat, UNDP experts of whom Mr. Silas Brown of the United States was a leading figure, assisted the Central Groundwater Board in determining the quality and quantity of groundwater resources available and how best they could be utilised for the poor farmers of the region where the rainfall is insignificant. UNDP assistance so far for groundwater exploration and development may approximately be over \$ 4 million.

Switch-gear Tests

In the power sector also, UNDP assistance is being utilised to fill in certain crucial gaps in science and technology. The biggest share of aid was for the switch-gear testing and development station at Bhopal and the low-voltage switch-gear laboratory at Bangalore. Although the project had a chequered career extending to 10 years, it has fulfilled the long-felt need for a central organisation of applied research to resolve intricate problems relating to generation, transmission and distribution confronted by power supply undertakings and electrical manufacturing industries in the country. The testing and certification facilities have meant considerable saving of foreign exchange, apart from the impetus it has given to power development in the country. In addition to UNDP assistance of about \$ 2.6 million, further assistance by way of expertise and

equipment has been sought to establish a synthetic switch-gear plant for synthetic testing of circuit breakers, investigation into problems of extra high voltage AC transmission and application of fuel cell techniques. It is hoped that in course of time, these research and testing centres would be available for neighbouring countries under the auspices of technical co-operation among developing countries as it is probably the only centre of its kind in the region.

Load Dispatch

In the development of India's power grid, UNDP is making a notable contribution of \$ 579,000 for the present in the form of simulator equipment, expertise in the fields of load despatching and system operation and fellowships for training engineers abroad; but UNDP aid may well reach \$ 1 million mark when the project is completed. The rapid growth of electricity system, combined with geographical size of India, will require the use of 25 load despatch centres on which five regional stations will be superimposed. The proposed centres will require approximately 1200 trained load engineers. Although the Load Despatch Training Institute, set up in Bangalore in 1972, provides training in various aspects of load despatch, UNDP assistance will enable Indian engineers to gain experience to meet unexpected and 'dynamic' situations. The advanced training will be in New Delhi under the auspices of the recently established National Electricity Systems Operation Organisation.

Geothermal Power

With the help of UNDP experts, Mr. J. C. Bradbury and Dr. H. T. Meidev, the Government of India has prepared a project for undertaking a full-scale geothermal exploration programme. India is power hungry because of the growing tempo of agricultural and industrial activities and all sources of conventional and unconventional power have to be explored. Soaring oil prices and drought in certain parts of the country in the last three years have imparted an urgency to augmentation of power. It is expected that by 1979, the required plant capacity will be about 40,000 MW, double the present capacity, and it is therefore necessary to tap geothermal power also. Nearly 250 thermal spring locations have been identified by the Geological Survey of India, with

Uttar Pradesh and Maharashtra having sizable geothermal resources. For the implementation of the project, UNDP will supply expertise, and sophisticated equipment and provide fellowships for specialists in the field to get trained abroad and execute the programme. Although approved assistance is \$ 668,600 the Government's request for an additional million dollars is under consideration of UNDP headquarters.

Tidal Power

Prospects of utilising tidal power are also being explored by the Government in response to whose request UNDP recruited a British expert, Mr. E. M. Wilson, Professor of Hydraulic Engineering in Salford

University. He felt that there is a *prima facie* case for further investigations into tidal energy schemes in Gujarat and Sunderbans of West Bengal. He is of the view that Indian manufacturers are capable of producing all the electrical and mechanical equipment necessary, but some sophisticated equipment, especially relating to mathematical modelling of estuarial behaviour and undersea engineering will have to be imported.

In addition to the specific projects outlined above, UNDP has approved fellowships to the tune of nearly a million dollars in specialised fields such as power system planning, hydropower development, extra high tension problems and tidal power generation.



Assistance from the United Nations

R. K. BASU *

Among a large number of projects, in which the United Nations Office of Technical Co-operation is currently providing assistance to India, it is particularly happy of its association with the Central Water and Power Research Station at Pune. Even before the international assistance was provided to this institution, the United Nations was aware of the many significant contributions made by this premier research station in solving complicated problems in the fields of water resources development, hydro-power development and coastal engineering in India. Two decades of association of the United Nations with the research station and its various projects have been a fulfillment of an endeavour in technical co-operation. It was evident at an early stage that the request for assistance from the United Nations was a part of a serious national effort to take a giant step to equip itself in modern technology and know-how in the hydraulic and coastal engineering fields. This was possible, in large measure, due to the dynamic leadership of its Director, Mr. P. C. Saxena, who is also the Project Director for the United Nations project, and his dedicated and highly talented staff.

India, with its rapid industrialization and need for increased port and harbour facilities, has realised that hydraulic research is most essential to prepare a long-range and adequate programme of development in order to cater to its set requirements and therefore included in its fourth five year plan development of the Pune

Research Station. While some research capabilities were developed at the station regarding the hydraulics of estuaries and coastal waters, it was realised that there were gaps in research facilities and capabilities relating to coastal processes and their effects on maritime studies. The United Nations was pleased to provide assistance to meet this gap. Mutual co-operation between the United Nations and India was possible in this field.

New ideas could be developed because of India's eagerness to adopt latest techniques in research and develop advanced instrumentation for use in the research of oceanographic parameters such as wave height, silt charge and littoral drift.

As a stepwise process in developing facilities, the first was a project with UNESCO for ship model testing, then in 1956/57 the United Nations was asked to help in setting up a photoelastic laboratory at the Pune site. More recently, under the assistance of the United Nations, the Cavitation Research Centre at this station has become a reality. This facility has enabled the development of economic designs for turbines, pumps and high head gates for dams.

The United Nations has been privileged to provide the services of high-level international consultants to make useful short visits to the projects over the years and also to provide modern equipment needed for advanced

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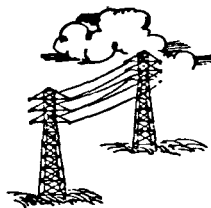
research. Annual fellowship awards for study abroad to nationals, both for medium and advanced engineering technologies related to the specific work of the Station, have also helped substantially. The experience gained by the United Nations in the collaboration of this project was also significant, particularly to test some of the methodologies, which it is hoped could be applied in other developing countries.

The project, assisted by the United Nations Development Fund, has not only benefitted India but also the other countries in the region. When in 1970 ESCAP recognised the Centre as a high-level regional laboratory ready to assist other countries of the region in similar engineering work, the United Nations heartily joined in the Centre's determination to strengthen its capacity in order to deal with scientific problems outside India. While the present project associated with the Centre, which is now in its last year, and where the services of high-level experts, provision of equipment and training facilities continue, not enough has yet been done to

enhance the status of the Centre for taking the full responsibilities as a regional institute for Asia and the Pacific. It is hoped that the Institute will justifiably earn its reputation as one of the most unique research centres in the region and make its facilities available, not only for research, but also for advisory services to other developing countries.

While the evaluation of the international assistance to this project has not been completed, it is evident from the impressive results already achieved and the plans for its expansion for the Coastal Engineering Research Centre, Hydraulic Instrumentation Centre, the Applied Earth Sciences Division and Hydromechanics Division, it has more than surpassed its initial goals as a scientific research centre.

The Diamond Jubilee of CWPRS will provide encouragement for further collaboration with other international organizations.



Contribution of CWPRS Photoelastic Studies to the Design of Bhakra Dam

I. P. KAPILA *

Introduction

The Bhakra Dam is a 225 m high mass concrete structure built across a narrow gorge of Sutlej River. The rock formations at the dam site are composed mainly of preponderantly massive calcareous sandstone which belongs to the Nahan (Lower Shiwalik) group of the Himalayan range. The sandstone is interspersed by bands of the claystone/siltstone. The stratifications are almost normal to the axis of the dam and dip generally 70° downstream. There are two major claystone/siltstone bands in the Bhakra gorge, and the dam was so positioned as to rest on the sandstone lying between them. Other weak zones in the foundation of the dam are the axis and toe shear zones, a middle claystone band of less thickness than the two major bands, a thrust zone, and several near-horizontal shear zones on the abutments. Some of these features are indicated in Fig. 1, which shows the maximum spillway section of the dam.

Weak zones in dam foundations are generally treated by excavating the unsuitable foundation material to some depth backfilling with concrete. The plug so formed in the foundation helps in the transfer of load from the weak zone to the more competent formations on either side of it. Whereas this general approach, largely based on the experience from other similar situations, was followed for the treatment of most of

the weak zones at Bhakra, it was recognized at the very outset that the 30.5 m wide claystone band located upstream of the heel of the dam would require some special measures because of its critical location. It was considered to be too important a matter to be resolved merely by empirical rules and judgement alone. A quantitative appraisal of the various factors involved was considered essential for evolving a satisfactory design, despite the apparent difficulties in simulating the heterogeneous foundation conditions in any experimental or analytical approach to the problem. Faced with this situation it was decided to request the Central Water and Power Research Station Pune, to undertake the task of providing quantitative answers to the problems posed by this important feature of the project.

The Heel Claystone Problems

The location of the heel claystone stratum with respect to the main body of the Bhakra Dam is shown in Fig. 1. Studies carried out for the stresses and stability factors of Bhakra Dam by the trial load twist method of analysis had shown that it was possible to adopt a section for the dam with a vertical upstream face for the entire height of the structure. This would have placed the heel claystone band about 46 m upstream of the axis at a location, where the stresses imposed by the dam could be high. Although known to be capable of carrying great loads in a confined and unweathered

* Chief Engineer (Thein Dam), Irrigation Works Punjab, Chandigarh.

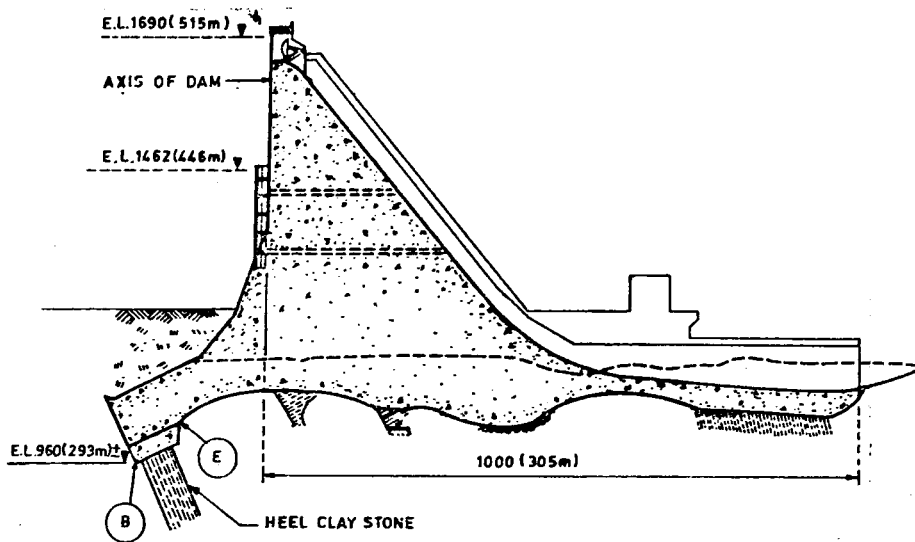


FIG. 1

MAXIMUM SPILLWAY SECTION, BHAKRA DAM

condition, the claystone did not inspire confidence when subjected to continued submergence or to alternate wetting and drying in an unconfined condition. It was, therefore, felt that the downstream dipping sandstone beds lying between the heel claystone and the dam axis could register an upstream movement under the imposed loads on account of some future incompetence of the claystone and consequent removal of support to these beds. To safeguard against this possibility, it was considered necessary to cover the intervening sandstone member with a suitable concrete slab to enable pressure grouting of the rock, even after the reservoir was filled. Furthermore, it was proposed that the covering slab should also be able to carry the load from the dam to the competent sandstone member lying upstream of the heel claystone. The necessity for this could arise if the claystone was rendered incompetent and an upstream movement was caused in the sandstone lying downstream of it, inspite of pressure grouting with cement grout. In such an eventuality the covering slab would, in addition, function as a massive strut to transmit the load from the dam. There was also the requirement to provide plug to some depth in the heel claystone band itself. With this general approach, it was decided to adopt a section for the dam with an upstream slope of 0.35 : 1 below EL 1350 (411 m) and to suitably connect the dam to a sloping strut as shown in Fig. 1. However, there were several differing views with regard to the

thickness of the strut and the depth of the plug to be provided, particularly in respect of the latter. The general level of excavation for the dam at the axis was EL. 1100 (335 m), i. e. about 15.25 m below the original river bed. Various proposals had been made for the extent of excavation in the heel claystone. One was to provide a plug with its lowest point at EL. 940 (287 m), i. e. to a depth of more than 46 m below the general excavation level. Another proposal considered it sufficient to have a plug extending only to EL. 1035 (315 m). In any event, it was apparent that the depth of excavation below river bed would be considerable, and that it might be necessary to do a considerable part of this by mining methods instead of open-cut excavation. The repercussions of such an operation, fraught with many hazards, on the overall schedule of construction posed a serious problem, and it became necessary to determine the optimum depth of the plug required for the heel claystone. It was with this background that the assistance of the Central Water and Power Research Station was requested by the project authorities.

Photoelastic Studies at CWPRS

An extensive programme of photoelastic stress studies was undertaken at CWPRS for the Bhakra heel claystone problem. Laboratory and in situ rock tests had shown that the modulus of elasticity of the claystone E_{CR} was

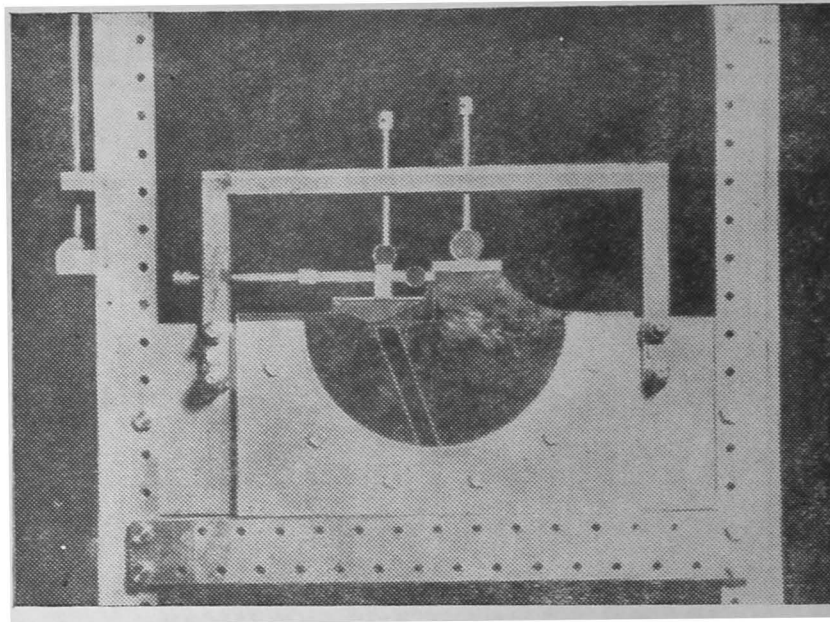


Fig. 2 Photoelastic Model.

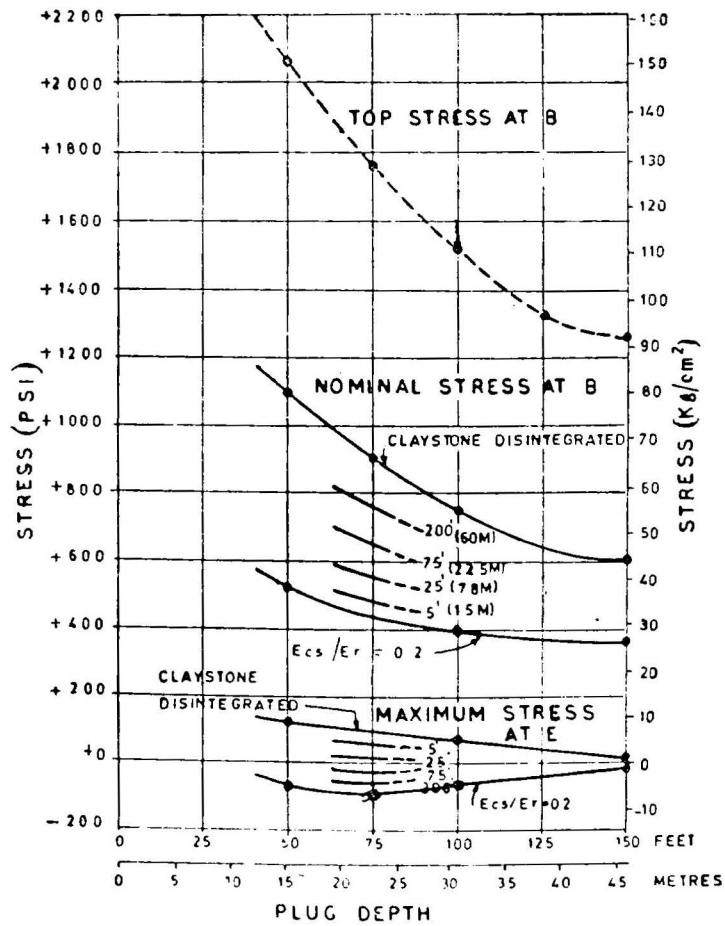


FIG. 3

STRESSES IN HEEL CLAYSTONE PLUG.
(Photoelastic study)

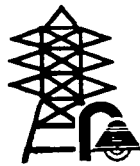
about one-fifth of modulus of elasticity of the sandstone rock E_r . In the worst case, the claystone could be considered to be completely disintegrated and ineffective. The photoelastic studies took note of these extreme conditions and stresses were determined at critical points assuming the claystone to be disintegrated in the top 1.5, 7.5, 22.5 and 62 m from its contact with the plug concrete. The experimental set up shown in Fig. 2 is for a plug with horizontal base. Later, a plug with a sloping base was adopted as it was found to be structurally better.

The results obtained from the photoelastic studies are given in Fig. 3. This shows the stresses at two critical points B and E, the locations of which are indicated in Fig. 1. At low values of plug depth, the maximum stress concentration showed a rapid fall with increase in depth, the reduction being very small for plug depths more than about 38 m. It was concluded, that from considerations of stress concentration, there

would not be much advantage in going deeper. As regards tensile stresses, it was seen that these vanished if the elasticity of the claystone was taken to be one-fifth of that of the sandstone with the top 7.6 m taken to be completely disintegrated. The plug depth as shown in Fig. 1 was finally decided on the basis of these results.

Concluding Remarks

The photoelastic studies referred to in the preceding paragraphs were conducted in 1955-56. Analytical studies (biharmonic analysis) were also undertaken at the CWPRS at that time. Later in 1963 the Station was associated with prototype behaviour studies of the upstream strut, when the dam had been completed and reservoir filled. Such continued involvement with important issues, which call for detailed engineering appraisal of intricate problems, is a distinctive feature of the activities of Central Water and Power Research Station.



A Perspective Review of Port Development In India—Past, Present And Future

BRIG. O. P. NARULA *

S. GOPALAN **

The history of port development in India can be reviewed in three broad periods viz :

- (i) Pre-Independence period;
- (ii) Post-Independence era; and
- (iii) Future prospects.

Pre-Independence Period

The oldest Indian ports whose origin date back to the 17th century are Calcutta, Bombay and Madras. In the olden days, ships used to lie in anchorage and cargo/passengers transhipped by small boats. There were no facilities for the ships to come alongside to load/unload their cargoes. This was the state of affairs upto the middle of the 19th century.

The period between 1850 and 1870 witnessed great technological changes, which gave tremendous boost to the world maritime commerce, owing to the advent of steam power for ship propulsion, replacement of wooden hulls by steel and above all, the opening of the Suez Canal in 1869. These changes which resulted in shortening of the distances between India and Europe brought out the first wave of port development in India which lasted upto the First World War. Dock systems with facilities for bringing ships alongside for handling cargo were started to be constructed for the first time in India. Kidderpore Dock System at Calcutta and Sassoon Dock,

Prince's and Victoria Dock and Mere-Wether Dry Dock at Bombay were commissioned by the end of the last century. The Alexandra Dock at Bombay and the first artificial harbour at Madras, with a line of alongside quays in a sheltered basin, were commissioned at the beginning of this century prior to World War I.

The outbreak of World War I in 1914 generally dislocated and adversely affected the port operations at Calcutta and Madras. But in Bombay, the traffic increased considerably due to handling of war material.

In the post war period, the main developments were the declaration of Calcutta, Bombay and Madras as Major Ports in 1921 and the birth of two new Major Ports of Cochin and Visakhapatnam. The work on the development of a new major harbour at Visakhapatnam was taken up in 1922 and completed in 1933. Visakhapatnam was declared as a Major Port in the same year. The 'Cochin-Saga' of developing Cochin as a major harbour was initiated by the eminent harbour engineer Sir Robert Bristow in 1925 and the new Major Port of Cochin was born in 1936. At Calcutta, a new dock called 'King Georges Dock' considered to be the most modern of that time was completed to meet the increasing volume of traffic.

The outbreak of World War II in 1939 virtually crippled the entire operations of Calcutta Port. The port

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** Executive Engineer (Civil), Ministry of Shipping & Transport (Transport Wing), New Delhi.

suffered heavy loss of equipments and manpower. What was Calcutta's loss became Bombay's gain as the entire traffic was diverted to West Coast to Bombay and Cochin with the closure of the Bay of Bengal for shipping. The increased volume of traffic resulted in a number of improvements being carried out at Bombay Port in 1943-44. But this received a serious set back due to two explosions which occurred in Victoria Dock in 1944. As far as Madras Port was concerned, there was no significant development in this period.

Post-Independence Era

The second wave of port development came after the attainment of Independence in 1947, when the country took to planned development through various Five Year Plans.

The significant development in the First Five Year Plan was the addition of a major port at Kandla to the maritime map of India, as a replacement for Karachi, which had become part of Pakistan after the Independence. In the existing major ports, the accent was on rehabilitation of war affected facilities and making good the deficiencies thrown up during the war and post-war period. At Bombay, a modern Marine Oil Terminal to receive the crude requirements of the two refineries set up at Trombay was commissioned in 1955-56 at Butcher Island.

With the industrial development set in motion after Independence, the volume of traffic passing through the major ports steadily began to rise from 19.2 million tonnes in 1950-51 to 39.5 million tonnes in 1960-61. More significantly, the composition of traffic, a very important parameter for planning the port facilities, also changed from break bulk to predominantly bulk cargo as can be seen from Table 1.

These factors mainly governed the port development programme in the Second and Third Five Year Plan periods. The important developments during the above plan periods are given in the succeeding paragraphs.

The berthing capacity at Madras was considerably increased with the construction of 'Jawahar Dock' consisting of six berths, of which 3 berths with the depth of 11 metres, were earmarked for handling bulk cargoes of iron ore and coal.

Table 1
Composition of Traffic at Major Ports

Commodity	In Million Tonnes		
	1950-51	1955-56	1960-61
Mineral oil	3.1	6.2	12.0
Iron ore	...	0.3	6.7
Coal	2.7	2.5	2.2
Fertilizer/rock			
phosphate/sulphur	0.3	0.4	0.6
Foodgrains	3.4	0.8	5.2
Other cargo	9.7	12.4	12.8
Total	19.2	22.6	39.5

(Source : India Ports & Shipping Statistics - 1969)

At Visakhapatnam, an oil wharf with two berths, to cater to tankers bringing crude to the Caltex refineries, was constructed. Also, four alongside berths, with one berth fully mechanised exclusively for loading iron ore, were also commissioned. In fact, the iron ore loading plant was the first of its kind to be installed in India with an annual capacity of 6 million tonnes.

At Cochin a new coal berth and four additional general cargo berths were commissioned. The port of Mormugao joined the list of Indian major ports after the liberation of Goa from Portuguese control in 1961.

The development of Paradip as an outlet for iron ore export, was started by the Government of Orissa in 1962, but was ultimately taken over by the Central Government in 1965. This port, which was developed as the deepest water port at that time with 11.91m draught, was declared a major port in 1966.

A beginning was made in 1960 on the development of two all-weather major harbours at Mangalore and Tuticorin with complete indigenous know-how.

The bulk cargoes account for nearly 80% of the world sea-borne trade. The constant quest for effecting economy in the transportation costs, which form a sizeable element in the total delivered cost of these cargoes, resulted in phenomenal growth in ship sizes in the last decade. In order to reap economies of scale, it became imperative to ensure faster turn round of vessels with higher speeds at sea, and faster cargo handling at ports. In India despite the programmes carried out

during the first three Five Year Plan periods, port conditions remained deficient and imposed costly delays to shipping and high port costs. Draught limitation and lack of mechanised handling facilities, especially for bulk cargoes, precluded use of large tankers and bulk carriers at Indian ports. These factors, along with the need to be competitive in the international market, influenced the port development programme undertaken subsequent to the third five year plan, which are briefly narrated in the following paragraphs :

The approach to the existing port of Calcutta, which is situated about 190 km inside the estuary, is marked by a number of bars and bends, imposing severe limitations and constraints on the draughts and lengths of vessels using the port. Hence construction of a satellite port at Haldia, 104 km downstream of Calcutta, to cater to the needs of modern bulk carriers and tankers, was undertaken in 1966. It has now almost been completed and is to be commissioned shortly. The scheme provides for a deep water impounded dock system with a designed draught of 12.2 m, and with modern bulk handling facilities for ore, coal, fertilizer, POL, and two general cargo berths. One of the general cargo berths will be fully equipped to handle containers.

Consequent on the agreement concluded with Japan for the export of iron ore, it was decided to develop an outer harbour at Visakhapatnam with an iron ore berth designed to receive 100,000 DWT vessels initially, and 200,000 DWT ultimately, and equipped with the most modern ore handling system with a rated capacity of 8,000 TPH initially, and capable of increasing to 16,000 TPH eventually. The outer harbour has been just completed.

At Madras also, an outer harbour has been constructed which is designed to receive 100,000 DWT oil tankers and 150,000 DWT ore carriers. The oil jetty is already in commission and the ore loading facility has also been almost completed.

At Mormugao, the premier ore loading port of India, modernisation of the ore handling facility, which was primitive and very slow, was launched in 1970 and is in progress. When completed, the port will be able to receive 60,000 DWT size vessels initially, and 100,000

DWT size vessels ultimately, and the rated loading capacity of the plant will be 8000 TPH.

At Bombay, the dock expansion scheme providing additional berthing facilities has almost been completed and the Ballard Pier extension to cater to passenger traffic has been completed and commissioned. At Mangalore, a new lagoon type harbour with 9.1 m. draught has been completed and a new major port called 'New Mangalore Port' was started in May 1974. Similarly at Tuticorin a new 9.1 m. draught artificial harbour is nearing completion. The Port has already been commissioned and is in operation. The Port of New Tuticorin was declared a major port in July 1974.

India has also joined, though rather late and in a limited way, the container era when M/s. American President Lines started container service touching Bombay and Cochin Ports in 1973. Interim facilities have been provided at these ports to handle the limited container traffic pending development of full-fledged container handling facilities.

With the tremendous increase in ship sizes, it has become prohibitively expensive and technically problematic to create and maintain the requisite depths. This has led to the creation of offshore terminals all over the world. One such terminal is under construction in India in the Gulf of Kutch near Salaya to cater to VLCCs, which will bring crude to the Koyali and Mathura refineries.

The agreement to export Kudremukh iron ore to Iran has necessitated the creation of bulk ore handling facilities at Mangalore capable of receiving 60,000 DWT ore carriers. The work has already been taken up and is expected to be completed by 1980.

An article on the development of ports will not be complete without making a reference to the close association that the ports sector has with the Central Water and Power Research Station at Pune. This Research Station has done commendable research studies for all the major ports and a number of intermediate and minor ports, and thus has helped in arriving at sound and economical designs. Complex problems, such as the navigation problems to the port of Calcutta, development of new ports at Nhava-Sheva, Mormugao, Mangalore, Tuticorin, Madras, Visakhapat-

nam, are all worthy of special mention. The Research Station also has carried out field studies such as tracer studies, to help fix suitable sites for satisfactory disposal of dredged material, and measurement of currents, waves and tides, which data are very necessary for use in the research work. Very valuable and timely advice has also been received from the Research Station in regard to planning of the construction stages of the various projects. The improvements and savings, that have resulted through the various studies by evolving the optimum requirements, are particularly to be mentioned. With the setting up of the UNDP aided Coastal Engineering Research Centre and Development of Hydraulic Instrumentation at the CWPRS, the research station is geared to undertake studies on such other fields, which could contribute in no small measure to enhancing the technical capability of the Station further, and making the research station one of the best of its kind.

Future Prospects

The traffic anticipated through Indian major ports by 1980 is about 80 million tonnes. Bulk cargoes of iron ore, coal, fertilizers, foodgrains and POL, will continue to predominate forming about 80% of the total cargo. While POL and fertilizer raw materials will constitute the main import bulk cargoes, iron ore will be our chief export bulk cargo. Recent trends point

out to the growth of coal traffic through our ports both for coastal movement and export. It has been projected that about 5 million tonnes of the general cargo traffic will be containerised in 1980

The major scheme under consideration in the Fifth Five Year Plan, is the creation of a satellite port to Bombay at Nhava--Sheva, capable of receiving vessels of 80,000 DWT size, with facilities for handling bulk cargoes and provision of a container berth. A project for the construction of a Super Tanker Oil Terminal at Cochin is under consideration. Haldia will be the chief outlet for coal traffic, and coal is expected to move through geared vessels. Interim coal reception facilities are being provided at the ports of Paradip, Tuticorin and Madras. It has been planned to provide a new coal berth at Tuticorin.

The future plans for provision of oil handling facilities, have to take into consideration the indigenous production and availability of crude, in which case the economies of scale of large ships may not be very relevant.

Considering the anticipated traffic realisations and port capacities, that will be available by 1980, the future emphasis is likely to be on specialised facilities for specific cargoes.

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Farakka Barrage Project—Its History and Stages of Cofferdam

BRIG. D. R. KATHURIA *
SM

Farakka Barrage Project as it stands to-day is not a recent project. Its necessity was felt and was conceived as early as 1853 by Sir Arthur Cotton, an eminent engineer. A number of committees formed later during 1881, 1883, 1919 and 1953 to examine the deterioration of river Bhagirathi-Hooghly system and the Calcutta Port to suggest the remedial measures—offered basically the same remedial plan.

Causes of Deterioration

The main cause of deterioration of Bhagirathi-Hooghly system was the shifting of the courses and decrease in water level in Ganga, resulting later entry and earlier stoppage of upland discharge into Bhagirathi through the offtake point at Nurpur (during 1958), thus causing insufficient head water at Calcutta Port. The records reveal that since 1910 at Rajmahal, which is 77.2 km. upstream of Nurpur, the lowest water level went down by 1.82 m.

Another major reason was the alteration in the course of Damodar the principle tributary of Bhagirathi. The river originally joined the Hooghly, 62.6 : m above Calcutta and its water assisted in scouring the Hooghly channel. In the eighteenth century, a series of large floods burst the Damodar embankments and the river mouth moved further and further down the Hooghly till it reached its present position 50 km. south of Calcutta, the old course of the Damodar

rapidly silting up, thus denying the port of Calcutta its beneficial discharge.

The Hooghly experienced strong tides and bores from the sea to a distance of 297 km upstream. It was computed that roughly 2.83 million m³ of silt were brought into Bhagirathi-Hooghly river every year and this together with the decreasing and sharply fluctuating supplies and tidal action brought in deterioration in depths over the bars in the Hooghly making the navigation more and more difficult.

The phenomenon of bore tides known to occur during the spring tides ever since the establishment of the port of Calcutta, became more and more regular and severe. In the past it was necessary to take precautions during perigee spring tides, between March to May and August to September. This has however now become a feature even of early December. Heavily laden ships could not be kept at river moorings and had to be necessarily moved into the docks causing congestion there.

The progressive reduction in the capacity of the Bhagirathi-Hooghly and the upland fresh water supply also resulted in the rapid rise in the salinity of the Hooghly water year after year. This went over 2000 ppm whereas the potable limit was 200 ppm. The river Hooghly being the only source of fresh water supply to the port, the city and the industrial suburbs of Calcutta,

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this rapid rise of salinity became a matter of great concern to all.

Remedial Measures

The remedial measures that were considered to improve the Bhagirathi-Hooghly system are enumerated below:

- (a) Dredging the bars and crossings in Bhagirathi-Hooghly.
- (b) Dredging the offtake of the Bhagirathi.
- (c) Bringing upland discharge through Feeder canal from Ganga into Bhagirathi by constructing a barrage across river Ganga.

The disadvantage of the first method was that the removal of the root cause of deterioration i.e. the formation of the bars etc. needed continuous dredging on a gigantic scale. It was necessary to carry out a yearly dredging of about 2.83 million cum. for which no place ashore could be located, where this huge quantity of sand can be dumped year after year, and this avoid the dredged spoils finding its way back to the navigation track again.

Another measure considered was to improve the offtake of Bhagirathi (Nurpur) in such a manner that water flowed into the Bhagirathi earlier so that the proportion of flood discharge of Ganga carried by the Bhagirathi-Hooghly was increased and the period of the freshet discharge in it was prolonged. No practicable method of pegging down a favourable offtake could be thought of due to the vast and frequent changes in the course of the river Ganga, which prohibited dependence on this alternative for arresting deterioration of the condition of the Bhagirathi.

The third method consisting of construction of a barrage across Ganga and other structures, diversion of upland discharge into the Bhagirathi was considered possible and water so diverted would be comparatively free of sand and silt. With a controlled upland discharge a prolongation of freshet period so obtained would be most beneficial not only in arresting the deterioration of the Bhagirathi-Hooghly system, but also in increasing its capacity, improving the depths, reducing the salinity of Hooghly of water and diminishing the frequency and intensity of bore tides.

Location of Barrage

- At first two good sites for the barrage were chosen--
- (1) A site 3.2 km below Rajmahal and
 - (2) Farakka 25.75 km further downstream.

The length of the proposed canal taking off at Rajmahal would have been 71 kms as against 38.3 km from Farakka. Also in the former case an expensive drainage crossing at Gumani would have been necessary. The two arms of the river, which is wider at Rajmahal, would have been potential danger to the barrage as they would aggravate the outflanking tendencies though the right bank here would be more stable. The left abutment, a good portion of the left guide bund, and some length of the afflux bund would have to be built in the river channel, which would be more vulnerable and costlier than the corresponding structure at Farakka site.

Rajmahal is located just downstream of the two arms of the Ganga into which the river bifurcates some kilometers above. The right arm was predominant but there was no guarantee that the left channel would not revive at the expense of the right, at some future date. On the other hand, the river has a fairly straight course at Farakka over a considerable length.

Comparative estimates worked out for both the sites in 1952 showed a balance in favour of the Farakka site which was ultimately chosen.

Project

The project at Farakka consists of the following:

- (1) 109 bay R. C. barrage across river Ganga with a road and rail bridge over it.
- (2) A Head Regulator at the mouth of the canal on the right bank, just upstream of the barrage.
- (3) Feeder Canal connecting Ganga and Bhagirathi.
- (4) A Barrage across river Bhagirathi at Jangipur.
- (5) Navigation locks at Farakka and Jangipur.
- (6) Regulators across rivers Pagla, Tutianallah, Nimajallah, Bhagirathi and Ralindri on the left side of Ganga.

The most vital among all the construction was the construction of 2209 m long barrage across the river Ganga.

It was a challenge to the engineers who had to work on the flowing river. The period available for construction was also limited from November to June.

Cofferdam

Construction of the cofferdam was the most difficult of all stages before the starting of actual foundations for barrage. It was constructed in stages during every year since 1963-64 to 1968-69. Each stage of cofferdam was maintained or removed properly, before next stage of cofferdam construction was taken up next year. No where in this country a cofferdam was built, where depth of water even during lowest water level for the dry season varied between 4.5 to 9 m and discharge during closure was of the order of 2800 to 5600 m³/s. The bed materials being movable, deep water channel was susceptible to shifting within a wide range and river liable to meandering. It was impossible to predict the design and planning of the cofferdam based on available river conditions which would be suitable in future under a different river condition at the time of construction.

Construction of cofferdam first started in 1963-64 enclosing 3 bays on the right bank and it consisted of an earth embankment protected by gunny bags.

Season 1964-65

First cofferdam covering 3 bays was maintained and second enclosing 4th to 8th bay was done from the excavation of the pit and dredged spoils from the river by employing dredgers. It was 701 m long and raised up to R. L. 80.00 with side slopes 1:1, the maximum water level during the season being 74.28. To protect it against wave rush boulder toe was formed all along the length and pitching on the river side slopes was done at vulnerable points.

Season 1965-66

An earthen cofferdam of 853 m long with top R. L. 80.00 was constructed enclosing 21 bays in left bank from the spoil out of the excavated area by employing motorised scrapers.

During flood season the river side arm of the cofferdam collapsed at one section and breaches occurred in the upstream and downstream arm of the cofferdam.

Cofferdam on right bank was maintained.

Season 1966-67

Earth cofferdam enclosing the 12th bay including the first divide wall from 8th bay was made with top R. L. 79.00.

In order to minimise the difference of water level in the pit and river, on expiry of the working season, water was pumped into the pit from the river by pumps and protection to the cofferdam was maintained with two suction dredgers in making sand berm in the outer toe of the cofferdam.

On left bank the old cofferdam was repaired and extension of it was made to enclose upto 30th bay from left bank. Suction dredgers were employed to deposit the dredged spoils into the alignment of cofferdam.

Season 1967-68

On the right bank 3rd earthen cofferdam was removed to make room for placing protection block and boulder pitching around the first divide wall.

On left bank, the cofferdam in addition to the existing one was done in two stages. First stage enclosing the bays between 30th and 44th and second stage enclosing upto 56th bay from left bank. This was accomplished with the help of motorised scrapers, pusher and dredgers working round the clock.

The earth cofferdam was protected at nose both upstream and downstream by single row K II sheet pile 13.7 m long. On the start of sheet piling, river bed in bay 34 eroded away from +41.00 to +23.00 thereby increasing the water depth from about 6 to 10.5 m keeping major length unsupported. To prevent sheet piles from collapsing, cross sheet pile lines were driven at an interval of 4.5 to 6 m increasing the quantity of sheet piles.

Season 1968-69

In the 17th meeting of Technical Advisory Committee it was felt that in view of the successful construction of a single sheet pile cofferdam in the working season of 1967-68, it should be possible to construct a cofferdam from the right bank with a single sheet pile and sand

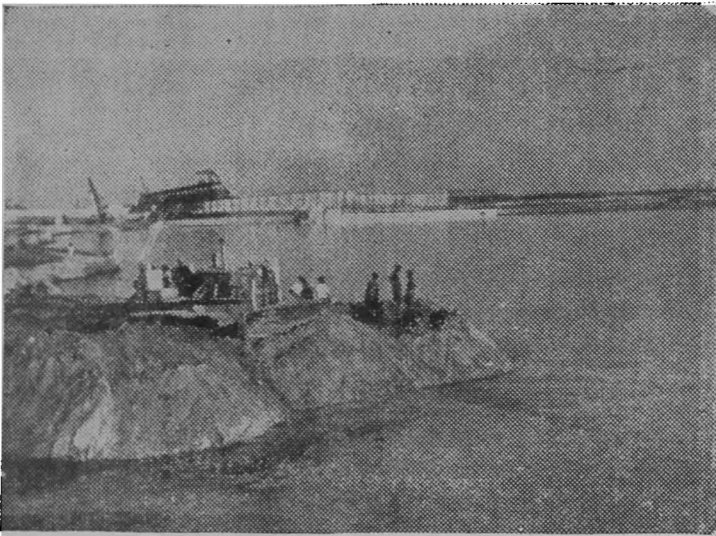


Photo 1
General View of Cofferdam under Costruction

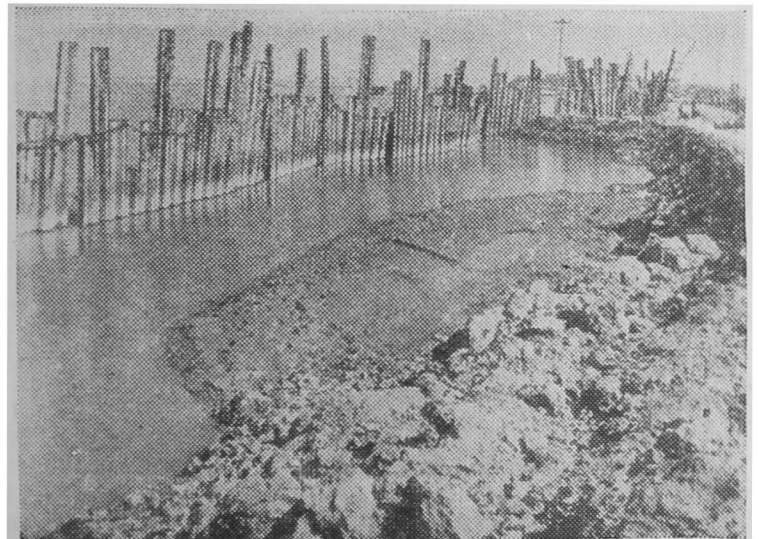


Photo 2
View of Sheet Piles in the Upstream of Cofferdam

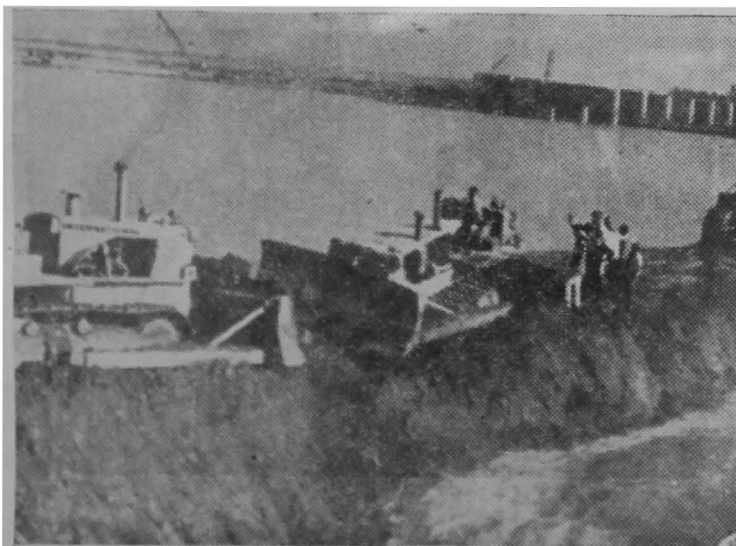
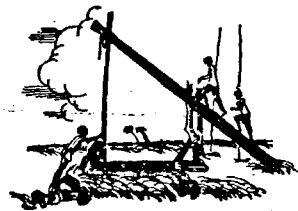


Photo 3
Machines at Work in Cofferdam

backing in the working season 1968-69 and in that case a submersible cofferdam will not be required for the construction of the barrage. After examining the river behaviour, the flow pattern, the extent of scour that could be anticipated etc., it was decided to take up the construction of 20 bays of the barrage during 1968-69 and the remaining 20 bays during 1969-70. Accordingly the work of 1968-69 cofferdam consisting of an earth embankment with protective sheet piles was taken up and completed not only more than a month in advance of the scheduled time, but also, enclosing of the remaining 20 bays was done so as to take up the construction of the entire gap in the barrage in 1968-69 itself. The construction of cofferdam during 1968-69 not only resulted in savings in the cost, but also advanced the

construction by two years and eliminated the uncertainty about the cellular type cofferdam to be adopted in 1969-70. Photos 1-3 show the construction of the coffer dam while in progress.

Construction of cofferdam and barrage over it in stages, other structures across feeder canal and across ancilliary rivers that branched from the Ganga would not have been possible without the able guidance from the Research Stations, who carried out different model studies to ascertain best location and alignment of the above and discharge in feeder canal necessary to improve the condition of the Calcutta port to the desired level.



The Beas Project

MAJ. GEN. T. V. JEGANATHAN*
PVSM, AVSM

Introduction

The Rs. 7000 million Beas Project, which constitutes two limbs, namely Beas Sutlej Link (Unit I) and Beas Dam at Pong (Unit II), has already started yielding irrigation benefits from Unit II. During the year 1977, both the units will begin to generate power.

The Beas-Sutlej Link Project, the largest hydro-electric tunnelling project in the country, comprises a link between rivers Beas and Sutlej through a system of tunnels and a high contour open channel. For the diversion of Beas waters, an earth-cum-rockfill dam at Pandoh would be constructed in the working season of 1976-77. This link would carry a discharge upto 212.4 m³/s to the penstocks, leading to the powerhouse at Dehar on the right bank of river Sutlej, and would thus divert 0.47 million hectare-metres of water in a mean year. This water outfalling into Bhakra reservoir would at first generate power at Dehar Power Plant having an ultimate installed capacity of 990 MW under a head of about 300 m and secondly augment the power potential at Power Plants of Bhakra System.

The Beas Dam at Pong comprises a 132.6 m high earth-cum-rockfill dam at Pong, the highest of its type in India, which on completion has created a reservoir of 0.73 million hectare-metre live storage capacity. A powerhouse, with ultimate installed capacity of 360 MW is under construction. The Project and five

diversion tunnels during construction stage, three of which are being utilised for housing the steel lined power penstocks and the other two as irrigation outlets.

The general layout of these two units of Beas Project is shown in Figs. 1 & 2. In working out the final design profiles of some of the important constituents of both the projects, extensive model studies were carried out mostly at the Central Water & Power Research Station, Pune and at the Research Institute Amritsar, to ascertain details of stress distribution, structural as well as hydraulic behaviour and hydraulic flow patterns etc. The design and construction of the dams and appurtenant works have entirely been manned by Indian engineers.

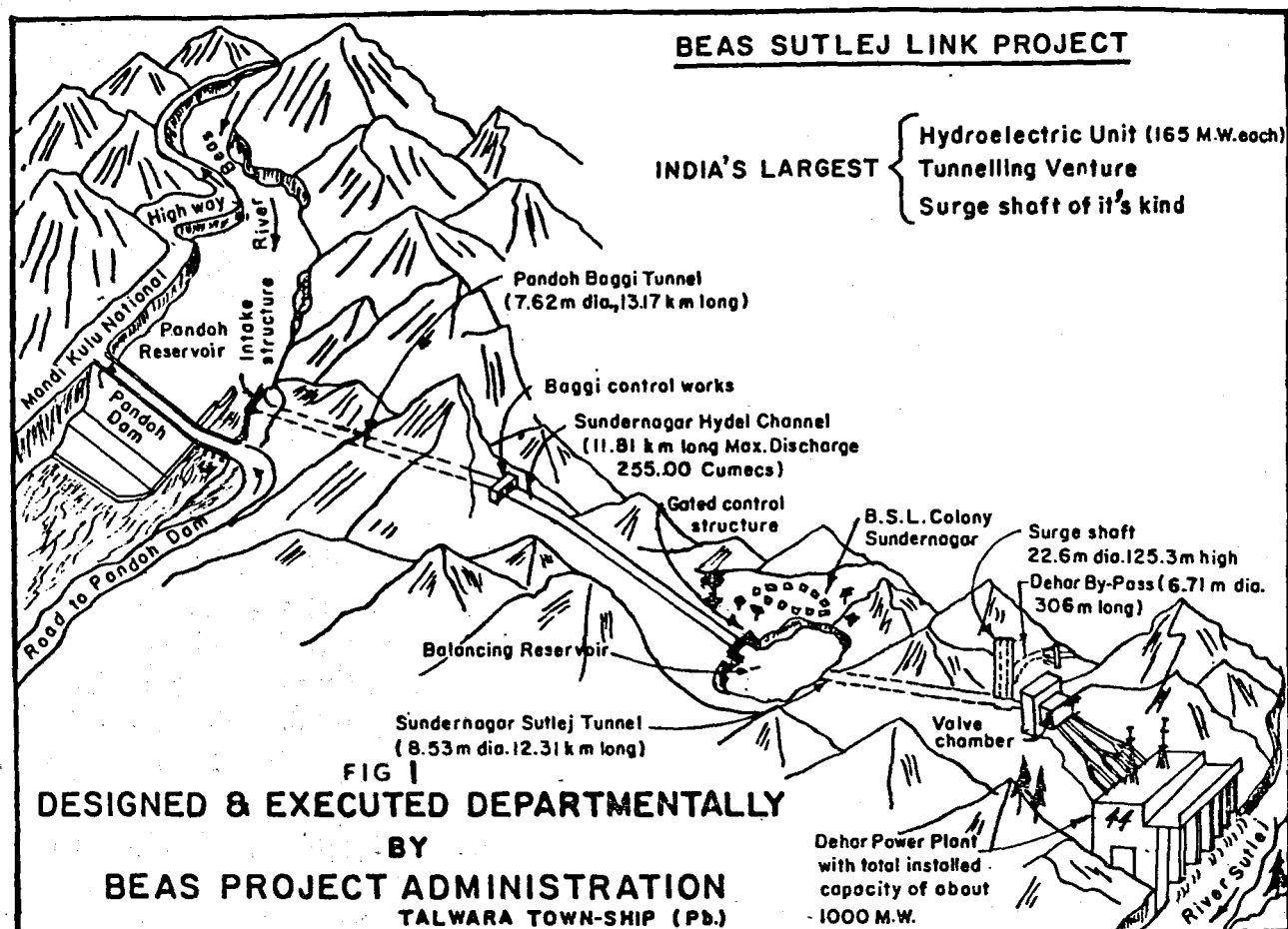
Beas Sutlej Link Project

A brief description of various works covered under this Project is given below :

Pandoh Dam

This is a diversion dam with top El. 899.16 m across river Beas about 21 km upstream of Mandi town in Himachal Pradesh. Scheduled for completion in one working season of 1976-77, it would be a zoned earth-cum-rockfill dam, with upstream sloping core rising 61 m above the river bed. For passing floods, a chute spillway having 9939 m³/s capacity at the

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maximum Pandoh Reservoir elevation, with flip bucket at discharge end, has been provided along the left embankment in cutting reach. An intake structure, located on the left bank, upstream of the spillway, has also been provided for feeding the water from Pandoh Baggi Tunnel.

The dam site is located in the mountainous reach of the river Beas in seismic region, and the Pandoh Reservoir is formed in a deep and narrow canyon. Due to steep river bed slope, large quantities of bed load sediment are rolled down. It is anticipated that Pandoh Reservoir might be silted upto the spillway crest level in a few years. This likelihood of rapid sedimentation of the reservoir posed difficult problems in the matter of designing the spillway and the intake structures, for diversion of water, free of bed load, to the water conductor system. The two structures are therefore designed as a common complex, since the

design of spillway is greatly influenced by the needs of the intake structure. Consequently, a series of hydraulic model tests were carried out at the Central Water and Power Research Station Pune, and at the Research Institute Amritsar, to evolve a suitable layout of works at Pandoh. As a result of these studies, a high level intake, located close to the spillway crest, with a divide wall in front of it and a curved approach upstream has been provided. The spillway is designed to function more or less like a barrage; and a flip bucket at the end of the spillway is considered more suitable in view of its ability to throw away the bed load finding its way over the spillway crest. Outflow through the spillway, which has five spans of 12 m each, is controlled by means of radial gates of 13 m height.

Similarly, on the recommendation of CWPRS Pune, concrete blocks of size about 1.52 m × 1.52 m × 0.91 m and 1.52 m × 1.52 m × 0.61 m over 300 mm

filter material bedding have been provided on part width of the Pandoh Dam toe, adjoining the spillway right wall, so as to take care of parallel flow with eroding velocities noticed on the model.

Pandoh-Baggi Tunnel

This carrier tunnel is 13.17 km long and 7.62 m diameter with a maximum discharge capacity of 255 m³/s. The upstream and downstream invert levels of the tunnel vary from El. 868.68 m to El. 835.15 m. It has a slope of 1 in 22.2 for the first 457 m length and then follows a slope of 1 in 670. A concrete lining of 250 mm thickness has been provided in the normal reaches of this tunnel. The thickness of the lining increases to 375 mm in reaches of poor rock strata, and is further reinforced with steel bars in certain reaches. As the rock strata varied along the alignment, rock supports comprising of steel ribs at varying spaces, depending upon the rock condition, were provided soon after excavation. Contact grouting has been provided throughout the length of the tunnel, and consolidation grouting is also to be done in certain reaches.

The Baggi control works, at the exit of Pandoh Baggi Tunnel, have been provided with regulation and emergency gates for regulation of inflow from Pandoh to meet the fluctuating demand of Dehar Power Plant. Studies on the gates were executed at CWPRS Pune.

Sundernagar Hydrel Channel and Balancing Reservoir

The Sundernagar lined hydrel channel takes off from Baggi Control Works and outfalls into the Balancing Reservoir, located upstream of the Sundernagar Sutlej Tunnel. This channel has been designed as a trapezoidal section for a maximum discharge of 212.4 m³/s. It is a concrete lined channel, about 11.81 km long, and is aligned as a contour canal. The hydrel channel runs along the foot hills through rugged country, and has to cross a large number of torrents necessitating construction of sixteen aqueducts, one superpassage, and a silt ejector in the head reach. Fourteen bridges have been constructed to provide communication facilities to the local population.

An automatic gated control structure has been

provided at the tail of this channel, irrespective of the discharge and water level in the Balancing Reservoir downstream. This has been done for the safety of the lining of canal.

The Balancing Reservoir has a 370 hectare metres capacity, so as to meet the fluctuating demands as a result of changing load conditions at Dehar Power Plant, which would act as a peaking station in the grid.

Sundernagar Sutlej Tunnel

This tunnel is the third and the last link of the long water conductor system for feeding the Dehar Power House with water of river Beas. The tunnel, 12.31 km long and 8.53 m diameter starts from the Balancing Reservoir and terminates into the Surge Shaft of the headrace complex. The tunnel is concrete lined, and reinforced in certain reaches. Rock supports, comprising steel joist ribs, have been provided, keeping in view the rock strata met with along the alignment of the tunnel. Contact grouting has been provided throughout the length of the tunnel, and consolidation grouting is also to be done in reaches.

Nearly 30,000 tonnes of steel supports used in both the tunnels would correspond to about 500 km length.

Dehar Power Plant, Surge Shaft and Appurtenant Works

The diverted river Beas water is discharged into the Surge Shaft, from where steel lined penstocks carry the same with a head of about 300 m to the turbines of Dehar Power Plant, having an ultimate installed capacity of 990 MW. Provision has also been made to bypass water into Bhakra reservoir, in case it is surplus to the requirement of Dehar Power Plant.

The Surge Shaft is of differential type and has been provided to take care of abrupt load changes in the Power Plant. This Surge Shaft, situated at the junction of the Sundernagar Sutlej Tunnel, the 6.71 m diameter by-pass tunnel and the three penstocks, is 22.86 m in diameter and 125.3 m high, having a reinforced concrete riser of 7.62 m diameter placed inside and monolithic with the main shaft. This structure is the largest of its kind in the country. Due to various

openings in the structure, approach to the design was complicated and thus to supplement the conventional structural analysis of various components, CWPRS Pune carried out photo-elastic tests for determination of stresses and their concentration around the openings to arrive at safe and economical design. Hydraulic model tests were also carried out at CWPRS Pune, to determine the surge elevations for different working conditions. Three penstocks of 4.87 m diameter take off from the fan shaped lower chamber of the Surge Shaft, and terminate at the valve chamber where butterfly valves are housed. Downstream of the valve chamber, one penstock header for future units terminates, but the other two penstock headers are bifurcated into four branches, 3.35 m diameter each, for the four generating units of Dehar Power Plant in the first stage.

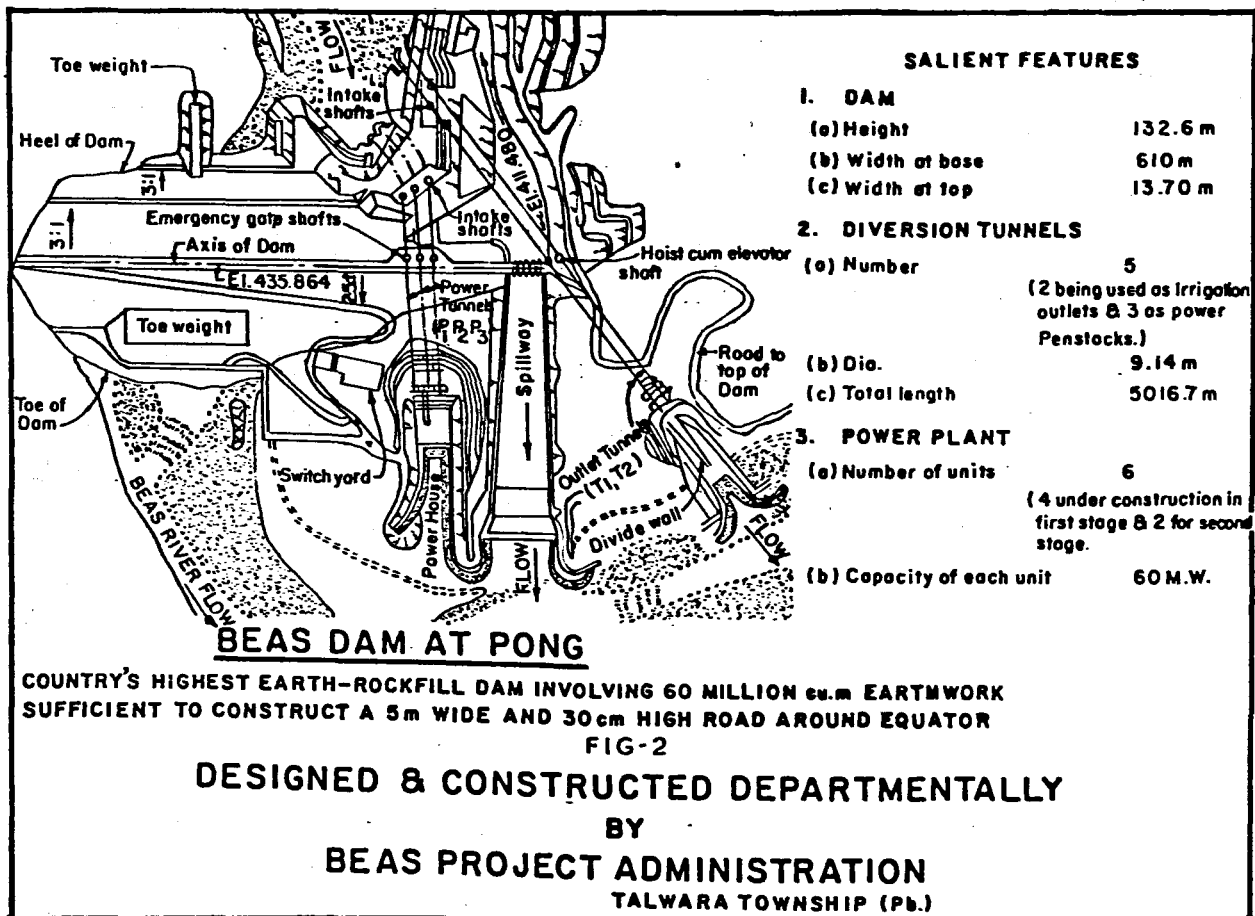
A controlled by-pass of 212.4 m³/s capacity takes off from the Surge Shaft riser to divert surplus water, not required by Dehar Power Plant, into Bhakra

reservoir, through a 6.71 m diameter tunnel, a chute spillway and a flip bucket.

Dehar Power Plant is a multi-storeyed reinforced concrete structure about 50 m high, with generating units spaced at 15.24 m. This Power Plant is designed to house six units of 165 MW capacity each, four in the first stage and two in the second stage. These units are the largest hydro-electric units in the country. To accommodate various service facilities, a service bay and galleries have been provided in the Power Plant Structure. Power will begin to generate from the first unit of this Power Plant in 1977. Gates and hoists have been installed at various locations such as Pandoh spillway, Baggi control works, tail regulator, bypass, valve chamber and powerhouse for efficient and proper control of water.

Beas Dam at Pong

The brief details of the various components of this project are :



Beas Dam

This is an earth-cum-gravel fill dam, 132.6 m high from the deepest foundation level. It has a central impervious core, with sand and gravel shell zones on either side. The length of the dam is 1950 m at the crest. The width at crest is 13.7 m and that at its base is about 610 m (excluding toe widths). The earth core-gravel shell dam has been considered suitable in view of the nature and geological stratification of the foundation rock, besides its location in seismic zone. The materials for the dam are local deposits of shales, sand rock and river gravels, available within economical leads. The quantity of embankment materials including impervious core material, filter material, pervious material and toe widths is approximately 35 million m³. Adding to it the quantity of excavation, the total earthwork of nearly 60 million m³ is sufficient to construct a road 5 m wide and 30 cm high all along the equator.

The drainage tunnels having drainage holes have also been provided to intercept seepage on the two abutments. The dam embankment has been adequately instrumented to enable study of the behaviour of the dam structure for its safety during construction as well as in the post construction stage.

A radial gate controlled spillway with a capacity of approximately 12374 m³/s at maximum reservoir elevation has been provided at the left end of Beas Dam. This spillway is one of the largest in the country. A stilling basin 99 m long and 213.4 m wide has also been constructed for energy dissipation. The spillway is guided by R. C. C. training walls on either side.

All the studies for the hydraulic and structural design of the spillway and the stilling basin were conducted at CWPRS Pune.

Diversion Tunnels, Intake Structures and Control Gates

The diversion of the River Beas was achieved through five tunnels of 9.14 m diameter and having aggregate length of 5016.7 m. Two of these tunnels are being

used as outlet tunnels for irrigation releases and the other three are for power penstocks of 7.28 m diameter, to operate the six units of Pong Power Plant, being constructed in the stilling basin downstream of penstock tunnels.

The water supplies are led into these tunnels by means of intake structures. The high seismicity of the Beas Dam site and other local geological and operational consideration posed difficult problem in selection of the type of intake. After extensive studies, broad based drop inlet type circular intake structures were adopted for the outlet and penstock tunnels. As the structure was to remain submerged for most of the time, its behaviour during an earthquake was not amenable to usual known procedures of design. The experimental technique was, therefore, employed to ascertain the structural behaviour. These studies were done at the School of Research and Training in Earthquake Engineering, Roorkee.

A series of hydraulic model studies were carried out at the Central Water and Power Research Station Pune, and the Irrigation Research Institute Amritsar, to examine the hydraulic performance of the above intake structure so as to incorporate necessary remedial measures against possible vortex formation. As a result of such tests, a peripheral grid structure at about the minimum reservoir level around each such structure has been provided.

For controlling irrigation flows and for closing power penstocks, high head outlet gates (slide type), and high head emergency gates, have been provided on outlet tunnels and power tunnels respectively. For high head gates, it is very necessary to study flow conditions past such gates. Necessary model studies were carried out for these conditions by CWPRS Pune, and I. P. R. I. Amritsar and they have suggested a number of improvements in respect of shape of the gate, hydraulic down-pull, air requirements with locations to avoid cavitation. These recommendations were taken care of while designing/fabricating/installing these gates. Incidentally, the slide gates used for operation of irrigation outlets are designed for the highest reservoir head in the country.

Similarly, stress analysis on models for the cylindrical bulk head gates provided for the closing of intake structures was carried out at CWPRS Pune. The original design of flat bulk head gate was accordingly modified as a result of experimental studies.

Pong Power Plant and Appurtenant Works

This power plant, a multi-storeyed reinforced concrete structure, is located in the stilling basin downstream of Penstock Tunnels. Four units, 60 MW capacity each, are to be installed, with a provision of two similar units to be installed in future.

These four first stage units shall be operated for generating electric energy, by water passing through two

penstock headers, 7.28 m diameter each, installed in power tunnels, and each of these bifurcated into two branches of 5.025 m diameter with angle of 35° between them. These wyes are of internal splitter type with two plates spaced at 750 mm braced together and space in between filled with concrete. The wye is designed for a hydrostatic pressure of 125 m including water hammer. CWPRS Pune, ascertained on model studies the pattern of stress analysis, its distribution on various components under different operating conditions, and hydraulic efficiency of such complicated large-sized wyes. These wyes, each weighing nearly 175 tonnes, are the largest in the country. First of the four units would start generating power in mid 1977.



Hydraulic Scale Models As An Aid To Management Decisions

A. VIJIARATNAM *

Introduction

It is heartening to know that the Central Water & Power Research Station (CWPRS) Pune, is celebrating its Diamond Jubilee this year. The Port of Singapore Authority (PSA) has had 5 years of close association with the CWPRS. This association has been very fruitful in that the CWPRS has helped the PSA by advising on a large number of port development projects. I am, therefore, particularly pleased to contribute this article, on this occasion and wish the CWPRS many years of success in its scientific contribution.

The PSA in its present institutional character came into being in April 1964 and took over the functions of the erstwhile Singapore Harbour Board and some functions of other Government departments. Provision and maintenance of adequate and efficient port services and facilities, regulation and control of navigation within the Port and its approaches and provision of pilotage services, conservancy of the Port waters, improvement and development of the Port and promotion of its use became the PSA's responsibility.

Special Purpose Vessels

The decade of the 1960s saw impressive increases in shipping activities. Containerisation was gaining popularity and specially designed container vessels required special shore based facilities for loading and unloading containers. The closure of the Suez Canal to international shipping gave rise to the emergence of

giant tankers. Very Large Crude Carriers of 200,000 DWT and above became a common sight towards the end of 1960s. The VLCCs required wider and deeper channels and suitably designed terminals for loading and discharging their huge cargoes.

Physical Characteristics

Singapore had the potential to provide such facilities not only because of its ideal strategic position on the shortest route between the Middle East and Japan but also because of its geographical advantages. Being almost on the equator, Singapore is out of the 'Cyclone' area and enjoys fine weather and good visibility throughout the year. Impediments or hazards to navigation attributed to adverse weather conditions, poor visibility, fogs etc. do not exist in this region. Singapore is also endowed with natural deep waters in close vicinity of the shores. This has facilitated establishment of offshore terminals for tankers upto 310,000 DWT.

However, Singapore has had other problems mainly caused by tides and tidal streams. Tides in Singapore are of 'mixed' type with large diurnal inequality in heights of low and high waters, thus giving rise to a complicated pattern of tidal streams. The strong north-east monsoons in South China Sea and southwest monsoons in the Bay of Bengal influence tidal streams in the Malacca and Singapore Straits. Coupled with this influence, which varies depending on the strength of monsoons, there is yet another influence, and that is the

* Director, Engineering Services Division, Port of Singapore Authority.

meeting of various straits, which also influence the tidal flow pattern. Due to lack of adequate sea area and the need for vessels to stem the currents when approaching a terminal, it has become necessary to restrict ship movements only to ideal tidal conditions. Large scale capital dredging has been essential. Dredging poses problems of finding suitable dumping grounds.

Reclamation and Its Effect

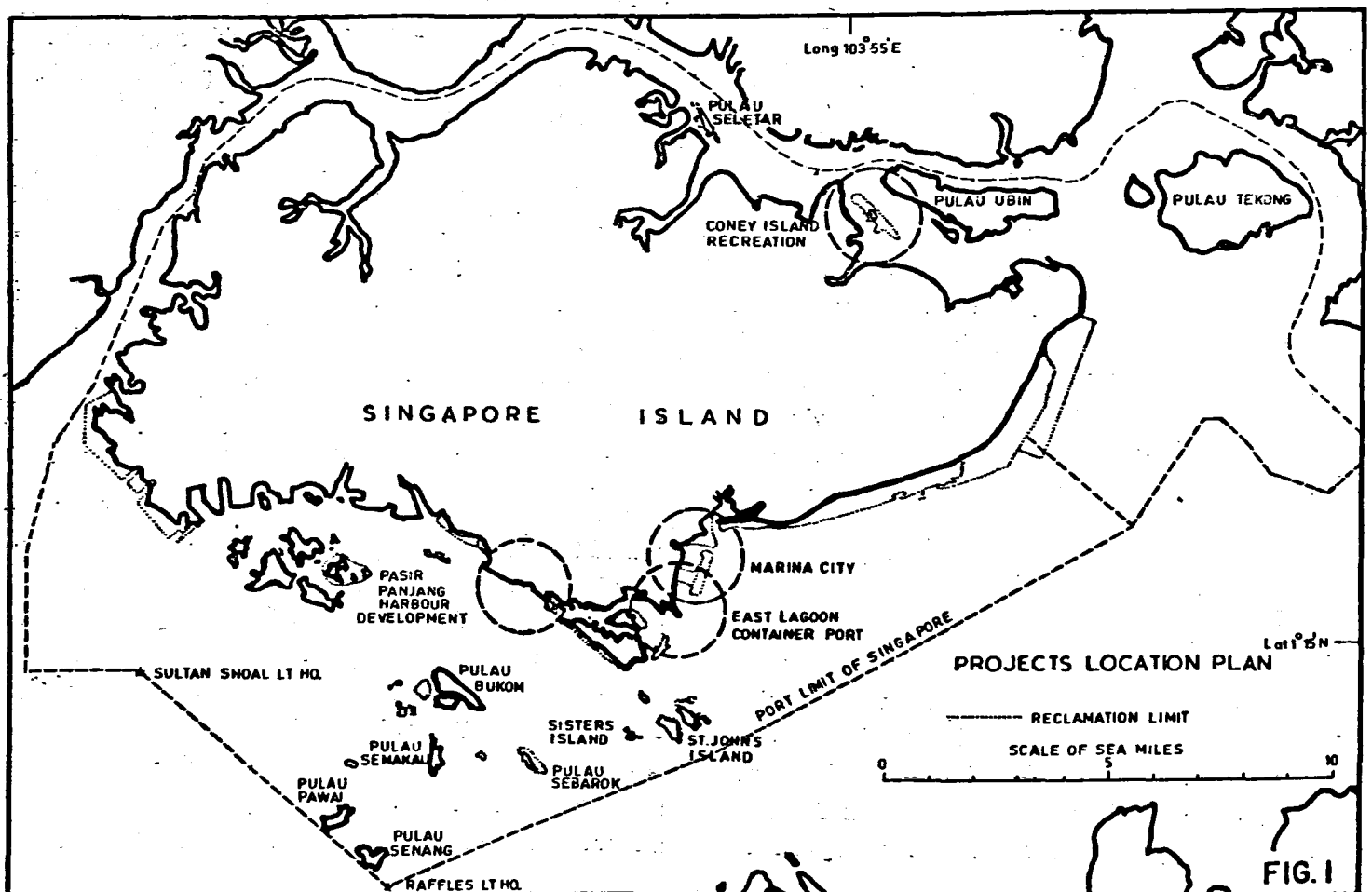
Land is at a premium in this City-State. Industrial Development has made big demands on available land. This has in turn required new areas for housing and recreation. To this end the Housing & Development Board undertook large reclamation along our southern shore in the eastern sector. Some islands were also reclaimed for industries. Fill material for such projects was obtained from the sea from shoals which were potential hazards to navigation. Such large scale reclamation and accompanying dredging had to be studied and it was one of the factors which led the PSA to

commission the CWPRS to build a hydraulic model. The CWPRS has studied these projects and suggested suitable modifications wherever necessary to ensure that natural deep channels in our harbour are not adversely affected.

PSA has also developed a few reefs and islands into marinas and recreational resorts. These resorts are in close proximity of shipping channels and are therefore, subject to occasional pollution caused by ships discharging slops. Two such resorts are located in the East Johore Strait and are affected by land based pollution caused by industrial effluent and sewerage. Hydraulic models were used to study the effect of such pollution on the beaches.

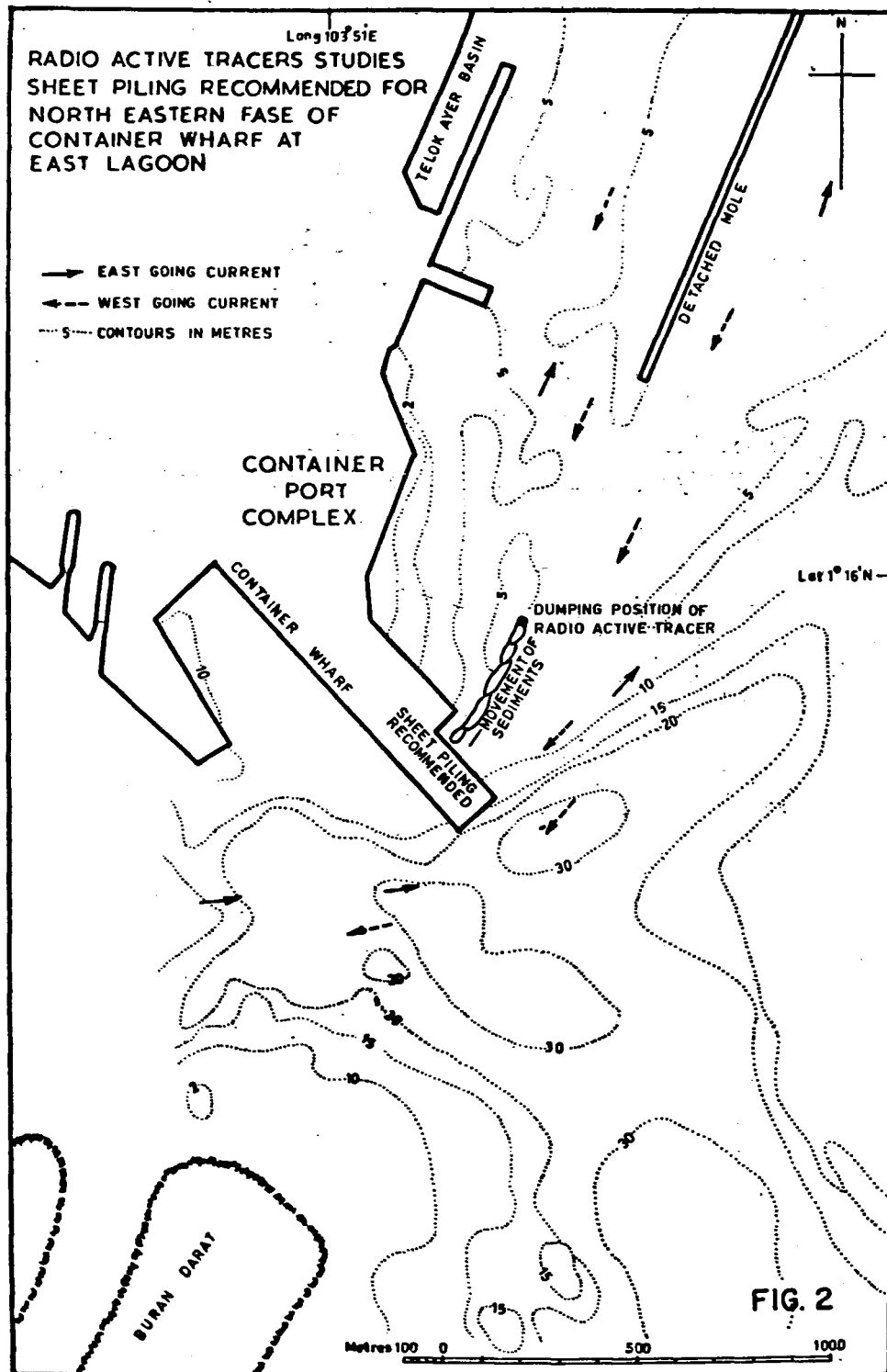
Port Development

Port development to provide much needed berthing space to cater to increasing trade, container berths and fleeting area for lash ship operations has been rapid



in the last 6 years. Most of new berths including our Container Port are located on reclaimed land. Apart from the problems posed by reclamation, there are other aspects such as capacity of channels, their depths, ease of navigation and construction, which have to be considered. Navigators insist on alignment of berths fair to

the flow pattern, hydrographers view the development from the point of maintaining adequate depths, and civil engineers look at it from their own point of view. Professionals from these three different disciplines naturally have differing view points and each group has valid reasons. The management looks for the most



economic methods and to get optimum utilisation of the new facility. This is where the Model Engineer has a role to play. By simulating the actual prototype conditions in the model they can view all the important problems readily and come up with an answer which satisfies all requirements or at least the best possible compromise.

Model Studies

It is not intended to describe all the development projects referred to the CWPRS by the Singapore Port Authority but the following examples will be an apt testimony of the varied nature of projects studied by the CWPRS. (See Fig. 1 for locations of projects.)

East Lagoon Container Port

In late 1960s PSA decided to build a Container Port to cater for the Third Generation Container Vessels. Considerations of access to the existing port area, warehouses and lack of adequate sea frontage, made it expedient to reclaim area immediately eastward of the

then existing Keppel Wharves and locate the Container Port there. The berthing face 900 metres long had to be aligned normal to the flow conditions. The original design was of open piled structure to allow for free flow of tidal waters through the piles. Tidal stream observations and radioactive tracer studies indicated bed load movement from east towards the Container Port. The project was studied further in the model and results of field studies were confirmed. To prevent siltation within the lagoon the eastern side was sheet-piled. Problem of ship-handling has been overcome by programming berthing/unberthing operations during periods of 'slack' or during weak flood currents. (See Fig. 2)

Pasir Panjang Wharves

Some 90 hectares of low-lying area along the western shore line has been reclaimed. 675 metres of wharves have been built for coastal vessels of 6.5 metres draft. In addition, a small basin has been provided for lighters' operation and for lash barges. Breakwaters have been

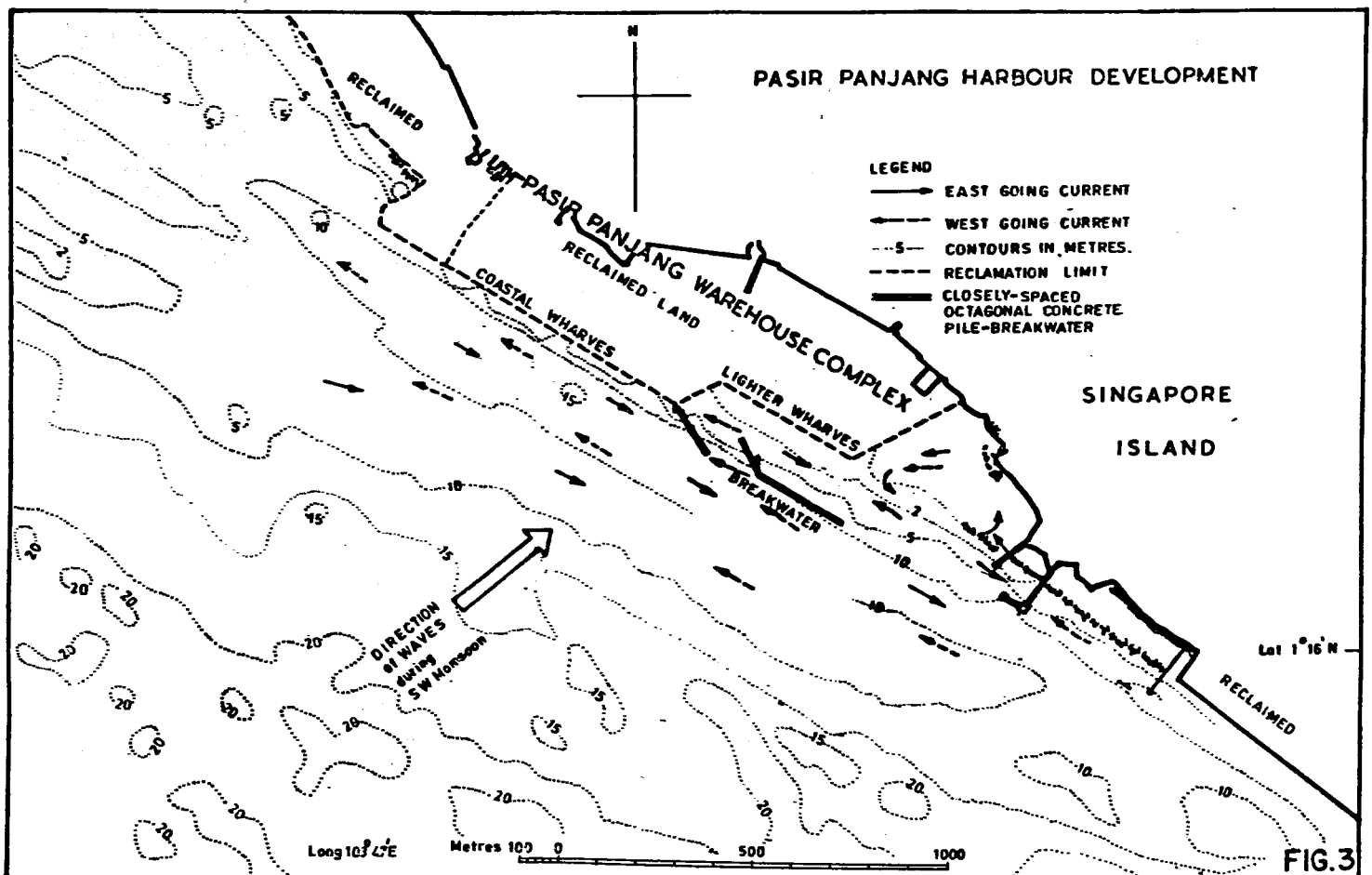


FIG. 3

constructed to create favourable conditions for lighters within the basin.

Prior to commencement of the reclamation, tracer studies were carried out to detect the movement of sediment during the reclamation process. This was necessitated due to existence of an intake of a power station eastward of the reclamation site. The study indicated that the part of fill material would travel eastward. To eliminate this, silt screen was provided at the eastern edge of the reclamation. When management decided to create a basin for lighters it was realised that the sheet piled sea face of the reclamation created unfavourable conditions for lighters. To overcome this problem, on the advice of CWPRS suitably aligned breakwaters of sufficient length were constructed to create tranquil conditions with due regard to the need for tugs towing the lighters to and from the basin. (See Fig. 3)

Marina City Project

The Housing & Development Board proposed reclamation of some 150 hectares of shallow sea bed area in the eastern sector of the Port.

The project was referred to CWPRS with a view to know the effect of the reclamation on the rivers flowing through the area, the change in the flow pattern due to reclamation, and consequent effect of such change on the Container Port and its future expansion and adjacent anchorages. After extensive model studies the CWPRS advised that the original proposal required considerable modification to eliminate or at least to largely minimise the ill effects of the reclamation. Modified proposals were accepted by the Government and the project is now in progress. (See fig. 4).

Coney Island Recreational Resort

PSA decided to reclaim shallow areas around an island in the East Johore Strait and develop it for recreational

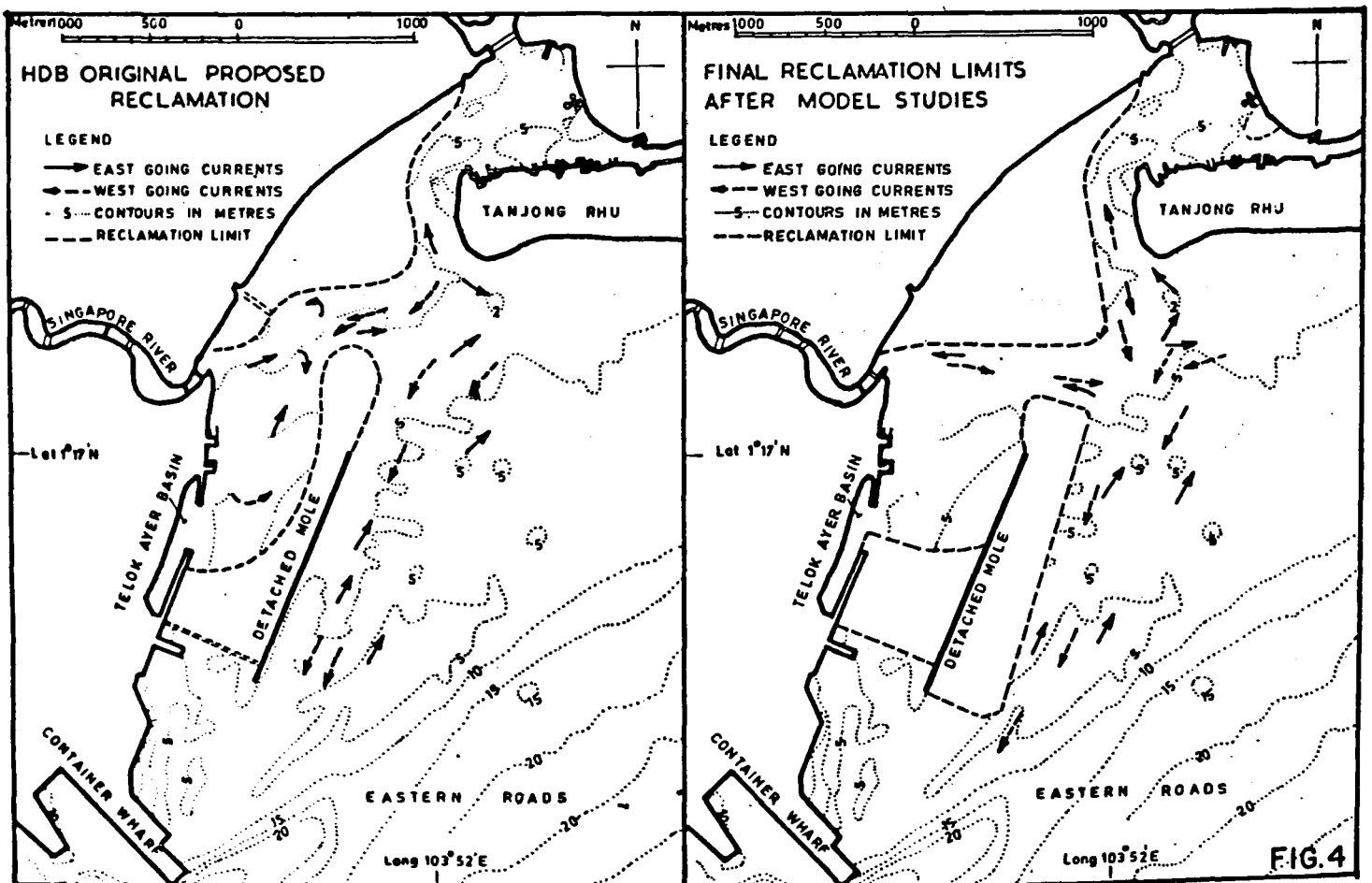
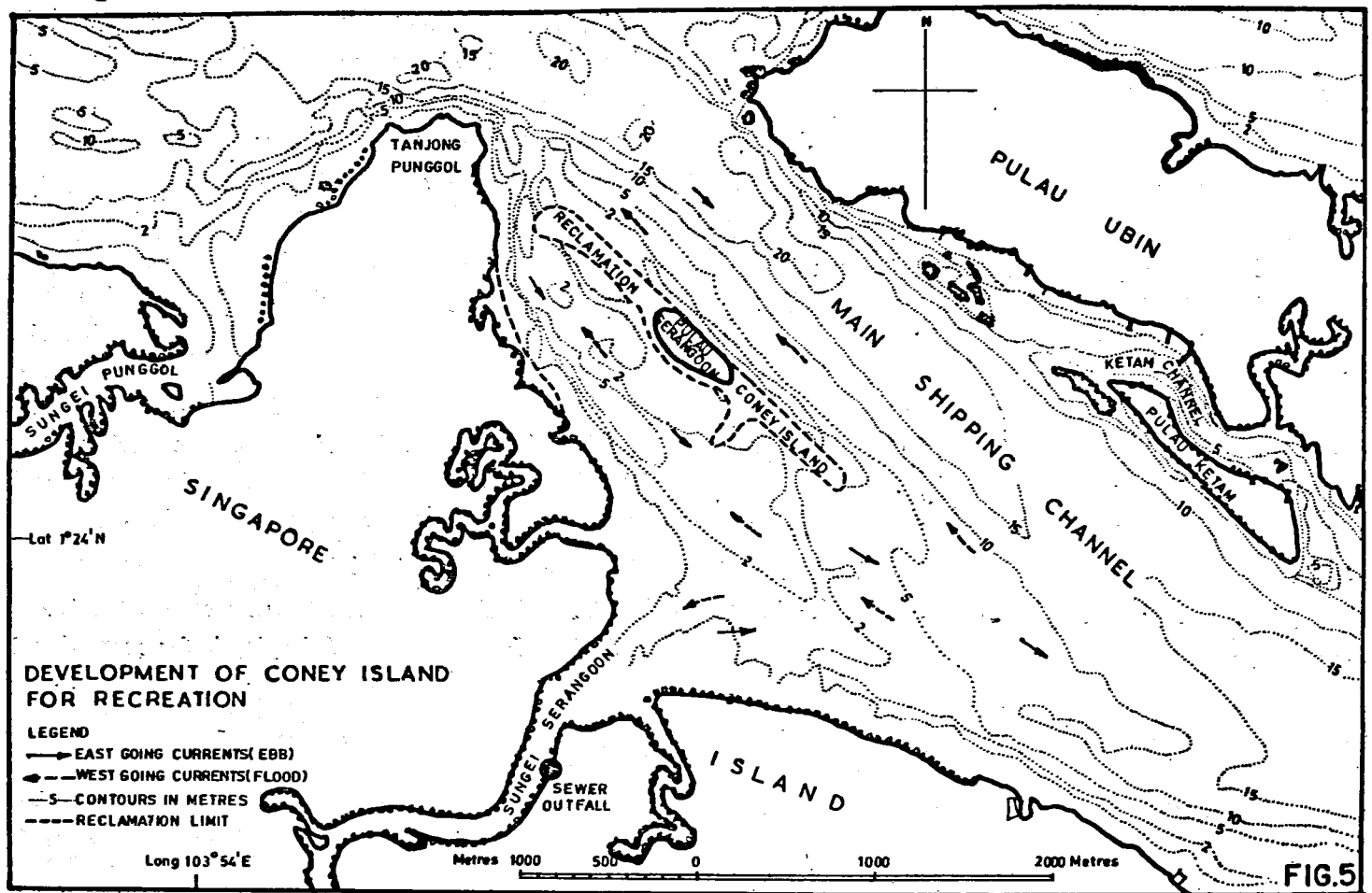


FIG. 4



purposes to provide marinas, swimming beaches, water sports etc. Original land area of 13 hectares was proposed to be increased to 50 hectares. However, PSA was concerned about the existence of a sewerage outfall on the eastern bank of the Serangoon River at its confluence with the main channel of East Johore Strait and its effect on the nearby Coney Island. The CWPRS was approached with a request that the effect of the sewerage outfall and consequent pollution be studied. The model studies indicated that the effluent discharge from Serangoon River would not pose any problem on the swimming beaches and the pollution of the water was well within tolerable limits. The project has since been completed. (See Fig. 5)

Conclusion

Model studies have been carried out for varying types of development projects for the PSA and the private sector. In most cases original proposals were modified to achieve the optimum benefit. In some cases such modifications resulted in additional initial expenditure in order to obviate even larger expenditure in

future. The Model Engineer has the advantage in that he can actually see both pre-development and post-development conditions in the model and taking into consideration overall requirements, he can reach the most acceptable solution to the problem. The results of model studies based on scientific considerations help the Management in taking decisions involving large capital outlay. It is possible that technical expertise and experience in various nautical and engineering disciplines may render it possible to arrive at the same conclusions as the ones arising from the model studies, but more often than not this will be coincidental. Apart from the economic aspect, which is generally of the highest consideration, Managements also require some guarantees that the project would be functional and without any restrictions on the users, and this is why Hydraulic Scale Models are preferred because of their versatility in dealing with most marine development. It was with this in mind that I chose to entitle this article as 'Hydraulic Scale Models as an aid to Management Decisions'.

The Interactions between the Central Board of Irrigation and Power and the Central Water and Power Research Station

C. V. J. VARMA *

Sixty years is a short span of time in the life of an institution or the nation. What Engineering and Technology have contributed to the betterment of the living conditions of the Indian people in this short period is really impressive. From the Grand Anicut to the mighty Nagarjunasagar and Bhakra, from the 20 kw hydro-station at Darjeeling to the 900 MW Sharavati, from no transmission line at all to the All India Super Grid, from the tiny Coolidge tube in the College Science Laboratory to the Giant Atomic Power Station, much that we take for granted today are the results of Indian Technology and Engineering Development. They are also the outcome of the innovation and persevering efforts of many many pioneers, dedicated men and women, who have sometimes given their lives to learn and apply what we now know today and use. In the early years it was a lonely and hungry business for those who were in research. With simple gadgets like a current meter, a wading rod, a levelling staff, a dumpy level, a bottle sampler and such lowly items, and a small band of semiskilled labourers, working in remote virgin areas, they unravelled the mysteries of regime flow in incoherent alluvium, the uplift pressures in weir, meandering and tortuosity in rivers and many other profound problems. Later as these inventions began to work and one great innovation led to the promise of many more, whole groups of people got involved in these investigations. In a relatively short period of time, this business of research and development became more

and more complicated as the demands on the research workers mounted. As the tasks became bigger and the people became impatient for quick results, the techniques had to improve, and the equipment became more sophisticated, and presently we are having highly developed institutions where a galaxy of specialists and experts direct their co-ordinated efforts to probe the dark areas of knowledge, and come up with newer answers. Thus have developed our National Research Laboratories, the modern temples to the Goddess of knowledge, and the Central Water and Power Research Station Pune, with its huge buildings, halls and halls of highly sophisticated equipment, and stack after stack of learned periodicals and publications, is one of this family.

It was in the year 1935, when the Central Board of Irrigation was discussing the question of 'Tortuosity of Rivers and their Training by means of Embankments' at their annual session, that the spark was kindled for the birth of the Central Water and Power Research Station Pune, in its present form. The Irrigation Development Division of the Government of Bombay had been functioning for some years past at Pune and had been doing commendable work. But in 1935 the Bombay Government had more or less come to a conclusion that they would not be in a position to carry on hydrodynamic research at that Centre further. During discussions on the above subject, the President

* Secretary, Central Board of Irrigation & Power,
New Delhi.

of the Board posed the question as to who would continue research on this subject. Members of the Board discussed the question in great detail and finally recommended that a central research station should be set up under the aegis of the Central Board of Irrigation. At the next meeting of the Board in 1936, the Board examined the question in greater detail, defined the scope of work to be undertaken at the proposed central research station, discussed the financial aspects involved, weighed the relative merits of locating the station at Pune as against an alternative location at Lahore and stressed the need for central financial support. After further persuasion the Central Government was prevailed upon to accept these proposals, and as the outcome of the efforts of the Central Board of Irrigation, the Government of India sanctioned the continuance of the Pune Research Station for a period of five years. In 1942, the members of the Central Board of Irrigation visited the Central Irrigation and Hydrodynamic Research Station at Pune. Being impressed with very great value of the work being done by model experiments at the research station, the Board pressed on the Government of India to make the institution permanent in order to ensure the continuance of the work and the accumulation of data and experience. In response to these requests the Government of India decided to continue the Central Irrigation and Hydrodynamic Research Station on a permanent basis. From these beginnings the research station has grown from strength to strength, and it is now an institution of international standing, having been recognised as a regional research station of the United Nations Economic and Social Commission for Asia and the Pacific.

Ever since its inception, the CWPRS and the CBIP have been having close collaboration in all their activities aimed at improving the technology for the development and utilisation of the water resources of the country. One of the earliest techniques successfully developed by the CWPRS and propagated by the CBIP related to the control and training of our rivers by studying their behaviour on models. The battle for Dibrugarh against the onslaughts of the mighty Brahmaputra was won in the Hydraulic Model Laboratories of the CWPRS Pune. Similar was the case with the control of the Kosi, Bihar's river of sorrow. The story

of these efforts are detailed in CBIP Publication No. 60-River Behaviour Training And Control by Dr. D. V. Joglekar. In the year 1959, when the CBIP initiated the Fundamental and Basic Research Programme, the CWPRS took up quite a substantial additional load, and undertook studies on design of channels, sedimentation in streams and reservoirs, vibrations in soils and concrete, instrumentation, utilisation of radio isotopes in subsoil investigation, soil compaction control and coastal erosion.

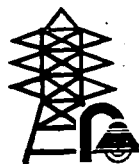
Substantial work on these subjects were carried out by the CWPRS and were reported at the various Zonal and Annual Sessions. The Board during its deliberations became specially concerned with the basic problem of Design of Alluvial Channels and the Development of Advanced Hydraulic Instrumentation. Accordingly in 1962, the Board recommended to the Government of India, to set up two special cells at the CWPRS, one to collect, compile, study and analyse all available hydraulic data on the performance of various canals in the different States and the second to develop and also assist the development in the concerned State Research Stations, advanced instrumentation for measurement, recording and telemetering of hydraulic parameters both in models and prototypes. The special cells were soon set up at the CWPRS and their contributions to the subject have been phenomenal. By 1966 quite a lot of study and analysis had been carried out on the subject of alluvial channels and this led to the evolution of improved formulae for design of such channels which was presented at the VI Congress of the ICID held at New Delhi. Further work led to the CBIP publications dealing with statistical design formulae for alluvial canal systems, current practices in canal design in India, and design practice for unlined incised canals. On the instrumentation side, the development has leaped from the simple resistance type wave height recorder for models to the highly sophisticated command controlled multi-channel telemetry system, multi-channel data loggers etc.

On a personal level the Central Board of Irrigation and Power has greatly been benefitted by its association with the CWPRS. The Director of the CWPRS has been always associated with the policy formulating and

programming functions of the CBIP a permanent member of the relevant committees of the Board. The Board and especially the Fundamental and Basic Research Programme owes a great debt of gratitude to the late Dr. D. V. Joglekar, former Director of the CWPRS, who nurtured and guided that programme ever since its inception till it was well established. In its turn, the CBIP has given public recognition and acclamation to the achievements of the topmost research workers of the CWPRS by honouring them with the award of the CBIP Medals and Certificates of Merit. The officers of the CWPRS have also won recognition by being elected to high offices in various International

Organisations such as International Association for Hydraulic Research, International Commission on Irrigation and Drainage, for which the Board functions as the National Committee.

Thus the interaction between the CWPRS and the CBIP has been a two way street and both the organisations have prospered and grown due to this interaction. It is our earnest hope that in the years to come this mutual co-operation and collaboration will increase manifold and lead to substantial contributions to the betterment of mankind.



Role Of CWPRS In Public Works Of Gujarat

M. D. PATEL *

Development Activity

The Gujarat State came into being about sixteen years ago after bifurcation from the then undivided Bombay State. Unlike other States, the Public Works Department of the State till today retains the original composition and covers practically the entire gamut of public works viz. roads, highways, buildings, bridges, irrigation, ports and harbours. Nevertheless, the rate of progress on all these aspects of development has significantly increased over these years. At the time of bifurcation the yearly budget of the Gujarat PWD used to be about Rs. 300 million. The figure stands at Rs. 1300 million in 1976. Even taking into account about 200% rise in cost of works, the rate of activities now is more than double the rate during 1961-62. With the traditional efficient managerial skills at its command, the State has made rapid allround progress. The contribution by the PWD to this progress can be seen from Table 1.

Assignments for CWPRS

Behind every engineering work lies a complex history of ceaseless efforts put in by various teams of workers, investigators, surveyors, planners, designers, engineers and contractors. Though we have got now well organised teams of engineers, designers, researchers and investigators, the role played by a national institute like the Central Water and Power Research Station Pune (CWPRS), especially in these early years of our new born state has been highly phenomenal. CWPRS teams

Table 1

Sl. No.	ASPECT	Status during	
		1961-62	1975-76
1	2	3	4
1	Length of black topped roads (km)	4400	15100
2	Length of surfaced roads (km)	12000	23000
3	Number of major bridges	157	479
4	Number of medium and major irrigation projects completed	6	49
5	Number of medium and major irrigation projects in hand.	52	68
6	Area under irrigation (hectares)	33500	146600
7	Trade through Gujarat ports (lakh tonnes)	24	31

have been involved in planning of spillways for most of the major irrigation projects of the State. They also have contributed to the planning, locating and design of protective works of most of the major bridges on the mighty rivers of the State. They have provided consultation for many port works and have helped design of most of the major flood protective works and river training works. After the devastating earthquake of Broach during March 1970, the CWPRS scientists carried out field investigations in collaboration with the State Geologists. A number of seismographs were set up in the State after this study. Apart from these assignments, the institute has provided multifarious consultations on a number of

* Secretary, Public Works Department, Gujarat State.

jobs, from material testing to geophysical investigations for foundation, from photoelastic model testing for foundation to design of gates and outlets, from setting up seismological observatories to setting up of hydraulic laboratory for the State. A list of jobs done by the CWPRS for the State will be long and hence I shall be content by describing the role played by CWPRS for a few of the outstanding engineering structures built by Gujarat PWD during the last decade.

Ukai Project

This largest multipurpose project of Gujarat, with storage as large as Bhakra, comprises about 5 km long, 60 m high earth-cum-masonry dam across the river Tapi. The dam taps about 50% of the river runoff on an average year. The gross and live storage capacities of this reservoir are 0.85 and 0.71 million hectare metres respectively. Besides firming up irrigation of 0.227 million hectares under Kakrapar weir command, the project will irrigate an additional area of 0.152 million hectares. Apart from irrigation, the storage is being used for development of hydropower through the power house downstream of the main dam. All three of the four units installed are generating power now. The third most important purpose of this project was to provide partial protection to the flood ravaged downstream country side and urban population of more than 500,000 people of Surat, the second largest city of Gujarat. Surat is situated near the mouth of the river where it drains an area of 64000 km² with an average annual rainfall of 775 mm, the maximum rainfall being 2000 mm. The Ukai reservoir with a water spread of 520 km² provides adequate flood detention space. With the help of advance releases and the detention storage the standard project design flood of 49468 m³/s can be moderated to such an extent that the flood passing by Surat is less than 28300 m³/s.

The CWPRS has played a very significant role in planning and construction of such a large multipurpose project and helped the State to build a safe structure in scheduled period of construction. This has not only helped us to keep the cost of construction low but also helped in reaping the fruit quickly so as to add to the prosperity of the nation. The main assignments for CWPRS on this project were : geophysical investigations

for discontinuities and shear zone in foundation; investigations for river diversion works; design of spillway on the basis of hydraulic model study; design of diversion scheme which was an open cut channel and one of the largest flood diversions ever contemplated; design of emergency gate of penstocks for power house; design of crest gates and stop logs of spillway and by-pass outlet and gates; photoelastic study for the drainage gallery under the irrigation outlet; hydraulic model study for the flood protection work for Surat city.

The Ukai spillway consists of 22 spans with probably the largest radial gates in India measuring 15.55 × 14.75 m. On the basis of model studies, energy dissipation arrangement in the form of a ski-jump bucket with a radius of 27.43 m, lip angle of 40° and invert at RL 51.82 m was designed. The arrangement caters to design overflow of over 39000 m³/s the MWL being 106.98 m. The scales for geometrically similar sectional and composite models were 1 : 72 and 1 : 100 respectively. The models were also used to guide the field officers regarding protection measures during construction stage.

A fixed wheel emergency gate 5.6 m × 8.05 m is provided for each of the four penstocks, which are 7.01 m in diameter. A 1 : 30 scale model was used to study performance of gate lip, slot, and air-vent against hydrodynamic forces. For the spillway gates again, a 1 : 36 scale model was used to determine vibration and flow characteristics. Similar studies were carried out for the stop log units too.

Model studies were also conducted for diverting the natural flood discharge of the river from the fourth year of the construction of earth dam in the gorge portion. The physical and economic considerations dictated construction of a diversion channel with a sharp radius of curvature compared to the normal hydraulic requirement with the large flood discharge. This needed elaborate model studies to ensure that the inner bank was in any eventuality fully protected against scour due to high velocities and turbulence. The left slope of the channel downstream of the spillway also needed to be similarly held in position to avoid uncontrolled damage to the tail race channel and other governmental properties such as workshops, staff quarters and agriculture

lands. The CWPRS carried out extensive trial studies and recommended a spur structure at the entry to the diversion channel on the right slope, which significantly shifted the attack on the left bank towards the centre and the right bank. Similarly, ingenious masonry block pitching (insitu) was recommended for the left slope downstream of spillway to stand velocities as high as 12 to 14.5 m per second. Both these works were executed as recommended and have stood the hydraulic requirements admirably.

Narmada Bridge on National Highway No. 8

The Bombay-Delhi (NH 8) Highway is one of the major lifelines of our country. A length of 504 km of this highway lies in Gujarat and crosses four major inter-state rivers Tapi, Narmada, Mahi and Sabarmati, besides a host of other rivers. The present crossing on the river Narmada is over an old railway bridge constructed in 1887 and converted into a road bridge during 1941. A restricted one way traffic with controlled laden weight is allowed over this bridge with speed restriction of 5 kmph. There was therefore an imperative need to provide a modern bridge to cater to present day traffic requirements. Such bridge construction was therefore undertaken at a cost of about Rs. 88.6 million including provisions for protection works of guide bund, apron, approach link roads, and another bridge on its left bank approach. The bridge is nearing completion. The new location is about 5 km upstream of the present bridge site near Broach. The bridge was designed for a design flood of 73634 m³/s corresponding to HFL of 14.94 m in consultation with CWPRS for foundation design. The road level of the bridge is at 20.83 m. Clearance below the soffit is 24.4 m.

The pier supporting the deck is in RCC hollow piers constructed monolithic at top with the superstructure and at bottom with RCC well cap. While the abutments are in open type column structures, 5.80 m long butterfly returns are in RCC. The foundations are 43.6 m deep below mean tide level. One well has been constructed in reinforced-cum-steel floating caissons.

Constructed in 13 equal spans of 96.16 m the bridge has single box prestressed concrete superstructure in Freyssinet system using 71 numbers of 24 wire cables

of 7 mm size high tensile steel at pier section and curtailed at the rate of 4 numbers at each axis. The superstructure is constructed as cantilevers of 48.09 m projecting from each pier on its either side in the shape of letter 'T'.

The method of construction, viz. the prestressed precast segmental construction, is adopted probably first time in India. Of the 14 'T's, 3 'T's have been cast insitu segments. The remaining were precast. The height of the box is 5.740 m at the centre with bottom slab thickness varying from 0.15 m at tip to 0.61 m at the pier support. The segments of 2.14 m and 3.05 m lengths weighing upto 40 to 45 tonnes were cast in yard, transported and launched in position by a fixed jib-floating crane specially devised for the job.

The river training works consisting of major guide bund on the left spilling bank and a small protective bund on the right bank end, have been constructed. Based on the recommendations of CWPRS, the left bank guide bund is 2133 m in length comprising the straight shank of 767 m, between mole head lengths of 1149 m on upstream and 217 m on downstream side. The guide bund is kept at an angle of 15 degrees to the normal. The 30.5 m wide apron in the straight shank on downstream portion and 40.85 m wide on the upstream lengths is constructed in 2.29 m thickness in curved portion and reduced to 1.83 m in the remaining portion. The guide bund slopes are protected by dry rubble pitching 1.30 m thick including graded filter.

The construction required 0.934 million cubic metres of earth work for guide bund and 0.316 million cubic metres of rubble weighing 36 kg to 54 kg for pitching and apron. The guide bund top is at level 17.19 m with pond level at 16.07 m.

The approaches to the bridge are 5 km in length on the north and 14.6 km in length on the south side. Height of embankment at the south end of the bridge is 12.2 m. The south approach is through a low terrace. The embankment slopes are protected with dry rubble pitching.

The work of constructing the guide bund and the south approach embankment was completed simultaneously in one working season, employing huge labour

force and a large component of machinery, which entailed expenditure of about Rs. 200,000 per day at the peak of working season.

The guide bund and the bridge structure have behaved well over the last two monsoons. The model studies conducted at the CWPRS and mutual consultations during construction phase have helped construction of this bridge and the protective works in record time.

Dharoi Project

The project now under construction comprises (i) about 6.6 km long (including saddles) and 49 m high composite dam across the river Sabarmati near village Dharoi (ii) a direct main canal having a design capacity of 20.23 m³/s on the right bank (iii) another canal having a design capacity of 4.95 m³/s on the left bank (iv) a barrage downstream of Ahmedabad city and (v) a link feeder canal for diverting flow of the river into existing Fatehwadi canal system. The river drains a catchment area of 5540 km² at the dam site. The scheme envisages irrigation to 37000 hectares of land in Mehsana and Sabarkantha districts, and water supply to Ahmedabad and Gandhinagar, and firming up irrigation of 25000 hectares under the existing Fatehwadi command.

The masonry dam consists of total 150 m long non-overflow dam and 219.5 m long Ogee-shaped spillway located in the gorge and designed to pass a moderated flood discharge of 16044 m³/s. Twelve numbers of radial gates of 14.94 m × 10.67 m size are provided over the crest to negotiate maximum flood discharge. For energy dissipation arrangements, a solid roller type of bucket is provided at the downstream of spillway.

The CWPRS Pune has played a remarkable role in evolving a sound and economical design of Dharoi spillway and component structures, such as energy dissipation device, downstream training walls, and downstream protection to envelope, through model studies of various components. Timely decisions and recommendations from the Station have helped the project authorities in maintaining the progress of work as per the schedule. Fortunately or unfortunately while model tests were still under progress at the Pune

Research Station, a flood discharge of unprecedented magnitude occurred during the 1973 monsoon. The design flood for the spillway had, therefore, to be revised. This modification in the flood discharge necessitated repetition of almost all the model studies that were performed earlier. However, all these tests were promptly attended to by the Research Station at Pune with the result that the overall schedule of construction programme could be maintained.

Kadana Project

Kadana dam, now under construction, across the river Mahi in Panchmahals district of Gujarat State, forms Stage II of Mahi river basin development, where the river drains a catchment area of 25580 km². The Stage I comprising a weir at Wanakbori and a canal system to irrigate 0.186 million hectares of land in Kaira district has already been completed. The Kadana Project will firm up this irrigation and provide additional irrigation of 74,000 hectares in Kaira district under Mahi Stage I, besides irrigating 17,000 hectares in Panchmahals district under direct command. Gujarat is to receive regulated releases of 31.15 m³/s from Bajajsagar Project being constructed as a joint project in Rajasthan on upstream. The project also envisages installation of four reversible turbine units of 60 MW each working as pumped storage scheme. The head works alongwith spillway gates are planned to be completed by June 1977. The revised cost of the project is Rs. 665.0 million. The project is aided by the World Bank through long term loan of Rs. 262.5 million.

The masonry dam comprising of spillway, power dam, transition dam, and keys is located in the river portion, while the earthen dam is on the left flank of the river. The spillway is designed to pass a moderated flood of 49000 m³/s. The maximum height of the dam in the river portion is 65.84 m. The power dam is on the left side of the spillway. A weir at Limbodra about 25 km downstream of the main dam is also proposed to be constructed as a part of the pumped storage scheme.

The design of the component parts of the project such as spillway, NOF dam, power dam, energy dissipation arrangements, gates, divide walls etc. have been carried out to suit the site conditions. These designs

have been checked at CWPRS Pune, in hydraulic models. The Pune Research Station has played vital role in finalising these component parts of the project. The Kadana Project has complex foundation geology due to presence of many low dipping faults in the direction of flow, and this situation had created problems of settlement and sliding. In order to assess the behaviour of these faults, structural analysis was absolutely necessary. Necessary field tests were carried out very systematically and timely by the CWPRS Pune, with their expertise knowledge in that field. The photoelastic model studies, simulating the prototype conditions of faults and type of foundation masonry, have also been also carried out at CWPRS, and effective and sound treatments have been evolved from these studies.

In short all the important designs such as spillway, energy dissipation arrangements, foundation treatments, outlets, tail race channel of power dam, divide walls separating the spillway and power dam etc. have been timely finalised in consultation with the CWPRS through model studies.

Vasna Barrage

The Sabarmati Reservoir Project envisages construction of the storage reservoir at Dharoi and a barrage near village Vasna, just downstream of Ahmedabad City, for diverting the Sabarmati waters for firming up the existing irrigation of 25000 hectares under Fatehwadi canal system. The barrage comprises of 22 nos. of waste weir bays, 4 river sluices, 2 under sluices and a head regulator on right bank. The barrage, when completed, will create a pond on the upstream to provide a beautiful water-front to the Ahmedabad City and will also improve the water supply situation in the city.

Taking into consideration the importance of the barrage, model studies were referred to the CWPRS Pune, to study afflux, scour, diversion of river flow from left to right i. e. towards head regulator, provision of scour sluices, silt excluders and energy dissipation works. For this purpose two hydraulic models viz. (i) composite model of the river Sabarmati from Railway Bridge on the upstream extending upto Narol Bridge and (ii) sectional models for three different barrage sections were prepared.

The CWPRS has played a very important role in evolving a sound and economical design of the barrage. To improve the existing flow patterns of the river at the barrage site, the Research Station had suggested to provide four river sluice bays with lower sill levels and a sand excluder in order to minimise silt load entering the canals. The downstream apron lengths were reduced by 3.1 m by increasing the height of friction blocks from 0.75 m to 1.2 m as per the model studies. The models also evolved and suggested suitable gate operation schedule for different discharges in the river so as to minimise the problem of silting. Moreover, suitable river protection and river training works have also been suggested on the basis of the model studies. Thus the model experiments carried out at the CWPRS have proved to be very useful in finalising the design, and in incorporating modifications, as and where necessary, to achieve overall economy without sacrificing any technical requirements.

Flood Protective Measures on Tapi River in its Lower Reach

Floods in lower Tapi basin are of frequent occurrence. Amongst the many devastating floods, which were experienced in the years 1727, 1782, 1822, 1837, 1944, 1959, 1968 and 1970, the flood of 6th August 1968 (about 40,000 m³/s at Ukai) was the unprecedented one. The city of Surat and the flat fertile lands in the lower reaches get severely affected even by floods of small magnitude of the order of 14,000 to 17,000 m³/s. The areas affected by the devastating floods of August 1968 were inspected by the then Union Minister, Dr. K. L. Rao. After inspection of the areas affected by these floods, it was interalia suggested, that flood embankments should be constructed on both the banks of the river from village Kamrej to 1.6 km downstream of Surat city for a flood intensity of 28,300 m³/s with a free-board of 1.5 m.

The design flood for Ukai dam is 49,468 m³/s. The outflow from the Ukai Reservoir is considered as 23,800 m³/s. Free catchment area of the river Tapi measuring 1760 km² between Ukai dam and Surat city can generate a flood of the order of 4250 m³/s. The maximum likely flood is the lower reach can, therefore, be of the order of 28,300 m³/s. However, the design flood for the flood embankment is considered as 23,800 m³/s

assuming that the peak of the flood from the free catchment area may not coincide with the peak of the outflow from Ukai Reservoir. In case such coincidence takes place the free-board of the embankment will take care of such flood.

Model Experiments

In order to determine the water surface profile with and without embankment, and to decide the optimum location of the embankments with minimum afflux level all along the river course, the problem was referred to the CWPRS Pune, for carrying out the model studies. The experiments were required to be conducted for three different discharges of 23800, 28300, and 37100 m³/s. Effect of tides was also to be studied on the model, as the influence of tides is felt upto 48 kms from mouth of the river.

In these experiments embankments upstream of Surat were located where spills were noticed in the model. The embankments were placed 150 m away from and parallel to the existing banks. The experiments were first conducted without flood embankments. At the upstream end of the model i. e. at Ukai an equivalent hydrograph with the peak flow of 23800 m³/s was run in this model. At the downstream extremity of the model i.e. at Dumas, effect of tides was imposed. The maximum

water levels at the various places along the river course were recorded. The other experiments were then conducted with the flood embankments reproduced in the model. The maximum water levels obtained at various places along the river course were recorded in this case also. In order to determine the top of the embankment, the water levels corresponding to 23800 m³/s with embankment condition obtained from the model experiments were considered, and free-board of 1.5 m over the water levels at the respective sections was added.

Thus the CWPRS has played an important role in determining the optimum locations and the design top level of the flood embankments for the lower Tapi. The work of flood embankments is nearing completion.

Conclusion

The successful completion of these major projects or assignments by the State, in collaboration with CWPRS, along with a number of smaller though not less important works, stand as a tribute to the golden decades left behind by the CWPRS. The Station has an outstanding technical record of association and participation in these ventures. We wish and pray for many more useful decades of service from this Pioneering Institute in the development of our country.



The River And The Engineer

G. H. KESWANI *

It is surprising that there are only a few books on river engineering or fluvial hydraulics, to put it pedantically. Perhaps, poets have written more on rivers than the engineers have. T. S. Eliot was not much sure about Gods, but he thought that the river was a God.

I do not know much about Gods;
But I think that the river
Is a strong brown God

Four Quartets Dry Salvages, I.

Or, take the following line of Wordsworth :
The river glideth at his own sweet will.

Sonnet : Upon Westminster Bridge.

But here, the engineer will join issue with the poet and the river. The engineer does not let the river flow at his own sweet will always. He likes to impose his own will upon the river sometimes. In building a bridge or a barrage he often does this. Occasionally in doing this, the engineer tempts Providence, but that is a price to be paid for attempting to interfere with the glide of the brown God.

A number of Indian poets frequently refer to the rivers. In northwest India, numerous folk songs have been composed around the story of Suhni-Mehar. Suhni, a beautiful married woman, used to swim secretly across the Indus river everyday to meet her wounded beloved, who lived on the other bank of the river. Ultimately the two are drowned and eternally joined

together with the river. The Sindhi lyrical poet, Shah Abdul Latif, wrote a long poem on this Suhni-Mehar love-affair. In one of his lines, a kind of finale to the theme, Shah assures us of the Vedantist's theme :

The seeker, the thing sought,
And the river are joined
Together into one single thought.

I said that there are only a few books on river engineering, *per se*. In fact, the only one still in print I know of, is by the Russian irrigation engineer Serge Leiliavsky, a book with the title 'An Introduction to Fluvial Hydraulics' or Hydraulics of Rivers. Leiliavsky worked in Egypt for a long time. There are other publications, no doubt, on the behaviour, control and training of rivers, but they are all kind of technical or professional papers, often not priced, and with only a restricted circulation.

Another book dealing with the limited problem of equilibrium of flow in canals and rivers, brought out by a noted publisher of scientific and technical literature and still current, was written by the British engineer Blench¹, who worked for long years in the Punjab Irrigation Department in India, and later migrated to Canada.

Now, rivers have been very important in the development of civilization on this earth. All ancient cities were founded on the banks of rivers. Even modern cities are

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often founded near some river. Building a bridge over a river or even protecting habitations and land from erosion, requires knowledge of the behaviour and control of rivers. Still the total research effort going in to the study of rivers is very meagre indeed. One reason why it is so, is because the physics of the rivers is very complicated. Rivers generally arise in the mountains and end in the sea. In between they would be joined by tributaries. The geometry of the wetted perimeter and the type of bed material encountered by water will vary infinitely with the changes in discharge and even the course. The curvature at the bends of rivers results in high centrifugal forces acting on the land mass in contact with the river. No doubt, the total potential energy between the place where the river arises and the sea level, has to be dissipated in the viscous and bed friction encountered by the river. But between its origin and merging with the sea, a river can follow a multitude of paths involving the same loss of potential energy. For a river, thousands of kilometres long, obviously, fluctuations of the order of tens of kilometres, in its path, can be consistent with the same total energy equation. The rivers therefore, change their course with impunity, but over long periods of time they seem to remain inside a small belt, (it is called Khadir in India), within which they meander merrily and vagariously, much to the distress of population around. An engineer is vitally interested in this phenomenon of meandering of rivers. For one, changes in the course of rivers cause distress to the people whose land and property they erode, and for another they could outflank and make redundant, bridges built on an earlier course.

The vacillations of the rivers have therefore, been a subject of long and painstaking studies by the engineers. The result is that the river and the engineer in many places have been *en rapport* with each other. Many an engineer's work has struck an answering chord in the brown God. But not always. The fault lies with the engineer. He does not quite understand the God.

Let us see how far an understanding of the physics of the river has gone. Work has mostly been done in India, U. S. A., Egypt, Russia, Holland and England. In this field, India has perhaps contributed as much as any other country.

The earliest publication² on the hydraulics of rivers was published in the year 1876 in U. S. A. It dealt with the river Mississippi. T. S. Eliot had this river in his mind when he talked of the river as a brown God. This river has been a subject of great study and discussion by the American engineers in the last century. Numerous technical papers were published by them in the Transactions of the American Society of Civil Engineers. Notable among these was a paper on the cut-offs on the Mississippi River and their effects on the channel above and below, by C. G. Forshey. In England, Vernon-Harcourt³ wrote a two volume treatise on rivers and canals in the year 1882. He also published a book on the river Hoogly in the year 1897. All these early publications are unfortunately out of print. There is a need to reprint the more significant and still pertinent papers. At about the same time British Engineers working in India, on a scale and with freedom for experimentation impossible in their home country, made extensive studies of river behaviour, and threw bold bridges across the Sindhu, Ganga and other mighty rivers of India. Incidentally the Indians had deified their rivers long before Eliot wrote his beautiful poetry. Among these early investigators was Sir Francis Spring, Chief Engineer of the Public Works Department in India, which then included the Railways. He began his investigations in the year 1870. A few years later he built the Alexandria rail-bridge over the river Chenab, a turbulent affluent of the Indus. He first built 64 spans of 44 m each, but by training the river reduced the number to 28. He was helped in his ideas by the earlier work of J. R. Bell, who had devised the guiding system known by his name (Bell Bunds). At the same time another engineer in India, R. A. Molloy, with his unrivalled experience of the Indus River, was writing about the theory of meandering of rivers in the alluvium. Reading his papers one feels as if Molloy was a portion of the river itself.

For years, little progress was made beyond what Spring⁴ said in this book of 1903. The works that followed, more or less, made a repeated circuit of Spring's ideas. A break-through reaching new ideas, was made by a Punjab Irrigation Engineer, Gerald Lacey⁵ in the year 1929, developing earlier suggestions of Kennedy and Lindley⁶. While Spring

had developed the theory of scouring and cut-off, and settled the essentials of the design of a guiding system of a river near its passage under a bridge, he did not know the dynamics of equilibrium or of regime flow of a river. More particularly, he had not answered the question: Given the discharge to be passed through a specified channel with erodable bed and bank material (say an alluvium), which could also be held in suspension in the stream, what is the size of the channel when equilibrium is attained (i. e. when the rate of erosion of the material from the bed and sides is equal to that due to deposition of the suspended material). Lacey gave the astounding answer that for a given material of the bed and banks of the river, the hydraulic mean depth will be proportional to the cube root of the discharge carried by the river or canal. It was astounding, because of its simplicity. The formulae seemed to fit observation quite well and are still very popular with the Indian engineers. Its physics is obscure. For example, dimensionally the equation is not balanced. A number of engineers, many Indian and Lacey himself, later suggested refinements⁷ to fit better the experimental data on mobile boundary channels. N. K. Bose, Sir Claude Inglis, D. V. Joglekar and S. V. Chitale have made significant contributions. One of the workers in the field is H. A. Einstein⁸, the son of the famous physicist Albert Einstein, who had himself written a paper on the effect of the earth's rotation on rivers. On this high note, we may leave the discussion of these theoretical investigations.

Although theory has been a useful guide in the study of equilibrium of rivers, its value in design and prediction has been rather limited. The engineer had, therefore, to fall back on the experimental method to study the effect of various variable parameters on the behaviour of rivers. But how can one experiment with the river, which will mean changing its parameters? The answer is to make a model of the river.

Now the modern physicist prohibits model making. After the advent of the quantum theory and Schrodinger's wave-equation, the space-time framework was no longer adequate to describe what happens to a particle, like the electron. A super-space, called phase-space, was to be the domain of description. This space was unpicturable. Only the engineers were left to play their games in the familiar world of space and time. There

has been softening in the attitude of physicists and he now talks of the probability-cloud model of an orbital electron, a liquid-drop model of the nucleus, and so on. The fact, as Von Mises has pointed out, is that even a mathematician tacitly assumes a model or picture before he can proceed with his abstract manipulations.

Let us make models openly. The hydraulic engineers have developed this into a fine art. In no branch of applied physics has dimensional analysis found use more than in hydraulic engineering. Model making is expedient and has an excellent predictive value. A river may take years to meander. In a small scale-model of the river, the effects can be produced speedily under a large number of conceivable variations.

What is a scale-model? We might say that it is a smaller replica of the prototype geometrically, and is subject to the same dynamic behaviour, i.e. the model obeys the same differential equations of change as the prototype (but, possibly, with different numerical coefficients). How do we know that a chosen model obeys the same differential equations? Intuitively. Intuition is the most powerful tool in the possession of an engineer—perhaps also of every man, including the physicist and the mathematician. No doubt, intuition builds first in the air, but it thus teaches one how to build on the ground.

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Model Testing And Association Of Bharat Heavy Electricals Ltd. With CWPRS PUNE

N. Y. NARASIMHAN *

A research and development facility for design -development and industrial testing of models of hydraulic machines is a vital necessity for Hydro Power Field. The successful application of the laws of dynamic similarity combined with the technique of model testing has proved an outstanding and valuable aid for developing prototype hydraulic machines having optimum hydraulic and cavitation performance. The full exploration of theoretical possibilities and comprehension of the underlying physical facts as well as a clear understanding of the type and scope of results expected are prerequisites for success in any model test.

Hydraulic model testing techniques have been perfected with the improvements in test stands, instrumentation and observation techniques. Attainment of improved operational performance, stability of flow, elimination of power swings and the widening of stable operating limits of performance have thus been possible on the basis of model tests and these have helped manufacturing organisations in developing and building very large hydraulic machines with satisfactory and reliable performance.

The multitest closed loop water tunnel facility set up at CWPRS Pune, with its sophisticated instruments for accurate measurements has enabled BHEL to foster progressive self-reliance and help indigenous design and manufacture of cavitation and vibration free hydraulic machines having optimum performance.

International codes of acceptance, emphasise on the necessity and significance of model tests as a basis for efficiency guarantees of the prototype machines. These efficiencies are of decisive importance when competitive bids are compared. For the customer, model acceptance tests hold the advantage in that evidence of attainment of guarantee can be provided well before the prototype goes into operation. In many instances, model tests in conformity with international codes are to be carried out by manufacturers for evaluation of the projected guarantees as a prior decision before an order for the prototype is placed.

CWPRS with its well equipped laboratory and facilities, has a vital and leading role in many of the design and testing activities of hydraulic machines. The complex hydraulic phenomenon occurring in the machinery under different operating conditions, and the required accuracy of performance data, necessitates careful testing of the models in special test stands. In order to be able to offer the very best solution for a special customer requirement, the proper type must be chosen and adopted in such a way that a reliable and economic solution is obtained. The rig set up in this laboratory has the following features :

- (1) Latest design, modern equipment and sophisticated electronic instruments calibrated to high degree of accuracy, possibility of testing large size models to enable fulfilment of all the

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requirements of model testing stipulated by international standards.

- (2) Advantage of testing both efficiency and cavitation behaviour without dismantling the model enables speedy and accurate measurement checks.
- (3) The entire test circuit is reversible and facilitates testing of reversible turbines of Francis, Kaplan, Bulb and Dariaz types.
- (4) Availability of high speed camera and stroboscope enables in depth study of cavitation phenomenon in hydraulic turbines and pumps.
- (5) Independent status held by CWPRS makes it suitable as a third party for carrying out contractual tests.

Bharat Heavy Electricals Limited has been utilising the research & development facilities developed by CWPRS from its very inception. Extensive testing of homologous models have already been carried out to check the prototype performance guarantees of Upper Bari Doab Canal, Dehar and Kalinadi projects. Similar testing is being envisaged for checking the performance guarantees of Pong, Koyna and Supa Hydel schemes. These model tests have proved to be a leap forward towards a better understanding of mutual problems of experimental investigations of turbine design for establishing confidence and paving the way to the progress of further design developments which are presently in hand. There has been active participation and co-operation between the BHEL and CWPRS engineers resulting in useful and constructive suggestions which have enabled adoption of improved designs and manufacturing practices of models.

We in BHEL have our own hydraulic testing laboratory facilities, which are at present used for development work. The increased necessity for an accelerated development activity to bridge the technological gaps, requires a joint and active participation of CWPRS for achieving self-reliance. We are at present actively engaged in the process of developing profiles for the cascades of conventional as well as new types of turbines. We would be needing elaborate laboratory testing of these variants for necessary feed back to our hydraulic engineers. Additional experimental work and techniques to include the following would be required :

- (1) Measurement of pressure and distribution before and after the runner.
- (2) Strain gauging on the cascade profiles.
- (3) Hydraulic torque assessment of guide vanes.
- (4) Determination of disc friction and volumetric losses in Francis turbine models.
- (5) Measurement of vibration and noise of model while operating in the off design regimes.
- (6) Measurement of quantity of air injection and also the bubble size.
- (7) In depth cavitation studies and materials.
- (8) Measurement of pressure pulsations at different sections of the model.
- (9) Measurement of axial and radial components of hydraulic thrust.
- (10) Development and testing of Reversible Pump and Bulb Turbines.
- (11) Testing of valves.
- (12) Improvement and additions to the existing facility to test turbines and pump turbines at greater differential heads of lower cavitation number with more accuracy and under more ideal operating conditions to advance the state of art in Model Testing.
- (13) Automatic data logging system with facility of data display and plotting.

At present there are some limitations in interchangeability of the models between the test stands at CWPRS and BHEL. We are taking suitable measures on model designs so that model testing can be carried out at any of the test stands with minimal changes.

In conclusion, it must be emphasized that exhaustive theoretical and experimental research should precede manufacture of hydraulic machines to ensure reliability and successful operation in service. The need to achieve overall economics of power installations, demands the development of high performance hydraulic forms, for achieving better efficiency and flow stability with improved cavitation characteristics. The unique facility available at CWPRS for model testing of Hydro Machines, is a national asset and will serve an important role in expanding the Research and Development work in the field of Hydro Turbines and Pumps.

The Technological Perspective and Its Significance for Hydraulic Research in India

K. R. DATYE*

Hydraulic research is only the part of national effort for development of technology with a view to achieve balanced and rapid growth. An attempt is made in this paper to point out some of the major short-comings of the process of economic development as has evolved in India over the past 25 years. A perspective is outlined for technological transformation of the economy which aims at correcting some of the imbalances that have developed in the recent past. Implications of the proposed approach to technology are explained with regard to hydraulic research and corresponding research needs are briefly outlined.

The economic development of the past 25 years was based on transfer of technologies developed in the advanced countries. This process has resulted in several constraints and has also given rise to uneven development and accentuation of inequalities. Some of the major short-comings, highlighted by recent experience, are mentioned below :

(i) Limited capacity of the rural economy to receive and absorb the benefits of industrial development. This phenomenon is characterised by shortage of demand for industrial goods and accumulation of stocks of food while the consumption needs of a large proportion of the rural population remain unfulfilled. Another manifestation of the above structural weakness is the non-viability of rural electrification programmes arising from shortage of

demand (Ref. 1). Yet the present level of consumption of electricity is extremely low as compared to the developed countries.

- (ii) Uneven development of water resources, resulting in accentuation of disparities between 'advanced' and 'backward' regions. Even within a group of villages development tends to get concentrated. Since improvement in agricultural technology is associated with irrigation, the poorly endowed areas remain permanently condemned to economic stagnation.
- (iii) Transport and electric power continue to be major constraints in development, of the economy and a major share of the product of heavy industries are consumed by the development of transport, electric power generation and transmission.
- (iv) Similar resource constraints arise in respect of the steel industry. By its very nature, development of steel and associated mining tends to concentrate in a few areas where the natural resources are located.

Considering the above mentioned limitations of the development process there is strong case for exploring possibilities of developing alternative technologies which would not rely to such a large extent on production of iron and steel, large scale transportation by railways or automobiles and electric power generation at large central plants. Since deposits of fossil fuels (oil and coal) are unevenly distributed in India and proven resources per capita are small

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relative to the availability of these materials in developed countries, there is a strong case for developing replenishable energy sources such as hydro power, wind, solar and wave energy.

If a technology can be developed for harnessing these sources of energy with minimal use of steel and products of heavy industry a major contribution would be made towards balanced growth of the economy. In the advanced countries the highly fluctuating character of energy generation from wind, sun, tides and waves renders them unsuitable and large outlays are often required to undertake complementary development for balancing these fluctuations. Since the utilisation of energy in the developed countries is primarily for modern industry and transportation, fluctuations in generation would not be tolerated. On the other hand in the alternative systems contemplated, which seems to be better suited for Indian conditions, energy is proposed to be utilised in rural industry and agriculture. Since investment on the plant and equipment utilising electric power would be relatively small, low overall annual utilisation factors may be acceptable for such industries.

It follows from the above reasoning that the alternative technology can only be conceived as a system for energy generation and its utilisation in dispersed industry and agriculture. Special emphasis would be laid on use of energy for utilisation of raw materials which are relatively abundant and the sources of which are well dispersed. Further if a system of transportation can be developed which consumes less energy and which can be constructed with minimal use of products of heavy industry, the transportation system could be utilised for conveying raw materials, which are concentrated in a few areas, to widely dispersed points of utilisation. By these means India may be able to replicate the experience of China with regard to cement and coal based fertilizer plants (Ref. 2). The coal resources are far better dispersed in China as compared to India. This is a major factor, apart from public policy, in favour of dispersal which resulted in small scale industry making a major contribution to production of cement and fertilizers in China.

In the following paragraphs the proposed integrated energy - resource system is described for typical situations :

In the first instance the concept of an integrated system of energy generation and its utilisation is described for a small area comprising a few villages. The primary source of energy would be wind and sun. The wind mill should be fabricated largely from locally available structural materials and machine components which can be fabricated in small workshops. A pump storage unit is built into the wind mill system wherein the pump may be a low cost reciprocating pump operating under a wide range of wind velocities. The pumps feed an elevated storage tank which in turn would supply a constant head turbine. The power generated from such turbines will be fed into a network say of 11 kV which is connected to low head pump turbine units. These pump-turbine units could be installed at a series of small weirs and dams for generation of power as well as for lifting water for recharge of large areas. Solar pumps as well as other electrically operated pumps would be integrated into the system to lift water to high level reservoirs which may form part of a pumped storage system as well as an irrigation system for hill slopes and waste lands. Solar energy would be harnessed primarily through the intervention of biological processes. Thus feed stock for bio digesters producing nitrogenous fertiliser and methane would be produced from marginal lands and sloping hill sides.

The system described above ensures full utilisation of the principal resources i. e. land and water and solar energy, and dispersal of benefits will also be achieved. With proper land management a wide range of products can be obtained from sloping or marginal lands, apart from conventional horticulture or cultivation of grain, legume and tubers in rotation. It should be possible to produce fibres, fodder, small dimension timber, fuel wood and even develop natural sources of raw material for polymers such as furfural, castor oil, rubber latex etc. If wind and solar energy is produced cheap enough it can be used in chemical and metallurgical processes for manufacture of products such as steel fibre, glass fibre, basalt and alumina fibre, graphite, electrolytic hydrogen, ammonia

and oxygen, cements and high grade ceramics. It may be noted that the above products would be useful for the development of the region since material for structural fabrication, manufacture of machine components, and equipment for water resource, wind and solar energy development would be supplied by the local industry producing the above mentioned materials.

The concept of the integrated energy and resource system can also be evolved for large regions. An example of this would be use of tidal and wave power combined with pumped storage installations. This system could be used for evening out the fluctuations of tidal generations and further to supply energy for lifting water over large inter basin systems. Another approach would be development of series of low head dams in the hilly regions (e. g. Himalayas) for gradient control and seasonal generation of power which would be used to lift water surplus in major rivers (e. g. the Ganga) to drought prone regions. A third example of the integrated system would be transportation of coal and ores through a system of pipelines and inland waterways. By a judicious combinations of pipelines and waterways the energy input into the transportation system could be minimised. This would greatly facilitate dispersal of industries based on coal and ores.

Research Needs

In order to develop the above mentioned integrated systems, research would be needed in the following areas :

(i) Development of reinforced earth techniques for construction of overflow dams and weirs. The feasibility of constructing walls upto 30 metres height and overflow rockfill dams even upto 50 metres height has been established (Ref. 3 and 4). In the designs developed abroad mild steel bars, wire ropes, galvanised steel strips were used for reinforcement. With modest research effort it should be possible to develop structural forms wherein bamboo strips and fibre reinforced concrete can be used to substitute steel rods, wire or galvanised strips. Low cost techniques of bamboo preservation are

known and all that is required is limited amount of adaptive research followed by field trials. Very large economies are possible in the construction of low dams upto 5 metres hights for recharge work as well as dams upto 50 metres height for gradient control on major rivers. The system of dams could be designed for replacement (of reinforced earth dams) at intervals of 25 years without disruption in the functioning of the system. The reinforced earth technique has also a potential for modified and improved design for flood control levees which would be allowed to spill at selected locations and the flood water could then spread in a controlled manner over a wide area. This would allow sediment to be distributed without causing excessive flood damage while the distribution of the silt would arrest progressive degradation and rise of river bed levels.

(ii) Recent developments in low cost fabrication using fibre reinforced cement mortar could be extensively used for bringing down the costs of casings, scroll cases, draft tubes and various other components of turbines and pumps (Ref. 5, 6, 7). Here again the developmental process would still create demand for products of industry wich would utilise locally produced power.

(iii) In a contribution on 'Structural Uses of Bamboo' (Ref. 8) the writer has made certain suggestions regarding structural uses of bamboo, which could be applied for construction of low cost pipe. The pipelines could be useful for the power development upto 50 metres head as well as pipelines for hydraulic transport.

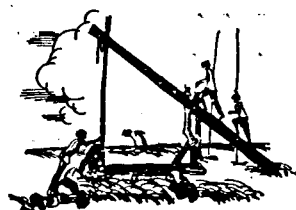
In addition to the above mentioned research, essentially in the field of hydraulic engineering adaptive research will be needed in development of small scale industries utilising abundant and dispersed minerals and raw materials produced on land on the basis of agriculture and plantations forming part of the land-water resource energy system described above.

The conclusions that emerge from the reasoning developed above are that the system comprising land and water resources energy generation and its utilisation, as well as raw materials for industry using the power generated must be considered in order to define the technological perspective. Secondly developments in hydraulic engineering are not yet matched by research in material technology which would lead to more economical hydraulic structures, and hydraulic machines, which would simultaneously facilitate better dispersal of benefits of development. Thirdly the most fruitful areas of research are not necessarily the high head hydro power developments or ocean engineering for major offshore structures. Design developments for harnessing tidal power, wave energy, recharge works, and low dams for gradient control, may be of greater significance for economic development of the country.

The purpose of this paper is to provoke thinking and focus attention on technological possibilities which have received inadequate attention so far. Some of the writer's suggestions may not stand critical examination and others may get substantially altered during the process of implementation. However, this contribution would have fulfilled its purpose if it leads to intensification of effort in neglected areas of research which appear to be crude and unsophisticated in comparison with the outstanding achievements of modern technology.

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Glory, Thy Name is Hard Work

P. M. DAMLE*

Every institution of public utility usually has a modest beginning. The institution takes the first few years of its infancy in finding its own roots. With the passage of time, a stage comes when it can stand on its own legs and creates confidence in the minds of its workers as well as that of the clients. As the work develops, the activities expand into new channels and methods of application with capacity based on experiences to achieve greater and greater results for the benefit of the country. Behind the growth of the institution, however, there lie supreme efforts of its pioneer members, who not only lay the foundation of the institution but also mould its destiny by piloting it with wisdom and courage through many ups and downs, which are usual in any history of development.

One finds all the above characteristics and landmarks in the history of the Central Water and Power Research Station, Pune. The work of the station began very modestly with the investigations for the improvement of irrigation outlets and development of modules for controlling discharge in the distributaries. With the shifting of the Station to Khadakwasla, major problems started flowing in, such as training of rivers and designing silt free off-takes for the canal head works of alluvial rivers. The Station way back in 1938-39 recommended the design of the off-take for the Right Bank Canal at Sukkar Barrage utilizing the behaviour of the suspended load in a curved flow. This principle was widely adopted subsequently in similar situations. Use of spurs and guide bunds for training rivers through bridges was successfully

adopted in the case of Ganga at Hardinge Bridge (now in Bangla Desh) and river Rupnarayan at Kolaghat. These and many other works were then executed with untiring efforts both on the Part of the Director and the Research Staff alike and that too with an astonishing lack of sophisticated equipment and paucity of data. Then came the realisation of the importance of considering silt load and its character in the design of canals and study of the river behaviour. Hundreds of experiments were undertaken under laboratory conditions, small flow channels in noncohesive material to study this aspect and meandering in the context of other hydraulic parameters. Innumerable relations were worked out with the help of statistics for the known stable irrigation canals to confirm or otherwise and improve the various theories put forward by eminent hydraulic engineers such as Lacey, Kennedy and others.

Late Sir Claude Inglis, the pioneer Director of the Institution, had worked very hard with dedication and unflinching loyalty to the cause of hydraulic research. He was a hard task master and volatile by nature. He was however gifted with uncanny intuition and called the model techniques as an art. He succeeded in instilling the 'spirit of research' in the minds of his staff. It was left to Shri K. K. Framji and late Dr. D. V. Joglekar, who took reins after Sir Claude, to develop the Research Station to its blooming stage. The former imparted his clear analytical approach and foresight to every problem

*Formerly Research Officer, CWPRS, Pune.

combining his engineering skill and experience. The latter elevated the hydraulic model technique by his pains-taking and untiring application to the work in his unassuming lovable manner.

In 1947-48 Dr. A. N. Khosla, the then Chairman of the Central Water and Power Commission, strongly recommended not only the strengthening of the existing Research Divisions but also the expansion of the Research Station to include other allied branches of science such as Navigation, Physics, Soils and Soil Mechanics, Mathematics, Statistics and Chemistry. He had the vision that the Station should be in a position to tackle any or all problems posed to it especially in view of the number of hydraulic structures, river training and flood control works, that were envisaged in the River Valley Projects under the Five Year Plans of Independent India. The Expert Committee appointed for the purpose recommended after due consideration the expansion of the Research Station at Khadakwasla - Pune instead of shifting it to Delhi as was proposed alternatively. One wonders whether the Station would have developed to the same stature as now in the climatic and other conditions obtained at Delhi.

The expansion and the newly created divisions brought in its wake specialization and the heads of the divisions gradually accumulated experience and deeper knowledge, so as to become experts in their respective fields. Dr. Joglekar was lucky to have such

a band of experts and other competent research officers, who worked with zeal and devotion as a team. The Research Station in succeeding years has tackled countless problems by model technique - projects of national importance, including port and harbour developments, barrages and bridges on mighty rivers, surge systems in hydro-electric schemes, foundation and structural stress studies and protection works at toe of high head dam spillways and outlets etc. Brevity precludes me from enlarging this list. It was my proud privilege to belong to the research team of the Station, which enabled me to contribute in my humble way in the functions of the Station. It was indeed a joy to discuss one's problems freely in a healthy atmosphere with the colleagues. 'The Spirit of Research' inflamed by Sir Claude had paid very large dividends.

The position of eminence that this Station occupies now, as one of the best Research Institutes in the South East Asia, was the outcome of these happy conditions, close co-operation between different units and last but not the least able direction by the successive heads of the Institute. With better and better facilities and with help from the Government, I have no doubt that this unique position connoting responsibility and promise will be maintained and the Research Station will render greater and greater service to the country as well as to the developing countries of the world.



Pride of Hydraulic Research

V. N. NAGARAJA *

The history of the Central Water and Power Research Station is legion and for any one to participate in its activities is a matter of pride. That I have had the privilege of working as a member of its staff in the fifties and of being closely associated with its many-sided activities since is indeed a matter of pride for me.

When one sees the present stature of the Research Station, it is difficult to believe that it could have achieved such a striking development since its humble beginning at Hadapsar in 1916. It owes it entirely to the enlightened and inspiring leadership provided by men of international standing like Sir Claude Inglis, K. K. Framji, D. V. Joglekar, C. V. Gole and their successors. Through all these years the centre has provided a fertile ground for training a large number of engineers and scientists in a multitude of disciplines contributing to the development of water resources for the benefit of man. Today the Research Station is recognized as the Regional Centre of hydraulic and allied research serving the entire ESCAP region - experts are drawn from there to all parts of the region for the solution of problems relating to water development and people from all parts go there to seek training and expertise.

Water development is no longer the handiwork of a few individuals as it was in the past. It has become a complex multidisciplinary enterprise which calls for

co-ordinated efforts of engineers, scientists, economists and a host of other disciplines. The Central Water and Power Research Station achieves this through co-ordinated research carried out in its numerous divisions such as Bridge Engineering, Flood Control, Gates and Valves, River and Canal Hydraulics, Ports and Harbours, Coastal Engineering, Model Engineering, Soils and Concrete, Statistics, Computer, Mathematics etc. It is not easy to make an exhaustive list of the disciplines engaged.

While the Station has been engaged on applied research activities for the solution of water development problems as they arise, basic research is not neglected. Full advantage is taken of the computer technology and the Station is able to solve many complex problems through its use. The research facility available draws a number of engineers and scientists for postgraduate work. The spread of technology is further fostered through refresher courses and the Annual Research Sessions organized through the Central Board of Irrigation and Power.

With this background and having a band of experts in diverse fields and the very healthy environment that the city of Pune provides, the Central Water and Power Research Station can look back to its achievements with pride and is poised to play even a greater role in its noble task in the years ahead.

* Project Manager, Office of the United Nations Development Programme, Paraguay, South America.



Life in a Research Station

S. D. PHANSALKAR*

The Central Water and Power Research Station had already grown in eminence, though not in size, in June 1949 – the time when the writer joined it. He was perhaps the last to join just before the process of its growth was commenced. The preliminary outline for the first phase of expansion of the Research Station had already been completed by that time and the author had the privilege of being immediately associated not only with its detailed designs but with its execution also.

Initially the Hydraulic Laboratory of this premier station occupied a few acres of land situated on both sides of the Mutha Right Bank Canal in the immediate vicinity of the Khadakwasla dam. With the completion of the first phase of expansion, the Research Station had a much larger area – about 24 hectares – developed into a well planned hydraulic laboratory. Its centre of activities also shifted further downstream of the dam, which incidentally proved beneficial about 10 years later in 1961 when the Khadakwasla dam breached the damage to the Research Station's property was very much reduced in extent. An additional facility created with this expansion was the provision of a small workshop which could go a long way in preparing the various model components to the required precision.

The first phase of expansion of the Research Station which was completed in 1951 provided for a number

of compartments for laying the field models and also an independent water recirculating system with a pumping capacity of 2.83 m³/s. meant to supply water to the models. These provisions were expected to meet the future requirements for a good number of years to come. But very soon it was found that the models occupied the new area fully and some model work had to be held in abeyance due to shortage of space. Naturally this forced the authorities to acquire more land and develop additional facilities of water recirculation system and compartments for the model trays, envisaged under the second and the third phase of expansion. As the things stood to-day it can readily be seen that the requirements of the Research Station have outgrown the expansion visualised earlier.

The writer spent twentyfive useful years of his life in the Research Station. He was rather privileged to be associated with some of the important and complicated works at the Research Station right from the beginning. He was rather privileged to be associated with some of the important and complicated works at the Research Station right from the beginning. He would not hesitate to state here, that in the beginning of one's career, it is better and advantageous in the long run to work under hard task-masters, who set a good example by their own hard and devoted work. The writer was fortunate in this respect right from the beginning of his career as a civil engineer.

* Director, River Research Station, Beltola, Gauhati (Assam)

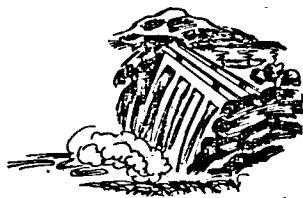
The work of the Research Station is purely in an advisory capacity. It is not obligatory on the part of the Project Authorities to accept the Station's recommendations. The ideal way, however, is that both the sides discuss the problems together, and find a solution that is both technically sound and at the same time workable on the site. This aspect is all the more significant, taking into account the extent of applied research that is being carried out at the CWPRS Pune.

During his period of association the writer found the CWPRS as a growing organization both by way of eminence and size. It is true that personal efforts at all levels are required to encourage and sustain this growth. But it is equally important that the research personal, who form a part and parcel of

this great organization also rise with it and are entitled to the sweet fruits of their labour.

Continuity of the personnel in the field of research is no doubt a very important aspect, as that is the only way to build up the necessary expertise and experience. But simultaneously with this continuity, it is equally important to ensure adequate prospects for the staff. Even persons interested in and having an urge for research, do need some incentives and adequate prospects to keep up their interest.

The writer is proud, that he was associated with CWPRS for such a long period, and that too during a very important period of its growth. The experience that he gained there is still useful to him and he cannot forget it to the end of his life. On this auspicious occasion of the Diamond Jubilee, he wishes the Research Station further growth, eminence and utility.



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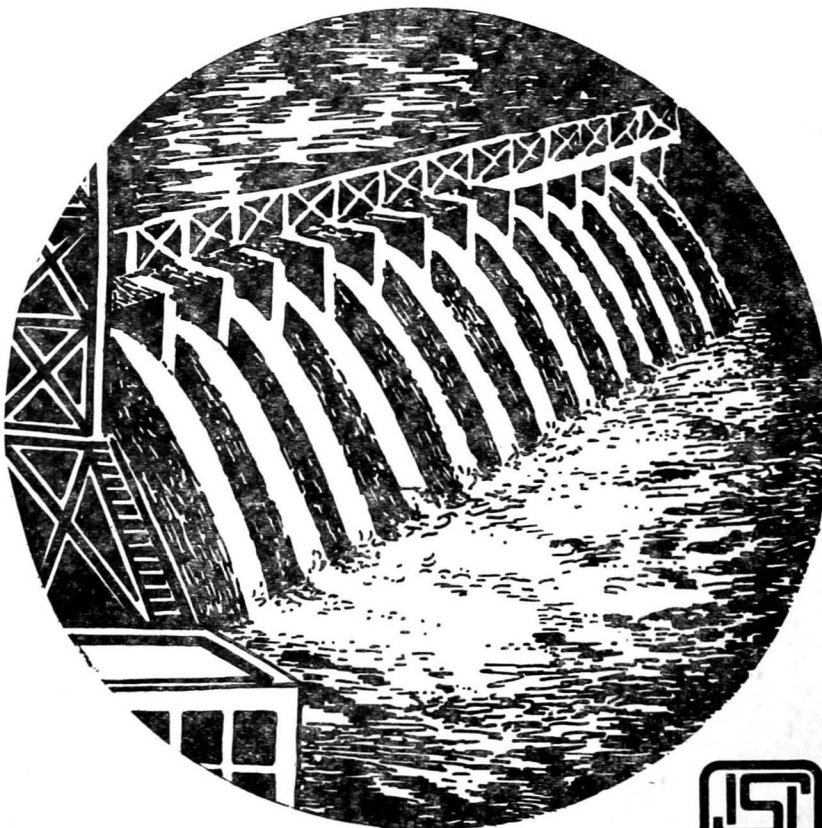
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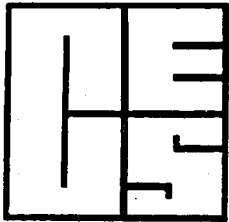
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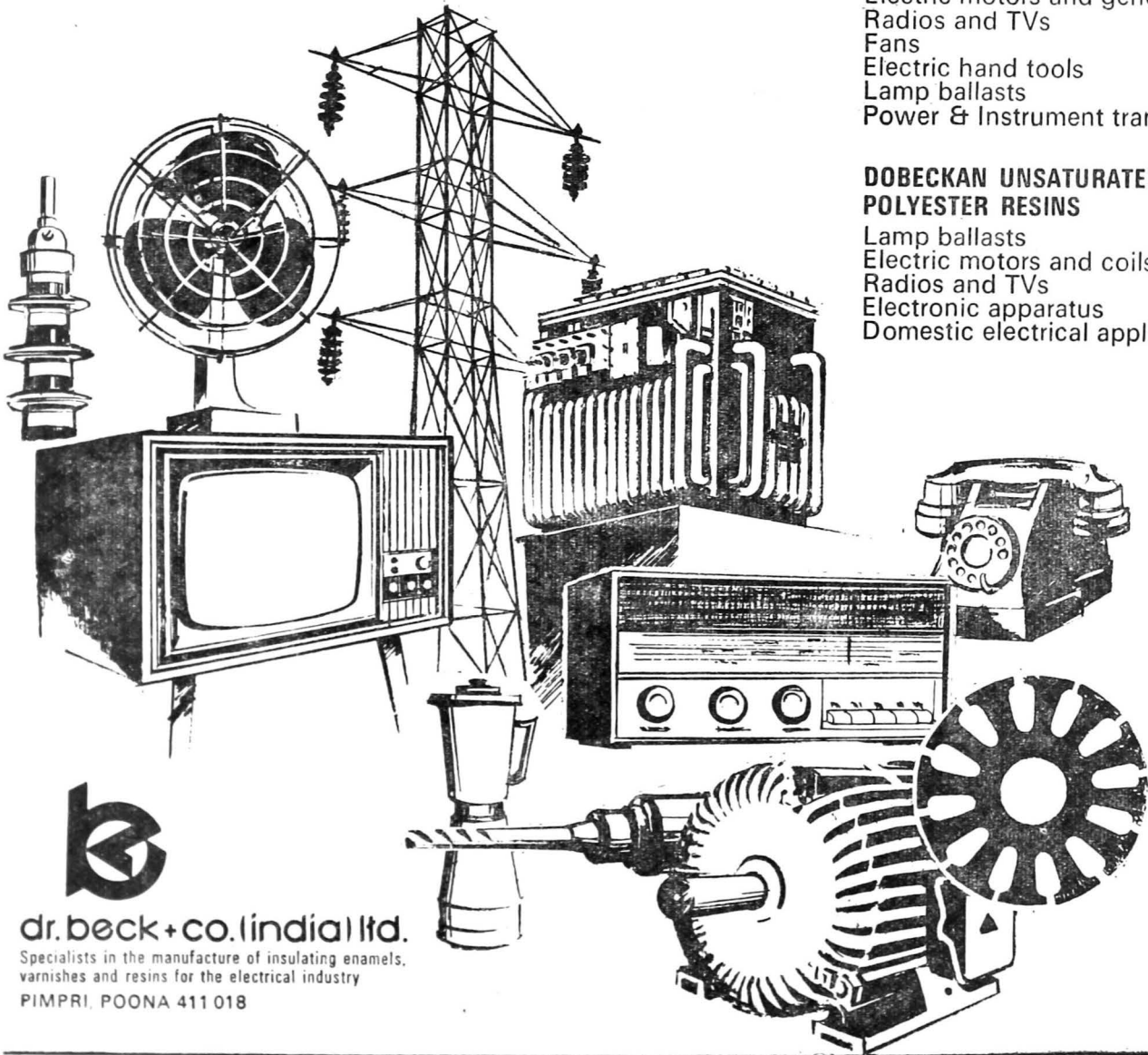
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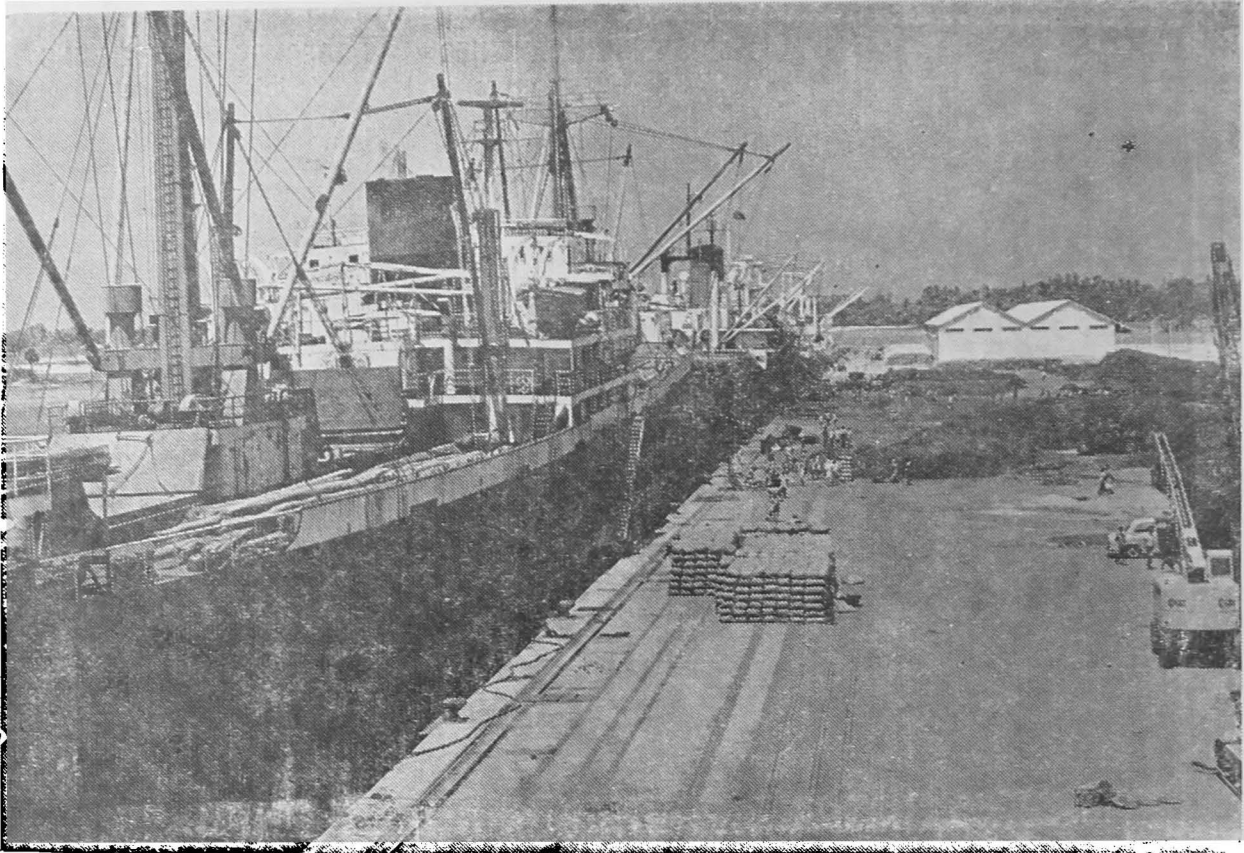
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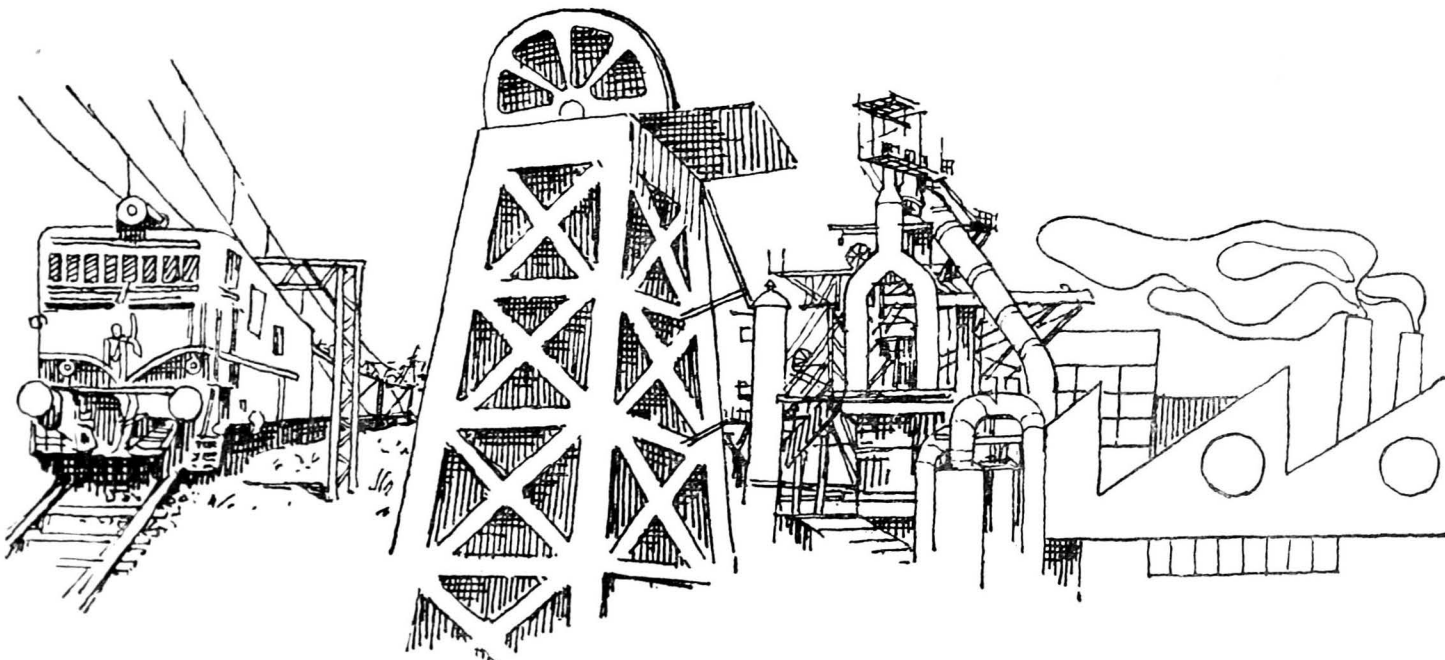
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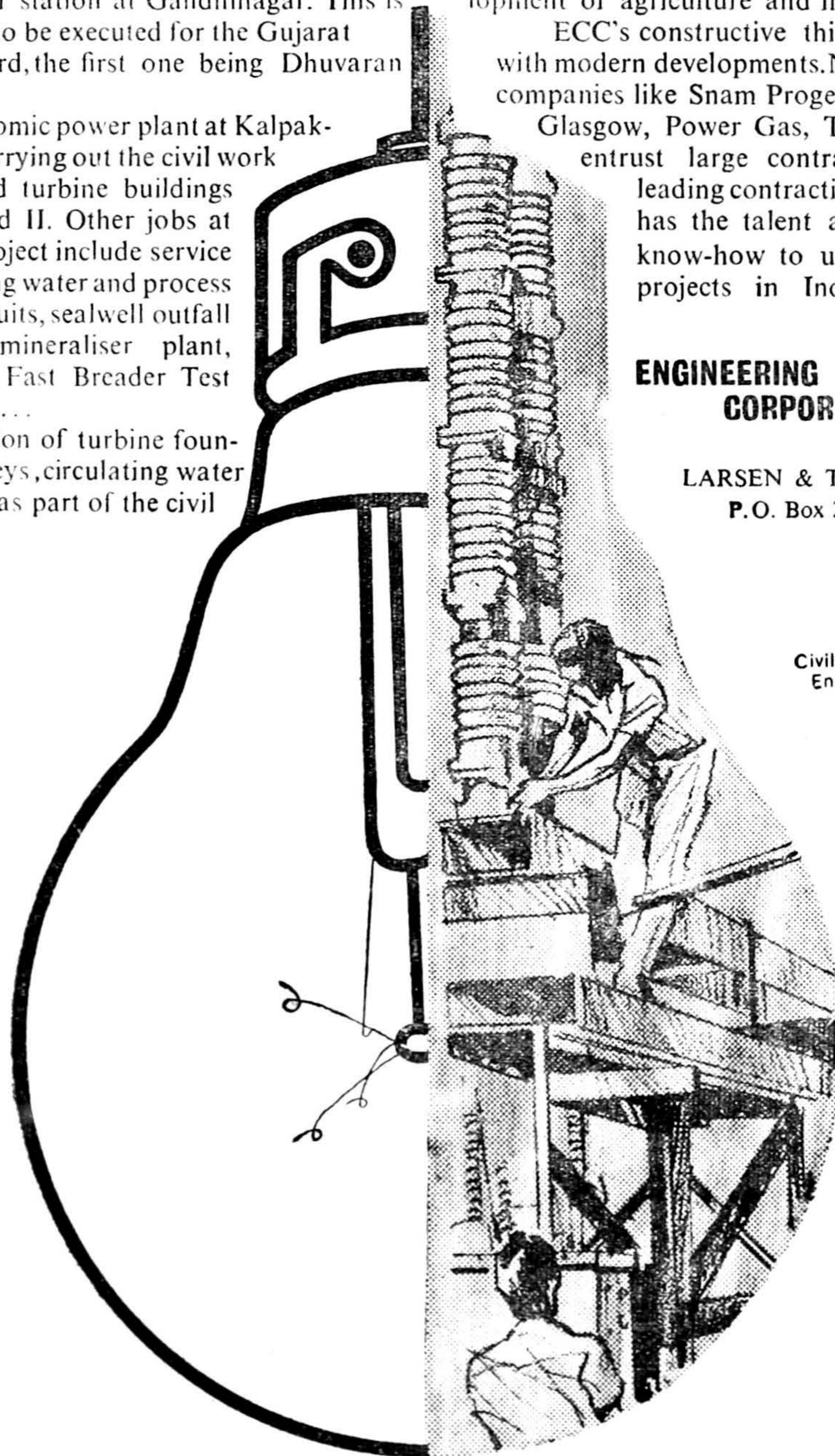
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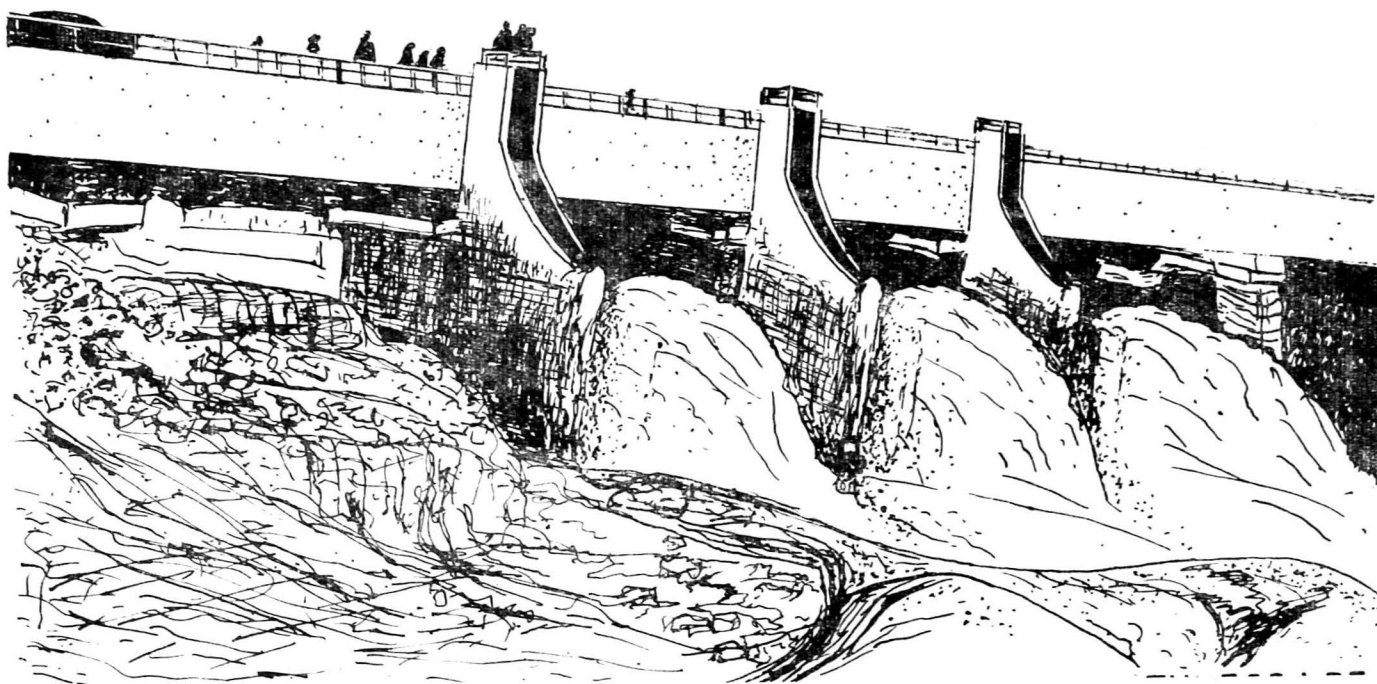
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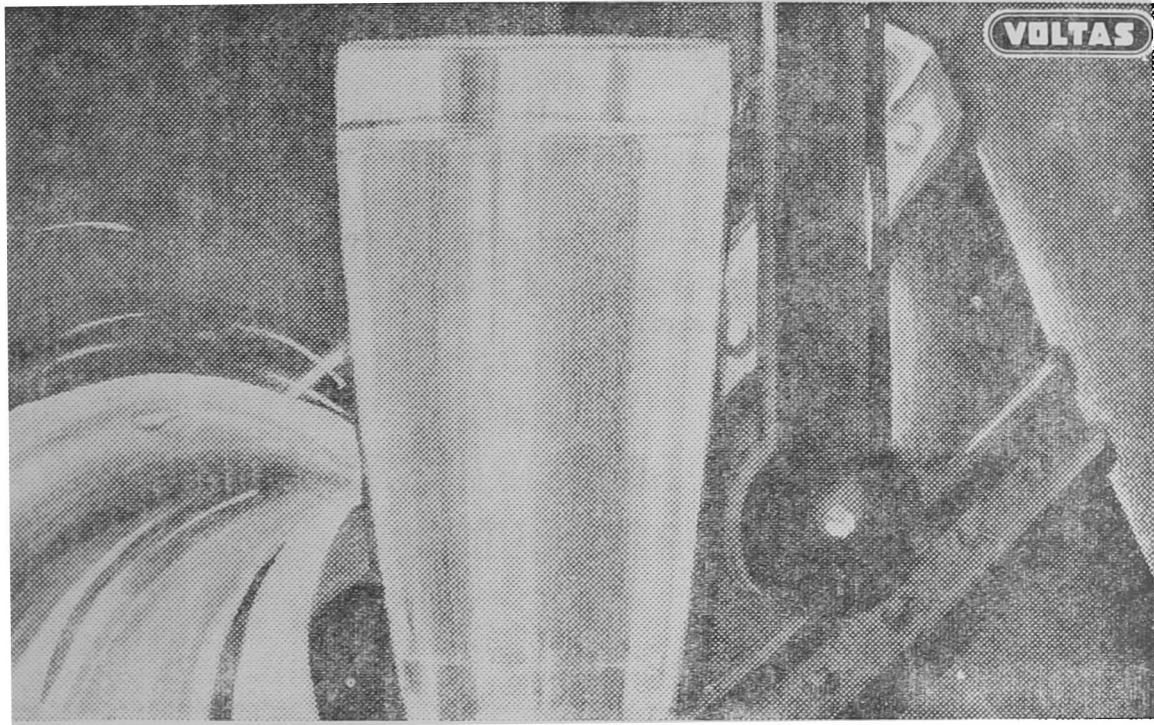
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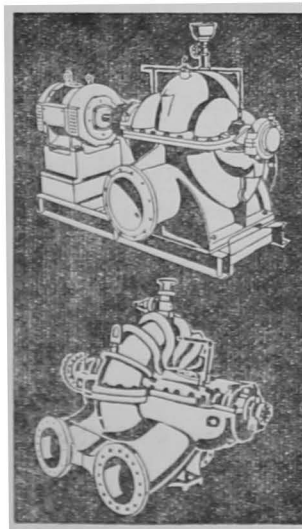
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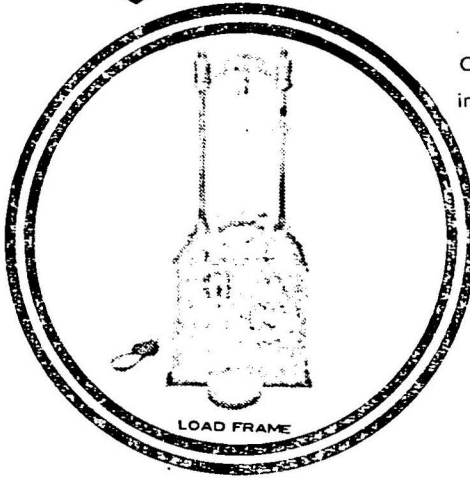
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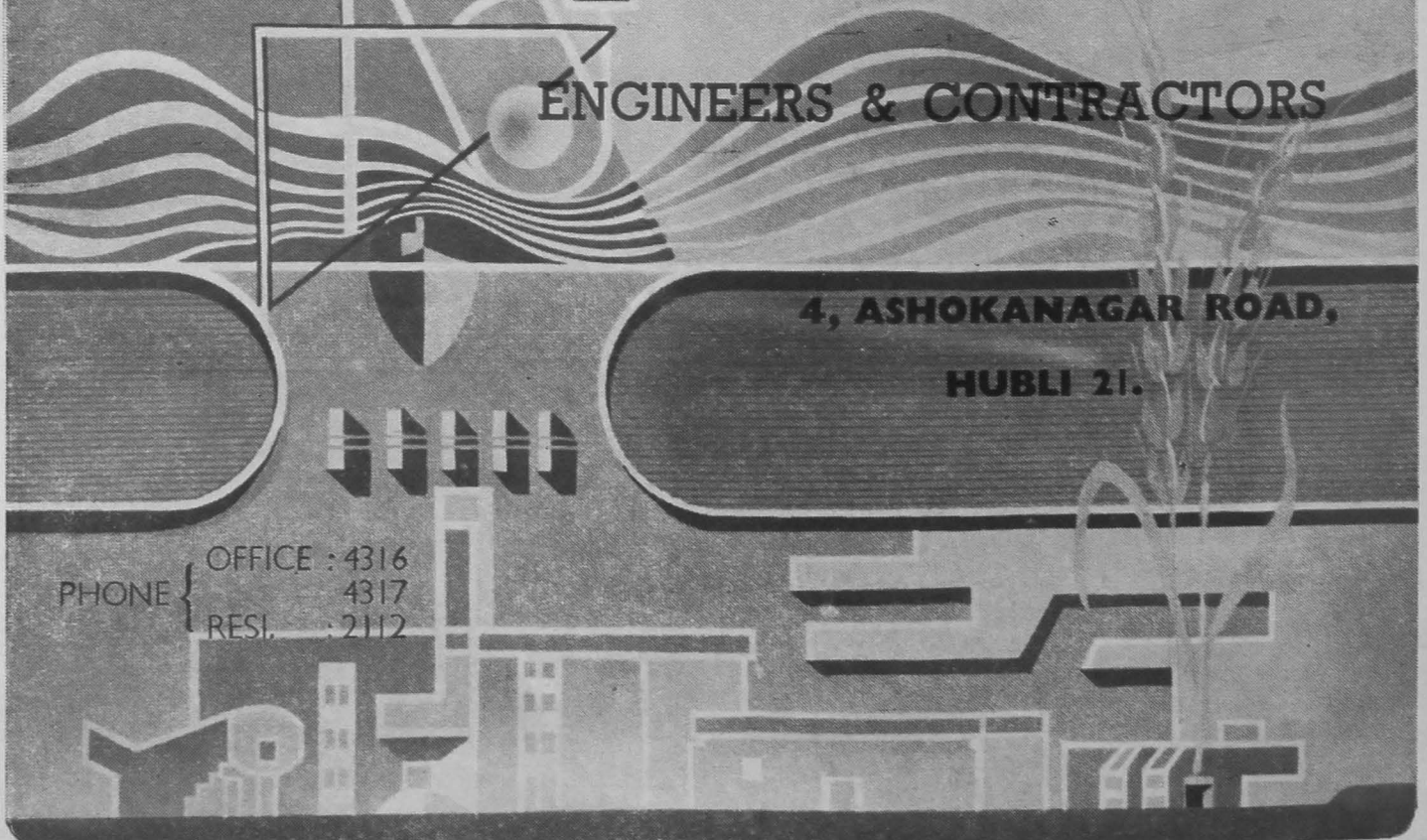
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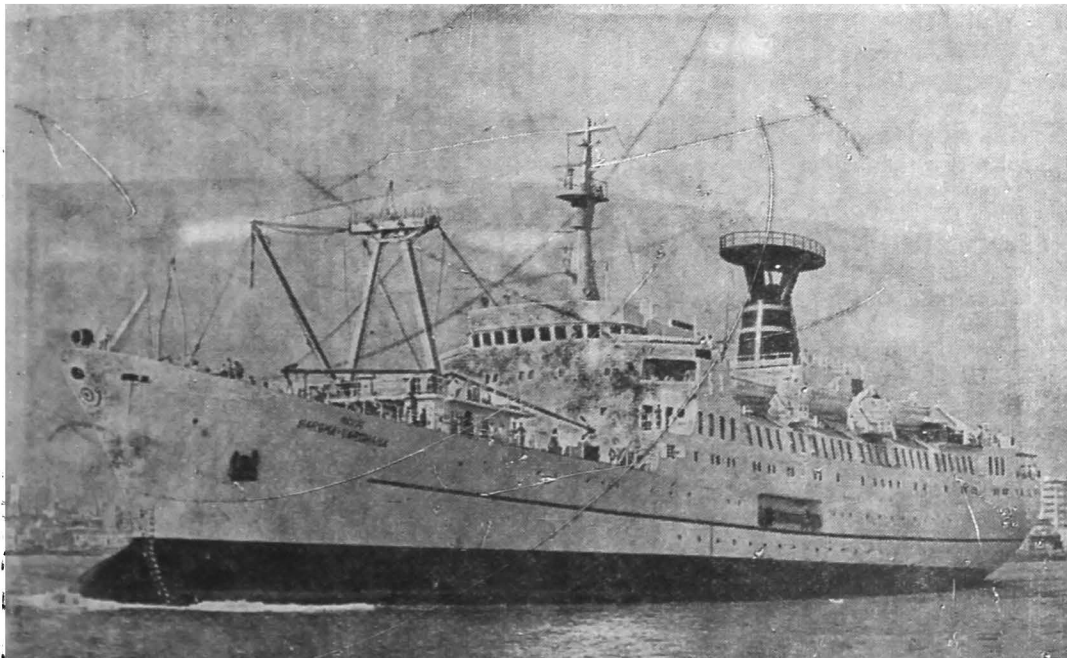
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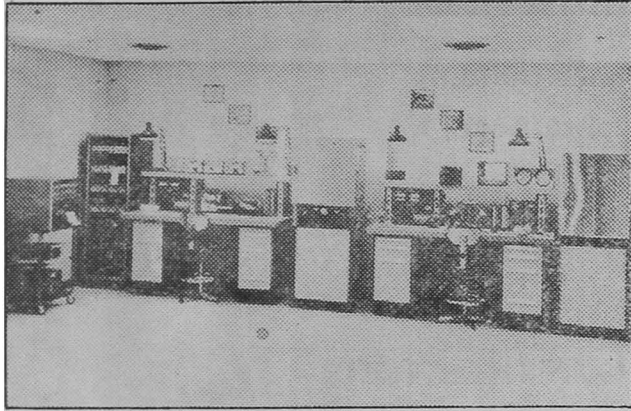
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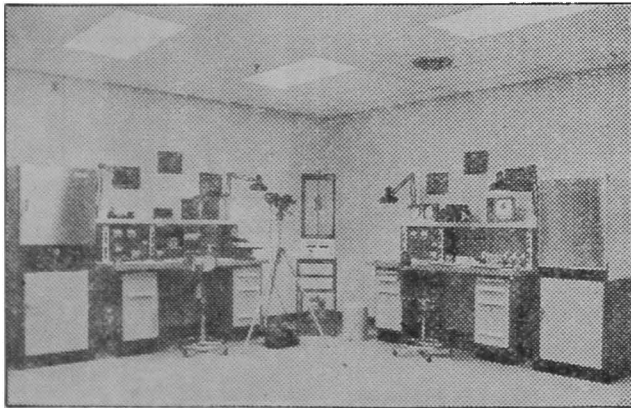
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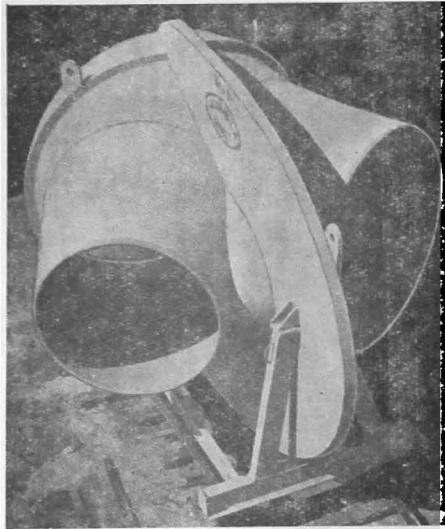
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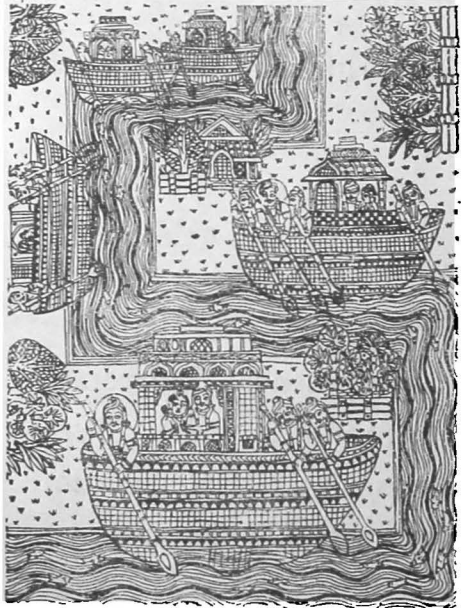
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So was it when the Bodhisattva appeared on earth as the master mariner Supparaka—Kuinara. He had knowledge of the stars and seas and knew navigation and thereby he was vigilant and unwearied. With him aboard, no ship came ever to harm.

It happened that the traders of the sea-port town of Bharukaccha who hoped for a successful voyage persuaded him to be their skipper.

Upon the high seas the ship was overtaken by a storm. Seven hundred souls aboard this ship were in fear of death.

The Great Being performed an Act of Truth: "Ye merchants and Ye Gods be my witness, that never in my life have I injured any living. By the power of this truth and the strength of my merit may the ship return in safety."

Full of joy the grateful merchants praised their saviour on their safe return.

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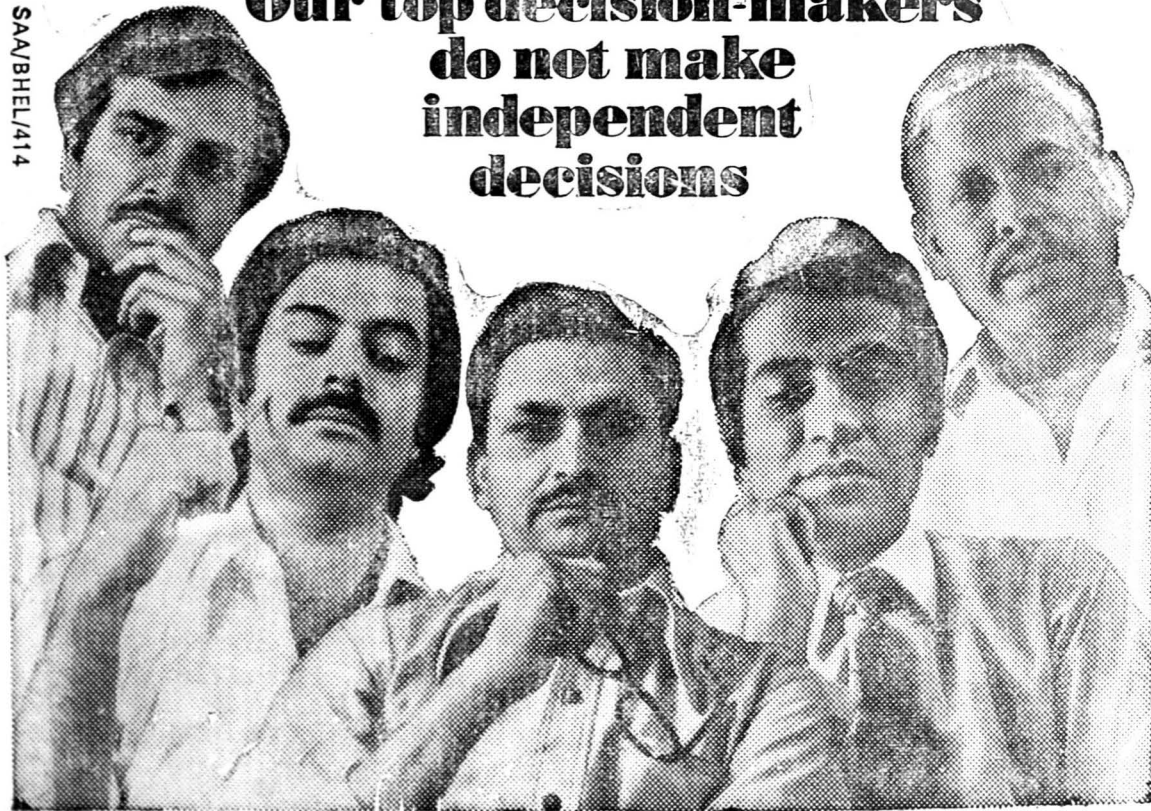
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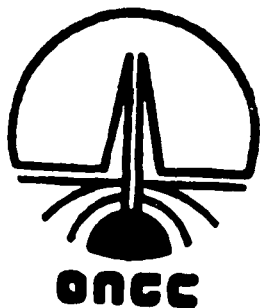
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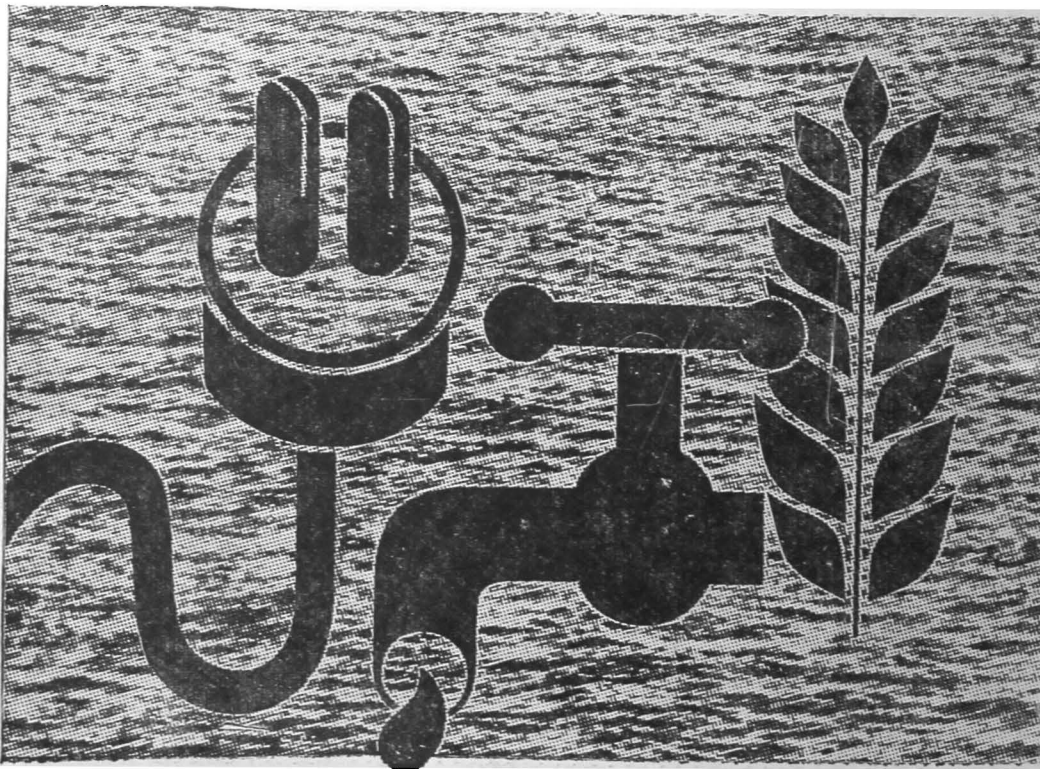
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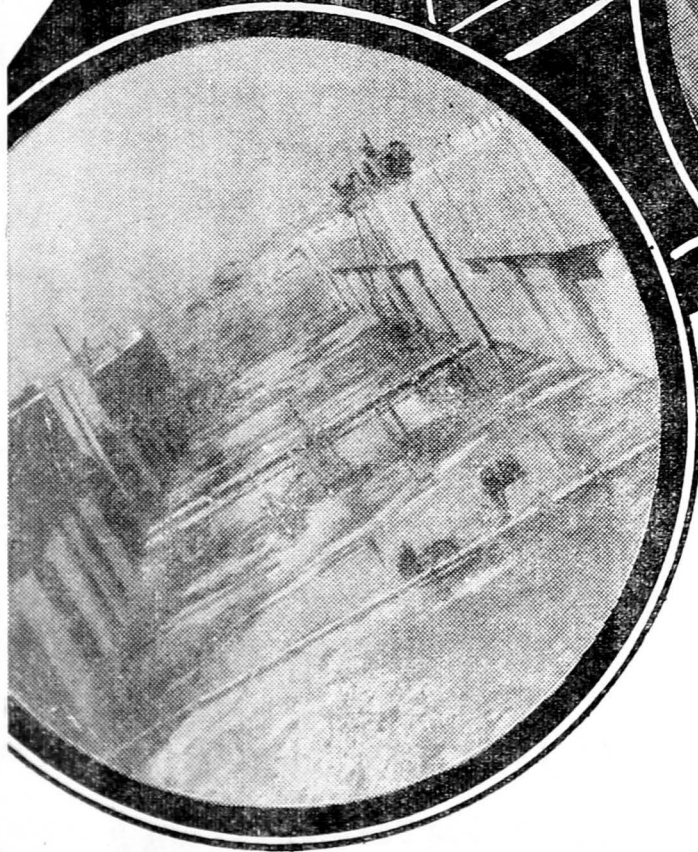
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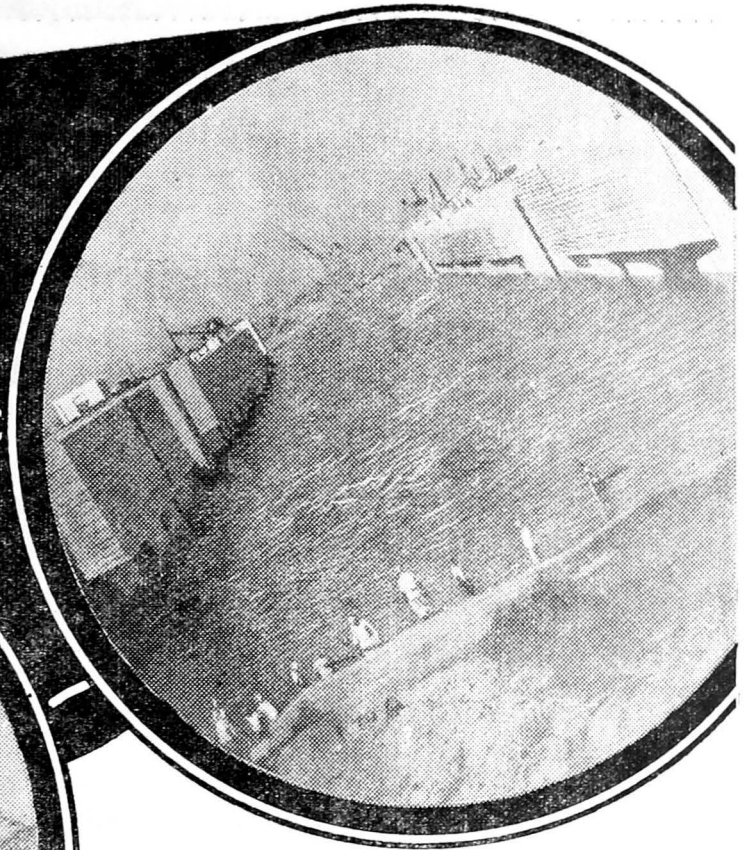
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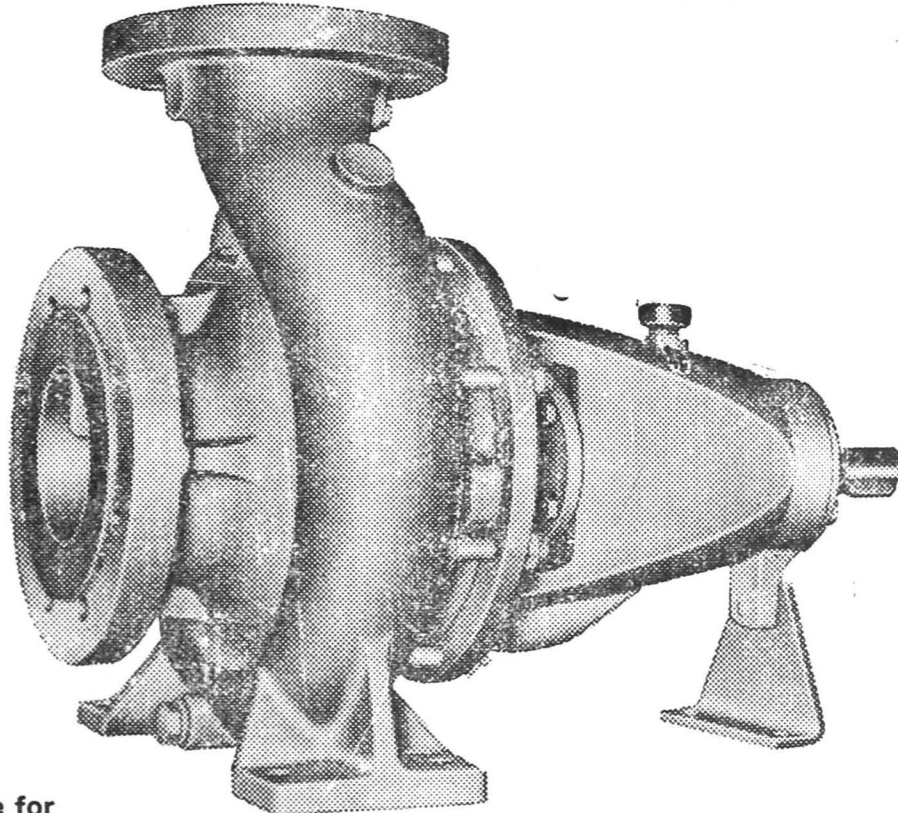
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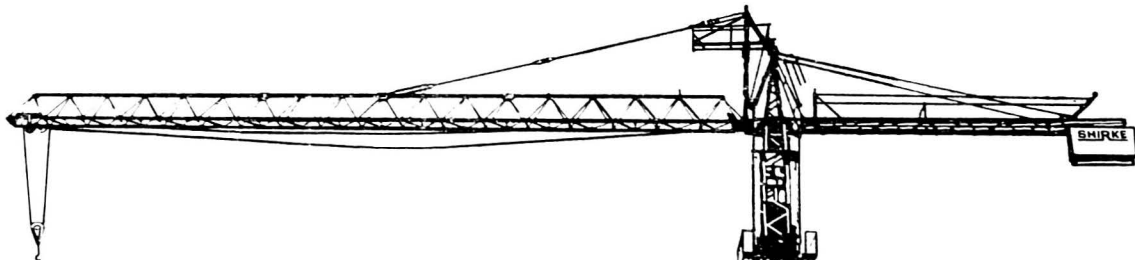
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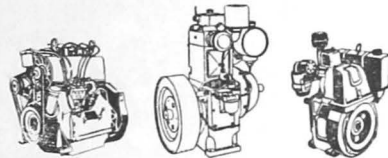


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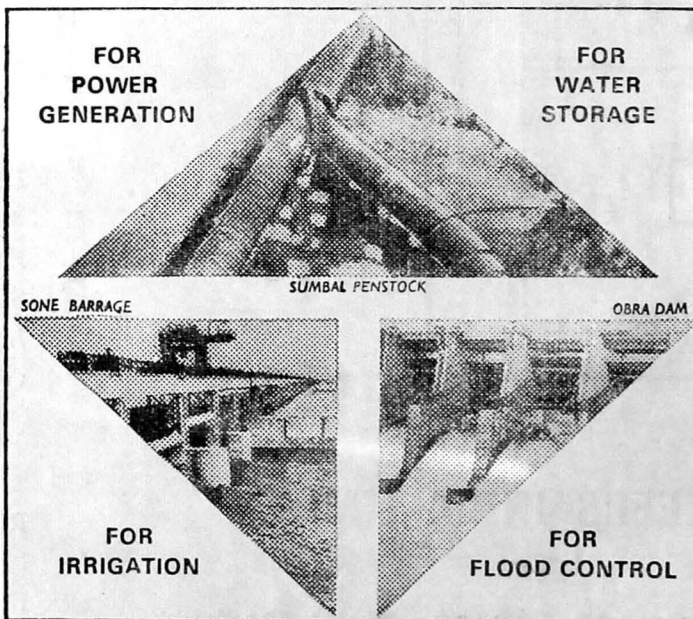
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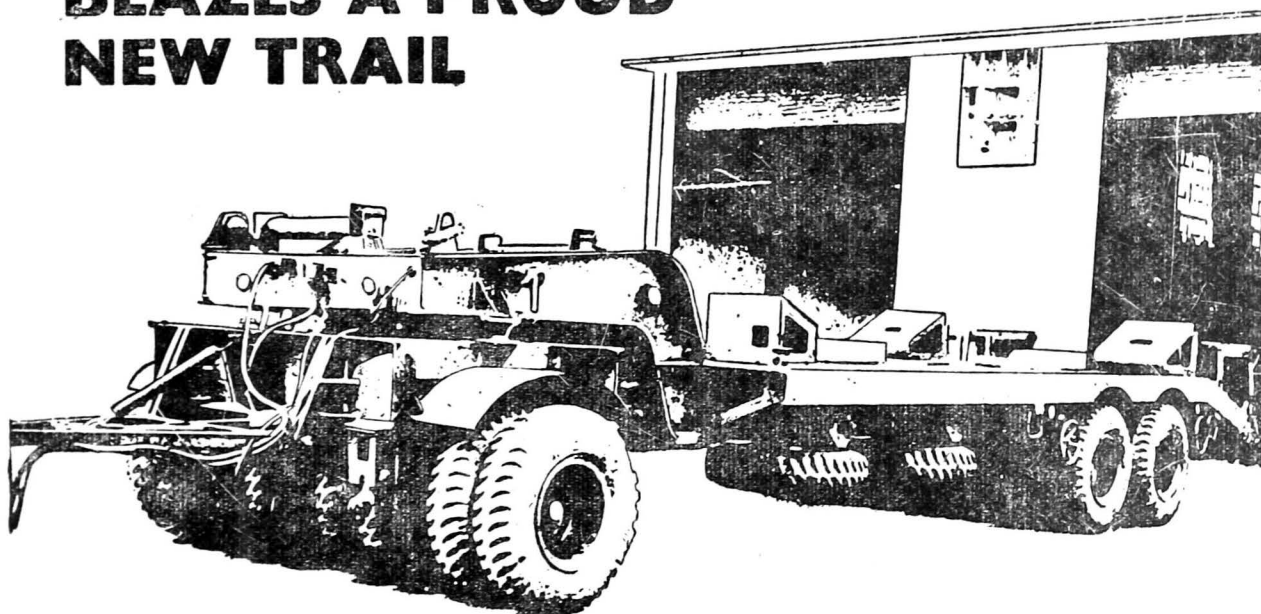
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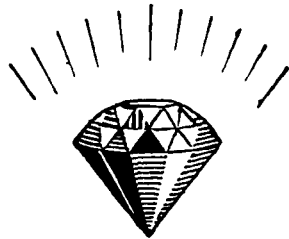
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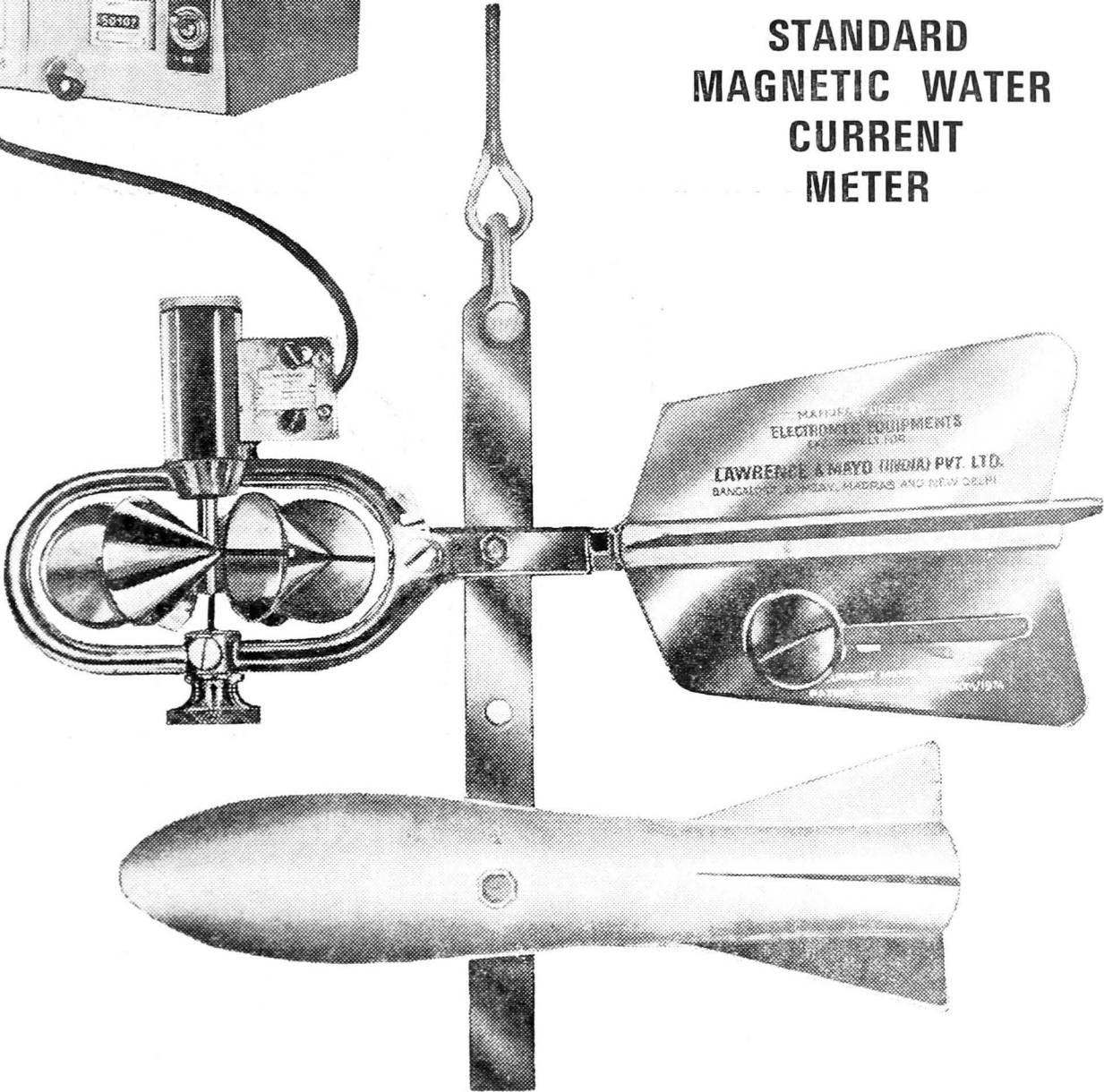
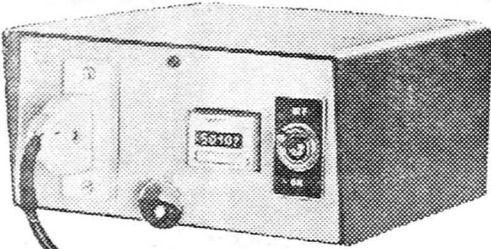
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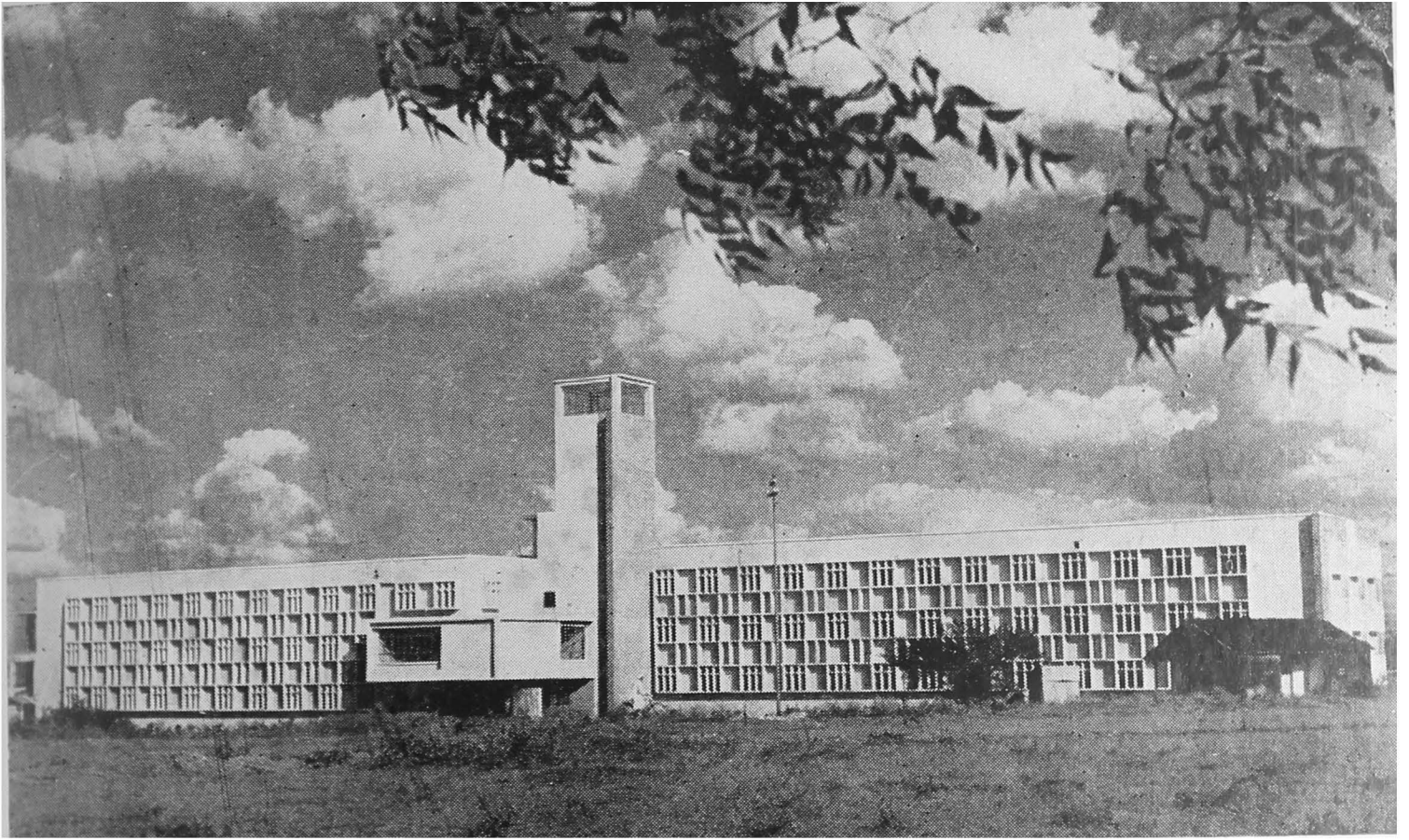
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