EXPANDED TECHNICAL ASSISTANCE PROGRAM

FAO Report No. 917

Report to the Government

of

JAPAN

on

THE HYDRAULIC DESIGN OF SPILLWAYS

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

ROME, 1958

Report No. 917 Proj./JAP/AGL

REPORT

to the

GOVERNMENT OF JAPAN

on

THE HYDRAULIC DESIGN OF SPILLWAYS

by

Charles W. Thomas
FAO Hydraulic Engineer

Rome, 1958

FAO/58/8/5958

TABLE OF CONTENTS

INTRODUCTION

In accordance with a request made to the Food and Agriculture Organization of the United Nations by the Government of Japan for an expert,

> "to assist and advise the Government on design of spillways of dams, barrages and specific schemes, and to train local personnel",

FAO provided the services of Mr. Charles W. Thomas, Hydraulic Engineer. The services of Mr. Thomas were made possible under the terms of a "Special Service Agreement" between the Organization and the Bureau of Reclamation, United States Department of the Interior.

Mr. Thomas arrived in Japan on 13 November 1957 and remained for nearly seven weeks, leaving the Country on 29 December. His advice and assistance was rendered primarily to the Ministry of Agriculture and Forestry which Ministry has as one of its functions the planning and design of irrigation works.

In the past two decades, water storage facilities to support the expansion of irrigated agriculture have been increased at an accelerated rate in Japan. The added volume of storage has been accomplished by the construction of dams, primarily of earth materials, about 30 meters in height, on small watersheds. The water is normally impounded in the upper reaches of the tributary streams and consigned for beneficial use in the valleys at lower elevations. Streams in the areas of storage development have relatively high gradients; thus, the reservoirs have small storage capacities in relation to dam heights. This causes a relatively high cost per unit volume of storage. Rainfall intensities in the catchment areas are high. The high yield of runoff and small reservoir volumes, incapable of storing peak discharges, combine to make the problem of flood spillways very important. Adequate spillway capacity is further accentuated by the fact that earth dams are highly susceptible to failure by overtopping.

Extensive consideration has been given to adequate spillway capacity. Notwithstanding, there have been failures of some dams, with consequent loss of life and property.

The problem thus became one of providing, at reasonable cost, spillways having sufficient capacity to insure that the threat of damage to the dam and its foundations had been removed. To provide such structures, in view of the circumstances enumerated above, would require the solution of many design problems with which the Japanese engineers were not entirely familiar because of the lack of an abundant store of knowledge gained from direct experience.

Present irrigation developments are pointed toward:

(1) expanding the cultivated area by using uplands to a greater extent;

(2) rehabilitating and expanding old systems;

(3) consolidation of small diversions by construction of larger and more permanent diversion dams and conveyance systems to feed into a number of previously developed distribution networks and

(4) providing supplemental water to developed lands and water for new lands by construction of storage facilities.

While in Japan, the expert was primarily concerned with the latter two.

I. ACKNOWLEDGMENTS

The expert wishes to express his thanks to the many engineers of the Japanese Government who so ably assisted and cooperated in making the work productive and enjoyable. The work was greatly facilitated by staff members of the Ministry of Agriculture and Forestry in Tokyo and at the many developments visited. Local staffs of these installations were especially helpful. The following individuals were closely associated with the expert during his assignment, and their assistance should be especially mentioned: Mr. Shinji Tohda, Chief; Mr. Takeo Nakamura, Mr. Michio Nakahara, and Mr. Kiyoshi Suzuki of the Design Section, Construction Division, Agricultural Land Bureau, Ministry of Agriculture and Forestry, Tokyo.

The assistance of staff members of the Commissioner's Office, Bureau of Reclamation, Denver, Colorado, who contributed to this report, is greatly appreciated.

II. SUMMARY OF RECOMMENDATIONS

A transition from design of spillways and hydraulic works for relatively low earth dams to higher structures is being experienced in Japan. To improve design procedures, insure safe construction and train personnel in the more advanced practices, the following recommendations are made:

1. Give greater consideration to construction of multi-purpose projects.

2. Study relative costs of providing:

   a) a primary spillway of large capacity;

   b) a higher dam with some flood storage in the reservoir and a primary spillway of smaller capacity;

   c) a primary spillway and an auxiliary spillway; and

   d) possible combinations of the above.

3. Study the past costs and quantities of each item in spillway construction to determine if the high cost of the spillways may not be due to certain high cost items which can be at least partially avoided by changes in design.

4. Include a sediment program in the investigation of storage projects. Large changes in storage capacity can affect spillway considerations.

5. Give greater consideration to the use of gated control sections of spillways.

6. Utilize the vast store of knowledge on spillway design in the world by seeking the advice and counsel of eminent hydraulic engineers from those countries in which the experience was gained.

7. Select and train suitable personnel in other countries and in Japanese colleges and universities by utilizing fellowships, scholarships and other means available.

8. Make maximum use of all existing data needed in design.

   a) Establish the best possible rainfall runoff relationships from all available data.

   b) Develop best values of maximums.

   c) Give the designer the best hydrologic information possible.

9. Obtain additional hydrologic data during the investigation stage.

10. Constantly adjust and improve the basic hydrologic data and methods of analysis.

11. Calculate the maximum probable flood by rational analysis instead of using a 200-year probability.

12. Design each element of the spillway for the maximum flow that it will be expected to carry.

13. Use general hydraulic formulas with caution.

14. Make extensive use of hydraulic models to assist in spillway design and make maximum use of the models to provide design data.

15. Give greater consideration to overflow crest shapes having a high coefficient of discharge.

16. Use bends of longer radius of curvature in both open channels and tunnels designed to flow partly full.

17. Make more comparative cost studies of types of spillways other than side channels.

18. Use air vents more extensively in tunnels and conduits to lessen the danger of cavitation erosion.

III. CONDUCT OF THE ASSIGNMENT

The Situation

A proposed itinerary of consultations and inspections was presented to the expert for consideration and approval upon arrival in Japan. It was necessary to modify the prepared proposal slightly because of the length of time which was available for his stay in Japan. Inspections of some structures, which were considered of lesser importance by the Japanese officials, were eliminated from the schedule. Except for these deletions, the itinerary, which indicated careful prior planning for maximum and effective utilization of time, was followed while in Japan. The general location of the projects inspected is given in Figure 1. The time was apportioned to:

a) Design responsibilities and review of the design procedures being followed.

b) Inspection of projects in various stages of construction.

c) Consultation on hydraulic design of structures other than those actually inspected, and general hydraulic problems.

d) Inspection of selected hydraulic model studies being conducted for design purposes at facilities other than the hydraulic laboratories of the Ministry of Agriculture and Forestry.

e) Inspection of the two hydraulic laboratories of the Ministry of Agriculture and Forestry near Hiratsuka.

f) Formal instruction in the hydraulics of spillway design for engineers designated by officials of the Ministry of Agriculture and Forestry.

g) A continuing educational program for the technicians contacted during the entire assignment.

The previously prepared itinerary was devised to provide time for each of the above considerations. The arrangement was carefully selected to permit the expert become acquainted with and to secure his advice and counsel on a very wide range of conditions.

Design Procedures Followed

Design procedures being followed and some of the background which led to their use were summarized during the brief orientation period in Tokyo prior to starting the field inspections. This orientation was accomplished by consultations between the expert and the engineers of the Ministry. Design procedures were more fully explained during the progress of the assignment.

The unfortunate experience of having several irrigation storage dams of earth construction destroyed by overtopping due to inadequate spillway capacity to accommodate unusual floods led Japanese officials to review in 1950 the criteria followed in design and construction. The major points at issue at that time were: determination of design floods, hydraulic design of the spillway elements, and construction. Reasonable accord resulted from the review. The findings were formalized in a design manual first published in 1951 and revised in 1956. However, there were many factors which contributed toward the desirability for further revisions. Among these were the increase in size of the irrigation developments. The manual was based on criteria recommended for design of dams not exceeding 10 meters in height, while the more recent trend has been toward 30-meter heights, with the probability of reaching 50 meters. Another major factor was the greatly increased cost of spillways to accommodate the calculated higher flood discharges recommended by the review board. Recent analysis of the cost of the spillways for a number of dams was found to be a major portion of the cost of the entire storage facility. In fact, the economic feasibility of some projects was dependent on spillway cost at the site.

Therefore, revision of design criteria was indicated to insure provision of safe structures at optimum cost.

During the orientation, the expert offered only general advice. He raised many questions regarding the reason for following certain practices, and the excellent answers were of great assistance in evaluating the problems.

Inspection of Projects

The revised itinerary included 14 projects to be inspected. These projects were carefully selected to permit consultation on those in planning design, construction and operational phases. They further covered a wide range of conditions, such as type of spillway, local topography, geology, and other physical characteristics.

The 14 selected projects were not all visited in one continuous trip. In all, three field trips to projects were made. This permitted time in the central office in Tokyo to discuss the findings from each trip prior to starting on another. An opportunity was also offered to rotate engineers accompanying the expert. This was advantageous, since in this way instruction by the expert could reach more individuals.

The inspections included a briefing, a visit to the site, and a closing consultation or discussion. This procedure was usually followed regardless of the stage of development of the work. Summary discussions were usually held prior to leaving an area under jurisdiction of a sub-office, district office, or Prefecture office.

During the inspections, the expert acted primarily as a consultant. As details of the project being inspected were pointed out and particular problems raised, advice and counsel were given.

The briefing usually held at the project office or on the site, depending on the stage of development of the project, included examination of general plans for the storage or irrigation facility, specific plans for the spillway and other hydraulic features, basic design data, charts, pictures taken prior to the inspection, and any other information which might assist in better understanding the problems. This briefing gave the expert an opportunity to obtain an overall picture of the development, gain some idea of the design and operational problems, and point out particular observations to be made during the visit to the site or structure.

The visit to the site or the structure was made primarily to observe local conditions and to advise on design problems. These problems, many times, involved questions of practical field design, operation, or desirable alterations of completed structures. In the case of completed structures, an opportunity was offered the expert to observe the construction and evaluate design and overall adequacy. He was thus able to get a better picture of the design procedures being used and offer advice and counsel on specific details, such as spillway flow conditions in the entrance, in the discharge carrier, the energy dissipator, and the river channel downstream. Sufficient time was usually spent to permit discussion on the spot with the engineers closely associated with the problems. Good procedure was pointed out, or corrective measures to be taken were suggested, as appropriate. Considerable opportunity was offered to instruct local personnel, because larger groups were usually present on the field visits.

When time permitted, a consultation was held at the project office following the field study. The participating group was usually small, normally being officials of the project. Because of the close schedule called for in the itinerary, many of the discussions were held in the evening at the hotel where the party was staying. These closing consultations were considered to be important because opportunity was offered to review the most pertinent questions and reach decisions regarding solutions. Design data, maps, and other pertinent information could be checked while all were familiar with the field conditions. The expert made it a practice of preparing notes at these consultations in order that the language difference might not cause misunderstandings.

Summary consultations were usually held with officials of areas of responsibility in which the inspection party was working. This area was normally a Prefecture. However, some officers had jurisdiction over parts of a Prefecture, and for others, the area of responsibility was more than a single Prefecture. As in the case of project consultations, written notes were prepared, when possible, to avoid misunderstandings because of language differences.

Inspection of the projects on the ground permitted the expert to evaluate the design procedures and analyze the problems for which solutions were desired.

Hydraulic Design of Structures Not Inspected

Designs of structures other than those visited were presented for opinions and suggestions from time to time during the field trips. This permitted review of plans for developments which could not be included in the program of field inspections. Discussion of the solutions for general problems in hydraulics was also possible. The length of such conferences was dependent upon the time available. At times, only a few pertinent questions were raised while in other instances, such as the meeting at Kyoto, complete plans were reviewed and numerous suggestions made. In each instance, the conference was conducted on an educational basis and was informal.

These meetings were helpful in evaluating the situation in the country because of the pattern established by the questions asked and the problems confronting the staff members in the outlying offices.

Inspection of Hydraulic Model Studies

The two hydraulic laboratories of the Ministry of Agriculture and Forestry are relatively recent additions to the facilities of the Design Section. Hydraulic model studies to assist in the design of spillways and other hydraulic works connected with the irrigation developments are also conducted by universities or at the project or district offices. The itinerary was arranged so that two such studies could be observed; those of the spillway for Koromogawa No. 1 Dam at the Engineering Department of Tohoku University in Sendai, and those for the spillway and irrigation outlet of Ainon Dam being conducted at the project office in Yokote City.

Inspection of the models was conducted in a manner similar to that followed in the field inspections: first, a briefing; next, an observation of the model, and then a consultation.

Both hydraulic models were observed prior to the visit to the structures. Advice and counsel was offered to the engineers in charge of the model work and a number of references to technical literature given to assist them in the studies. Recommendations for conduct of the model tests were possible at the time the models were observed. However, recommendations regarding design of the structures were made tentative, pending site inspections and closing consultations. Observation of the models in operation permitted better understanding of conditions when the field sites were visited. Also, the design recommendations could be better substantiated and more clearly defined on the basis of the model studies.

It was possible to observe the hydraulic model of the spillway and irrigation outlet for Ainono Dam in operation both before and after the field inspection of the site. The first observation indicated that certain changes should be beneficial to flow conditions, and suggestions were made for

changes which were incorporated in the model after the first viewing. Observation at a later time permitted evaluation of the changes and greatly enhanced the opportunity for instruction of personnel in the use of hydraulic models for design purposes.

Inspection of the Two Hydraulic Laboratories of the Ministry of Agriculture and Forestry

The indoor and outdoor hydraulic laboratories of the Ministry of Agriculture and Forestry are both near Hiratsuka, Kanagawa Prefecture. Both laboratories were visited on a single trip from Tokyo, which was arranged separately from the inspection trips to the irrigation developments. The visits followed a routine similar to those for structures. The closing consultations were, of necessity, longer to permit discussions of the operation of the laboratories, studies being made in the laboratories, and for instructing the staff.

At both laboratories, advice and counsel was given on a wide range of subjects, such as organization, use of the laboratories to supply design information, conduct of specific studies, and prototype observations to aid the model work and supplement the findings.

Training of Personnel

The training of personnel during the assignment may be divided into two phases:

1. Formal instruction in the hydraulics of spillway design for engineers designated by officials of the Ministry of Agriculture and Forestry.

2. A continuing educational program for the technicians contacted during the entire assignment.

Of the visits to the 14 projects, two days were set aside in the schedule for formal instruction to an assembled group of engineers. During this two-day period, which was near the end of his assignment, the expert covered the fundamentals of spillway design. Where possible, structures proposed to be built, under construction, or completed were used as examples to illustrate the points being covered. The instruction was conducted on an informal basis, and the numerous questions which arose were dealt with at the time. Many of the general recommendations for the entire assignment and those covering specific structures were presented and explained during this two-day period.

Interpreters were used throughout the formal instruction to insure that the language barrier did not prevent a complete understanding of the topics being discussed.

In the formal instruction, the hydraulic design of spillways was quite thoroughly covered. The subjects discussed were:

1. Hydraulics in general (the basis of modern hydraulics).

2. The difficulties with which a hydraulic engineer must cope.

3. Spillways in general (the definition of a spillway and the primary purpose for providing a spillway at a dam).

4. The hydraulic data necessary for designing the spillway.

5. The sources of these data and how to collect them. (Considerable detail was included in this subject on establishing precipitation stations and river gauging stations).

6. Use of the basic information.

7. Evaluation of the information.

8. Different means of handling floods at reservoirs.

9. Classification of spillways.

10. The separate elements of a spillway. (Each element of the spillway was discussed in detail: the entrance channel, the control, the discharge carrier, the energy dissipator, and numerous variations and combinations of these elements).

11. The use of hydraulic models as an aid in the design of spillways and other hydraulic structures.

The notes followed in conducting this formal instruction were copied by one of the interpreters and made available to those individuals interested.

Instruction to Personnel Contacted in Offices and in the Field

Throughout his entire stay in Japan, the expert carried on a continuous educational process for the technicians with whom he came in contact. Spillway design practices followed in the United States and other countries of the world with which he was familiar, were discussed. At one time or another, nearly all points covered in the formal instruction for selected individuals were also covered in discussions in the field. Advantage was taken of every possible opportunity to give a detailed explanation of why it was necessary to follow certain procedures to obtain the best results.

The many uncertainties, particularly in the hydrologic data, with which the designer of hydraulic structures is faced were carefully pointed out. The use of aids to be used in designing structures which may be expected to operate safely was explained carefully.

IV. ANALYSIS OF PROBLEMS AND CONCLUSIONS

The field inspections of spillways completed and under construction; visits to sites and review of plans for spillways being planned or designed; demonstrations and proposed utilization of hydraulic models as design aids; and, continued discussions of design procedures and pertinent background on their use afforded ample opportunity for the expert to analyze the problems of the Japanese engineers. A number of the more important factors, together with conclusions reached, are discussed in the following paragraphs.

Problems in Providing Storage

The project areas to be benefited by stored irrigation water are generally not extensive. Therefore, the volume of storage necessary to serve a project is relatively small. However, there are a number of difficulties encountered in providing this small storage volume.

Probably the most important of these are the steep slopes of the rivers and the lack of good reservoir sites. The result is that dams must be relatively high to create the required small capacity storage basins. The expense per unit volume of storage is, thus, considerable. There is no easy solution to this problem.

Most of the dams for irrigation storage are built in the upper reaches of streams, and the reservoir intercepts the runoff from small drainage basins. Expected rainfall intensities are high during the typhoon season. Steep land slopes and depletion of forest cover in many areas result in large water yields per unit area of watershed. Usually, the small capacity in the reservoir in excess of that occupied by irrigation storage cannot absorb sufficient volume to reduce flood peaks appreciably. Protection for the dam must then be afforded by flood handling facilities of adequate capacity to carry the expected floods. To build such structures involves costs which reach an appreciable portion of that of the entire storage project.

The Japanese Islands are of volcanic origin, and the resulting geology is such that dam sites with good foundations are not easily located. Preparation of the site for the dam and the spillway has not been a problem of major importance in the past because dams were constructed primarily of earth materials, and the average height was generally under 30 meters. Spillway foundations have created problems at some sites. The trend toward construction of both earth and masonry dams of greater heights will increase foundations problems for the dam and spillway.

The Japanese technicians are faced with these adverse problems created by nature without benefit of a vast store of knowledge gained from experience. They do have experience in the smaller structures and have developed good designs. The transition to larger structures has complicated their problems. In spite of these complications, they have done well in meeting the challenge.

The combination of problems outlined above indicates that more consideration should be given to construction of multiple-purpose reservoirs. The increased heights of dams necessary to create larger storage facilities would intensify foundation problems. Suitable dam and reservoir sites to accommodate the additional storage may be difficult to locate. However, the stream valleys are very generally narrow and deep. Dams presently being constructed are low in comparison to the depth of the valleys. Thus, the cost of higher dams would probably not be increased out of proportion.

It would be necessary to consider each project separately early in the planning stage. Sufficient economic studies would indicate the proper course to follow. It has been found, broadly speaking, that cost-benefit ratios for the planned purposes are usually improved by multiple-purpose construction over those for single-purpose construction. Multiple-purpose reservoirs might thus be a means of reducing costs allocated to irrigation.

Spillway problems, particularly in regard to costs, could probably be decreased by use of multiple-purpose reservoirs. Inclusion of flood control storage in the larger reservoirs would permit storing a volume of the peak discharges. A study of a number of actual hydrographs of Japanese rivers shows that although the discharge at peak flood is excessively high for the size of drainage basin, the duration is surprisingly short. Therefore, a large volume of water would not have to be stored to reduce the flood peak considerably. The maximum capacity of the spillway could then be decreased. Another possible advantage at many locations is that higher dams will place the spillways higher in the valleys. Higher locations, off the steep hillsides and in more favourable terrain, could reduce the amount of excavation necessary and result in a more economic structure. Discharge carriers and stilling pools for the spillways might be more expensive for the higher dams because of the greater energy in the water to be handled. The foundations for these portions of the structure would also need more consideration. However, if capacities can be reduced by absorbing peak runoff in flood control pools, a reduction in cost could probably be shown

Almost without exception, the dams presently being considered are quite low in the stream valley. This negates the possibility of providing auxiliary spillways located in topographic saddles to handle unusual floods. The higher dams could, in favourable topography, permit construction of primary spillways having sufficient capacity to handle only the usual floods, while unusual floods should be cared for by large capacity, auxiliary spillways which may be constructed at a fraction of the cost of the primary structure.

It appears then that more extensive consideration of multiple-purpose construction, with appropriate economic studies, would be a possible means of reducing costs under the adverse conditions of geology, topography, climate, rainfall, etc., as outlined previously. It also appears that flood handling facilities by means of other than a large capacity primary spillway may be more economical. Providing flood storage in the reservoir and a smaller spillway may be the most economical solution even though no charges are made to flood control benefits.

Problems in Design Data

Records of rainfall in many locations in Japan have been kept for a number of years. In the past few decades, streamflows have been measured and recorded. Rainfall records are presently available from many locations, particularly those which are intensely settled. The network of stream gauging stations has not as yet been extended beyond main streams. Adequate rainfall and streamflow records are not available for the areas where the major portion of the irrigation storage developments are located. Recorded gage height-discharge curves of the streams at the dam sites are non-existent or are not adequately developed.

This situation is not peculiar to Japan but exists in many parts of the world. Engineers working in areas where records have been maintained for a number of years usually wish they had more such data for design of hydraulic structures.

In the absence of streamflow records at proposed dam sites, rainfall data are utilized. These data, combined with runoff coefficients, either determined or assumed, concentration times calculated by making certain assumptions, and other pertinent calculations form the basis for developing a flood hydrograph at the dam site. Rational methods of analysis have been developed for these calculations.

Explanation of the Design Manual, other design criteria followed, and the field inspections indicate that the greatest deficiency is lack of basic data with which to design. Calculations entering the design process from introduction of the basic informationtto establishment of maximum discharge, for instance, must include certain assumptions regardless of the procedure being followed. These assumptions are of minor importance compared to the importance of the accuracy of the basic information initially accepted. Statistical methods are based on samples which are assumed to be truly representative of the whole. Therefore, rainfall and runoff data should be adequate and as accurate as possible.

Since good rainfall records are not usually available in the immediate area where the work is proposed, records from similar areas must be used to the greatest extent possible. A similar statement may be made in regard to runoff from the areas and consequent streamflow discharges.

There are many records of rainfall in Japan. Further, rainfall over certain areas has been fairly well established. These data have been published but present only a mass of cold statistics. The fact that this information is available in published form suggests that it may be used to calculate the highest rates of precipitation which might be expected to occur in certain geographic areas of the country. Once these values have been developed, they could be used in the calculations for spillway capacities.

A similar procedure may be used in determining specific runoff for certain areas. For instance, in many countries of the world, the drainage area in square kilometers and the specific runoff in cubic meters per second

per square kilometer have been plotted on log paper, and working curves have been established that can be utilized in determining the expected runoff for particular drainage areas. This procedure is not as accurate as using records from the streams. However, maximum rates of expected runoff can be established. Such curves, if well defined, also negate the necessity for making assumptions of the value of coefficients of runoff.

In addition to the studies suggested above, utilization of all available data and handling it in various ways to bring out as many relationships as possible, supplemental rainfall and streamflow data must be collected. Networks of both precipitation gages and stream gages are being slowly expanded in the country. It is probably not practical to extend this permanent program of observations into the small drainage basins under consideration. If it were, some time would elapse before the intallations could be completed in all areas of the country. An even longer period would be necessary to secure adequate records.

As soon as a watershed and its streams are considered for development, there is an immediate need for rainfall, runoff, streamflow, and similar information. These data are necessary to determine if there is adequate water yield from the drainage basin to fill and sustain the storage, to determine maximum spillway capacity, to design the energy dissipator at the lower end of the spillway, and for other design work. This suggests that precipitation gages and stream gages should be installed in the area under consideration very early in the planning stage. The planning and design stages in the development of a project usually cover a considerable period of time. By the time the final designs are necessary, supplemental information can be gathered. These data may not necessarily be extensive, but if secured with due care, will be accurate and will be extremely valuable in confirming or disproving earlier assumptions, which, of necessity, have been made for the design calculations. An unusual rainfall and flood may occur after the gages are provided and may produce evidence of inadequate capacity which would justify last-minute revision of plans to insure the safety of the dam.

Runoff coefficients are very difficult to estimate. There is also a probable error in applying coefficients developed in other areas because of the extremely wide range of combinations of topography, soil, type, vegetal cover, and other terrain characteristics. Under circumstances of inadequate rainfall and streamflow data, assumptions must be made. Thus, the initial calculations contain uncertainties. Application of an exact value of a runoff coefficient will do little to correct these previous uncertainties. Therefore, under existing conditions, steep slopes, rocky terrain, and incomplete vegetal cover, a high coefficient, perhaps 0.9 or higher, should be assumed for initial calculation. This will be on the conservative side and will probably include some factor of safety. The Design Manual recommends the use of 0.8 as a general value.

As data become available from the precipitation and stream gauging stations suggested above, they can be used to confirm and correct the assumed runoff coefficients. Even if the data are meager, they may be extended by acceptable means and provide considerable assistance in design. This adds another strong argument for making these installations early.

Calculation of concentration time can only be accomplished by making estimates as to type of flow, roughness coefficient, velocity of floodwaves, etc. The accuracy of such calculations can best be improved by making use of data collected as outline previously.

Probably the greatest necessity for establishing a stream gaging station at or near the dam site early in the investigation is to develop data for a gage height-discharge relationship of the stream. This relationship is very necessary for proper design of nearly all types of energy dissipators for both spillways and outlets. It should also be available for proper design of diversion tunnels used for care of the river during construction. Establishment of the relationship by calculation requires many estimates and assumptions. It will thus contain uncertainties and may not provide the required degree of accuracy for good design.

The value of the calculated maximum probable flood can be no more precise than the accuracy of each of the many variables which enter the calculations and the method used for the calculations. Several methods have been developed for calculating peak flood discharge. The best method to be used is dependent upon several conditions. The big problem is obtaining adequate and accurate basic data. If these are not available, then the maximum design flood should include some margin of safety. It is admitted that this procedure may result in increased cost. However, the additional cost may be justified on the basis that it will provide insurance against failure and loss of the entire investment plus payment for any damages resulting from the failure.

The Design Manual recommends that the maximum spillway design flood should be the flood of 200-year probability. Reference material used in compiling the Manual deals with structures with heights to the spillway crest not exceeding 10 meters above the natural stream channel. For higher dams, a longer period should be considered. Furthermore, maximum design floods based on probability, contain a considerable degree of uncertainty because the probability curve is based on available records. If additional records are obtained, a new probability curve can be constructed, and a different 200-year flood would be obtained. When uncertainty enters because of limited data, spillway capacity should be based on the maximum probable flood developed by a rational analysis which includes careful consideration of all pertinent factors in the watershed. A flood hydrograph can then be developed. The resulting flood will usually be more severe than the 200-year probable flood. The possibility of the failure of the dam is thus further removed.

The above discussion assumes that spillway capacity will be provided for the maximum flood flow or for this amount reduced by reservoir storage above uncontrolled spillway level. Such maximum flows will be of rare occurrence; yet, it must be recognized that there is a possibility of occurrence at any time. If the spillway structure is not adequate to care for such flows safely, the result would normally be an overtopping of the structure and destruction or partial destruction of the dam.

It is recognized that there are rare situations which may justify spillway capacity for only the more frequent and, therefore, somewhat smaller flood flows. This should never be justified when human life is endangered. Neither can it be justified when economic studies show the calculated risk to be favourable when frequency of failure and all resulting damages, including loss of crops, etc. , are compared with savings effected by providing for the lesser discharge. In other words, when danger to human life is not involved, maximum overall economy should be the objective when a rare situation indicates that exception be taken to providing an adequate spillway for maximum flood flows.

Hydraulic Design Problems

The questions posed in hydraulic design discussed here are only a few and more important of the many raised during the stay in Japan.

From an overall standpoint, the evidence is that actual hydraulic design of the spillways in Japan is a much lesser contributing factor to dam failures than the hydrologic considerations.

Numerous questions regarding hydraulic design concerned analytical solutions. The Japanese engineers sought advice on calculations which, they felt, should have a ready solution, but, for some reason, they could not obtain the desired answer by mathematical analysis. Some were of the opinion that this was a deficiency peculiar to their methods. In general, it is not. Many of the questions raised are common to hydraulic engineers throughout the world. No feeling of defeat should be entertained.

Engineering hydraulics is not an exact science. Therefore, experimental knowledge must, many times, be used instead of rational theory and mathematical solutions. During the past 200 years, many thousands of experiments on flowing water have been performed. The results of these experiments form the basis of our present knowledge of hydraulics. These experiments, to date, do not cover the range of conditions required in practice. The results of the experiments do not all agree. Therefore, it is very difficult to make accurate rules and formulas from them. The result is that hydraulic engineers throughout the world are still performing experiments to expand their knowledge and provide empirical values for new formulas and relationships. The job of the hydraulic engineer is, therefore, to make what appears to be the most reasonable application of the available data to each problem that he meets. If a suitable solution cannot be obtained with the available data, he may be forced to secure additional information by experiment.

Problems in Spillway Design

The purpose of spillways is to provide controlled release of water in excess of the reservoir capacity and convey it to the river channel below or to natural escape in some other drainage area. This must be accomplished in a manner such that the dam and its foundations and natural terrain features, which confine the reservoir, are protected from erosion and scour. The object of spillway design is to provide a safe and adequate spillway structure for the least combined cost of spillway and dam. In general, cost is not directly proportional to increased capacity, and a structure of adequate capacity may be found to be only moderately higher in cost than a structure of inadequate capacity. To insure that the object of spillway design has been attained, each integral part must be designed for the greatest discharge it will be required to carry. There should be no compromise of this precept.

The Japanese technicians are generally aware of practice to be followed in the design of the various elements of spillways and have produced many structures for lower dams. Procedures for designing spillways for the irrigation storage have been developed. These standards admit deficiencies in information needed for fully sufficient designs. The proportionate cost of flood handling facilities to the overall construction and ultimate cost per unit volume of stored water has also been considered. The transition to higher dams, with consequent greater heads, from control structure to tail water, and the tremendous increase in energy involved have greatly magnified their problems. In the analysis of these additional problems, some points need emphasis and clarification.

The problem of cost enters each phase of spillway design. A relatively wide selection of general types of spillways has been developed. Each is a result of studies to secure a structure which will, most economically and satisfactorily, fit particular conditions at the site under consideration. Since no two sites are exactly alike, no two structures will be exactly the same. Economic conditions vary from one location on the globe to another. Thus, one type of spillway may be built more economically in one country, while another type may prove more economical in another geographic area. This indicates that costs of the various operations and materials which go into construction of the spillways should be studied, using the economic base prevailing in the area of construction. The studies, based on prior records of construction, should indicate proportionate cost and specific item costs. For instance, in Japan, it appears that rock excavation has a high relative cost and may be one reason for high overall spillway costs. If cost studies show this to be true, then designs which involve the least rock excavation may result in lower total cost. Changes in types of spillway originally proposed may be necessary to avoid these high cost items.

For low dams, there was little need to consider other than a primary spillway. One possibility of reducing costs of the spillways for the higher dams is to consider reducing the necessary capacity of the primary spillway by providing some flood storage capacity in the reservoir.

Since the volumes involved in the peak discharges are not great, this may be quite feasible. Another consideration which may result in lower costs is the use of auxiliary spillways or fuse plugs. The terrain in Japan does not lend itself too well to these auxiliary spillways or fuse plugs, but, no doubt, there will be particular locations where they can be used. In the case of an auxiliary spillway, the primary spillway can be designed to handle only the usual floods, and the unusual floods, which are of short duration, can pass through the auxiliary spillway or the fuse plugs. Since these auxiliary spillways can usually be built at a much lower cost than the primary spillway when unit discharge capacity is considered, they should prove to be a definite advantage insofar as reducing costs is concerned.

One factor which was noted in the designs of spillways, particularly in the field inspections, was the tendency to use short radius curves. This applies generally to the open channel carriers and to tunnels flowing partially full. The use of bends of longer radius of curvature should improve hydraulic characteristics and greatly reduce maintenance costs. Short bends tend to aggravate flow conditions and, many times, may require raising the walls of an open channel. In the case of a tunnel, flows in the short-radius bend may be such that the tunnel will seal and the discharge reduced appreciably.

Some of the hydraulic problems which are encountered in the design of each element of the spillway, from entrance channel through the control section, discharge carrier, energy dissipator, and to the discharge channel, were made the subject of discussion at various times during the assignment.

Entrance channels are not common in Japanese spillways because of the type of control section generally used and the deep, narrow valleys which dominate the country. The designers recognize the problems involved in the design of entrance channels. Since only general rules are available for use in design of this element, solutions must usually be the result of experiment. This procedure may be considered as accepted practice.

Essentially all of the spillways for older irrigation storage dams in Japan have uncontrolled crests. Gates are used or contemplated for use on very few of the recent dams, including those in the planning stage. This general policy is followed because of the lack of operating personnel properly trained in the responsibilities and procedures for opening and closing the gates at the proper times. This deficiency is now gradually being corrected.

An uncontrolled crest requires a dam higher than that required for a controlled crest. Further, a much longer crest is necessary. Both items involve increased cost. In the deep, narrow valleys, the former is not a high percentage of total cost. However, the latter may be an important item of cost because of the extensive use of side-channel spillway and

the necessary rock excavation on the steep hillsides. In large-capacity reservoirs, an uncontrolled crest permits some flood storage which is always available. In small reservoirs, the limited flood storage thus created is not adequate to reduce the flood volume by a significant amount. The necessity for a gate tender and gate maintenance is eliminated. This is important in Japan because of the shortage of dependable trained personnel. An uncontrolled crest has greater ability to pass floating debris without interference. This is also important in Japan because reservoir areas are normally not cleared of timber prior to filling. Trees and brush killed by the stored water cause debris problems to develop later.

A completely controlled crest must immediately pass all incoming flood water if the flood starts when the reservoir is at maximum storage. It also offers a means of drawing down the reservoir water surface in anticipation of a flood. Combinations of controlled and uncontrolled crests have been used. If it were not for the shortage of gate tenders, selection could be made by a comparison of costs.

The major problem appears to be in the field of personnel. Economic studies should show which is the more advantageous: (1) present practice, or (2) meeting the cost of training selected personnel and paying the resultant higher wages necessary to keep these dependable trained men on the job. Each project would require this type of analysis, and the results would not always be the same. However, costs of some spillways should be reduced appreciably by use of gated crests.

Because of the similarity of topography at many of the dam sites - that is, the deep, narrow valleys with nearly parallel sides - the side-channel spillway is used extensively in Japan. Procedures for designing this type of controlled structure have been developed previously by Julian Hinds in the United States. This procedure has been adopted and is set forth in the Manual. The original procedure is based on straight crests and overflow channels. Just how much curvature can be tolerated has not been established by formula. Therefore, there is a considerable element of doubt regarding satisfactory flow conditions and adequate discharge capacities of curved or irregular crests and channels, designed to take advantage of terrain, when the procedures for design of straight channels are followed. Hydraulic model studies should always be used in such cases until reliable design formulas are developed.

Probably the greatest savings in cost of the side-channel spillways with uncontrolled crests can be effected by making studies toward utilizing an overflow crest shape which will give a high coefficient of discharge. There is much information throughout the world on this subject. More experimental work needs to be done, particularly in the field of the effect of submergence of the crest on the coefficient of discharge. In the case of the side-channel spillway, the overflow crest and channel must be studied as a unit. Providing the channel is adequate to carry the discharge without causing submergence of the crest, a higher value of discharge coefficient is directly reflected as an increase in discharge per unit length of crest without change in head.

Therefore, shortening of the crest length would be possible, and considerable rock excavation could be saved on steep hillsides.

The extensive use of the side-channel-type spillways in Japan should justify extensive laboratory studies to develop generalized information for their design. The studies should include the effect on flow conditions of crests which are not straight in plan and the changes in discharge coefficient of given crests under various degrees of submergence.

The design of open-channel discharge carriers presents some problems to the Japanese engineers as evidenced from inspection of completed structures. Mention should be made of the use of short radius of curvature for both horizontal and vertical changes of direction. As will be noted later, under discussion of specific projects, short-radius bends have been used at a number of structures especially in tunnels flowing as open channels. Unsatisfactory flow conditions and reduction of safe maximum discharge is the usual result. Minimum safe radius of curvature has not been established for all conditions of flow. Superelevations of horizontal curves in open channels have been satisfactorily used. Design is dependent upon velocity, discharge, and slope of the channel. At velocities and depths normally used in tunnel design, a very general rule is to make the radius of curvature 10 times the diameter of the tunnel. Hydraulic model studies should be used to obtain the most satisfactory and economic design to meet the given conditions at each site.

The angles of convergence and divergence of sidewalls for open channels are also a problem. The general rules for maximum included angles are based on observations of closed-conduit flow. Depth and velocity of flow and steepness of the bottom grade affect the angles of convergence and divergence which may be safely used for satisfactory flow conditions and reasonable free-board allowances. There are no general rules for all conditions met in the field. Combinations of conditions at each structure must be dealt with in design. Important structures usually require hydraulic model studies for most desirable solutions.

Another problem in designing conveyances for fast-flowing water is permissible offsets in the bottom and sides. Abrupt changes in grade create low pressure areas and cavitation erosion may result. A serious maintenance problem or possible failure of the structure can be caused by this cavitation erosion. Therefore, abrupt changes in bottom grades should be avoided. Permissible tolerances in deviation from line and grade have not been defined, although very recent experiments show that velocities need not be extremely high for cavitation to develop at relatively minor offsets. The trend should be toward obtaining surfaces as smooth as is possible without excessively high costs.

Japanese technicians are conducting research on energy dissipators. This research has advanced to the stage of employing hydraulic models to develop general information. The most critical design problem, at present, is the deficiency of data on the stage-discharge relationship at the proposed site.

The gauging stations suggested previously will improve this condition. Data from these observations will more precisely define curves which may be developed from surveys of cross sections and profiles in the river below the the dam site, estimation of values of hydraulic radius, roughness coefficient, and other hydraulic factors. The result of errors in depth of tail water on the design of energy dissipators for a spillway can be very serious, especially for certain types. Construction of secondary controls in the river downstream to produce desired tail-water conditions may result in another energy dissipation problem to control erosion. Therefore, such designs should be avoided whenever possible.

The tail-water curve is also important in the design of power-houses, outlet works, and river diversion facilities.

The major portion of the silt carried by a stream before a dam is built is deposited in the reservoir after construction. Water released from such a reservoir then has an increased silt-carrying capacity, and degradation of the channel downstream from the dam may result. Evidence of degradation was noted at some sites during the field inspections. Should such degradation reach a depth which will endanger the safety of the spillway by reason of the hydraulic jump being swept out of the stilling basin, corrective measures must be taken. These may be effected by lowering the pool or restoring the tail water by installation of a secondary control downstream. Ordinarily, it is not practical to allow for a great deal of degradation in design. However, in the absence of accurate tail-water curves, the probability that degradation will occur should be kept in mind.

More extensive use of hydraulic models for solution of design problems will aid in better and more economical structures. Furthermore, this practice will give the designer more confidence in his work. When he may encounter a feeling of defeat because a rational approach does not render an acceptable solution or empirical coefficients are not available to solve the mathematical formulas, proper use of hydraulic models will, many times, afford a solution and result in a feeling of success.

Problems in Hydraulic Model Studies

Although aware that hydraulic models provide a very useful tool in the solution of design problems, perhaps the Japanese technicians do not realize the full potential of this aid in hydraulic design. This is not unusual. Continued use of hydraulic models over a period of time increases confidence in the solutions obtained. This experience, coupled with increased familiarity of operation, leads to much wider use of models. Another point in favour of the use of hydraulic models to solve design problems for specific structures is that, in time, a store of information may be acquired which will permit formulation of generalized solutions for problems peculiar to the geographic area.

Establishment of an indoor and an outdoor hydraulic laboratory, use of university facilities, and construction of models at field offices indicate that the Ministry of Agriculture and Forestry realizes the value of hydraulic model studies. Financial support and encouragement of these studies should be continued. Experience and training of personnel by securing fellowships to older laboratories in other countries will improve the techniques. Study of the technical literature of the world and participation of personnel of the laboratories in the activities of national and international technical societies will also be of assistance. Periodic reviews of techniques and consultations by competent experts will permit more rapid development of the laboratory facilities.

V. RECOMMENDATIONS AND SUGGESTIONS FOR SPECIFIC PROJECTS

Basis

The itinerary while in Japan included visits to 14 projects, periods of discussion of plans for other projects, and consultations on hydraulic problems which were bothering the technicians. The expert was asked to make specific recommendations concerning each project visited. These recommendations and suggestions, together with necessary analyses, were made during the field trips and later summarized to assist in the formulation of general recommendations.

The general location and the order in which the projects were visited is given in a figure at the end of this report. Principal data on the dams and spillways inspected are given in Table 1.

First, the recommendations and suggestions for each project are given in the order visited, followed by recommendations and suggestions regarding plans of other projects reviewed and the hydraulic problems discussed. To aid in clarifying the recommendations, brief mention is made of the type of structure.

Hatori Dam

Hatori Dam spillway consists of two side-channel control sections, an open-channel discharge carrier, and a hydraulic jump stilling pool for the energy dissipator. The uncontrolled overflow crest section is irregularly shaped in plan, starting from the upstream face of the dam and following generally the contour of the hillside on the left bank. Two channels lead the flow from the crest to the discharge carrier. The center-line of the downstream portion of the curved left channel coincides with the center-line of the chute. Thus, the flow from this portion enters the chute directly. However, the flow from the right side channel must turn through an angle of approximately 105° at the entrance to the chute.

Since the dam is completed and initial filling of the reservoir to spillway crest level was completed at the time of the inspection, recommendations and suggestions are in the order of observations and calculations to be made rather than any modifications of the structure at the present time.

Since there has been no flow over this spillway, observations of flow conditions which will pertain in the various portions of the structure have not been possible to date.

Flow conditions should be carefully observed and recorded, at least photographically, at the following places when the spillway is discharging at low flows and up to the highest at which it may operate in the near future:

1) At the junction of the two side-channels where the flow enters the chute.- The acute angle between the centerline of the right side-channel and the centerline of the chute may cause very rough flow conditions, especially since the flow from the right channel is directed slightly upstream toward the flow coming from the left channel. These opposing currents may cause such undesirable flow conditions that modifications of the channel will be indicated from the observations. Particular attention should be directed to the flow along the right curved entrance to the chute.

2) In the chute. - Entrance conditions anticipated at the upstream end of the chute may cause diagonal standing waves which could overtop the training walls at flows considerably less than maximum design discharge.

3) In the stilling pool. - If standing waves develop in the chute, unequal velocity distribution of flows entering the pool will result. This may cause a large eddy to form in the trapezoidal pool and imperfect formation of the hydraulic jump. Degradation was noted downstream from the stilling basin. There may be a tendency for the hydraulic jump to sweep out of the pool at very low flows because of possible low tail water. Serious erosion or loss of the pool and subsequent damage to the toe of the dam could easily result.

4) In the river immediately downstream from the stilling pool. - Such observations should aid in evaluating tail water conditions.

Frequent inspections should be made of:

1) The abrupt change in grade in the bottom of the chute near the upstream end. Cavitation erosion of the concrete can occur at this point, and sustained flows could result in serious damage to the concrete paving and perhaps loss of the structure.

2) The concrete throughout the spillway structure. - This concrete was reported to have been placed during cold weather, and some areas showed distress at the time of the inspection. Repair should be initiated as soon as damage is evident. The high velocity which the water will attain in the lower portion of the chute can create serious damage once small failures have started.

Because of the evidence of retrogression of the riverbed below the stilling pool, presumably from flows from the diversion tunnel during construction, it is recommended:

1) That a backwater curve for the river be calculated as soon as possible, using surveys of the streambed to give cross sections and slope, and assuming a hydraulic radius and a roughness factor for the channel.

2) A jump height curve be calculated for the stilling basin if one is not already available.

3) These two curves be compared as soon as possible to determine if the hydraulic jump will remain in the stilling pool for all flows. It is possible that the low level of the riverbed immediately downstream from the pool will permit the pool to sweep out even at low discharges. If the comparison of the curves indicates that there is danger of the pool sweeping out, serious consideration should be given to immediate installation of a secondary control in the river downstream to restore the tail water to a depth adequate to hold the hydraulic jump in the stilling basin.

In connection with the entrance to the tunnel for diverting irrigation water to the other side of the divide, it was reported that some difficulty had been experienced in operation of the control gates in the intake structure. It might be well to suggest to the manufacturer of these gates that a bridle at the top of the gate would serve better than the present single cable attachment.

Since the reservoir was not cleared, considerable debris may collect in the arm of the reservoir in which the intake structure to the tunnel is located. It is suggested that a log boom reaching from near the tower to the far side of the embayment might be installed which would prevent logs and trash from fouling the gate operation.

Sokishiba Dam

Sokishiba Dam spillway is a side channel excavated in a steep hillside. A reinforced concrete arched roof, supported on the lining of the backside of the channel and on piers over the crest of the overflow, completely covers the channel and supports the rock cliff above. The discharge carrier is a tunnel. The energy dissipator is a hydraulic jump stilling pool. The uncontrolled overflow crest consists of ten bays, each 5 meters long, separated by concrete piers 1/2 meter thick. The crest is a very thin steel-covered section and is located very close to the edge of the canyon wall which is of tuff. There is a trashrack structure at the upper end of the reservoir to prevent large floating debris from entering the reservoir area and possibly clogging the entrance to the spillway.

Sokishiba is a completed structure. The reservoir had been partially filled, but there had been no flow over the spillway prior to the field inspection on November 19, 1957. Thus, no observation of flow conditions has been possible. The reservoir was empty at the time of the visit, and repairs were being made in the outlet tunnel which failed in March 1957 and released all the stored water.

The rock in the spillway area is of tuff. This rock is not too stable, as evidenced by the failure in the outlet tunnel. The spillway channel, especially at the lower end, is quite deep. A narrow ridge of tuff serves as a foundation for the overflow crest and the support for one side of the roof covering the channel. The reservoir is separated from the deep spillway channel by this narrow ridge. The percolation path is, thus, very short.

Full hydrostatic pressure of the reservoir may possibly be transmitted through the ridge of tuff and be applied to the outside of the concrete lining in the channel. Failure of the lining, damage to the spillway crest, and the roof supporting the cliff could easily result. It is possible that the structure could collapse and block the tunnel even before the reservoir is filled to spillway crest level.

Before the reservoir is allowed to fill, it is recommended that a review of the geologic conditions be made to determine the adequacy of the strength and watertightness of the ridge of tuff under the spillway crest.

Grouting of this ridge would probably increase the safety of the structure. It might be necessary to protect the face of the cliff below the spillway level with a reinforced concrete slab anchored into the rock. The geologic study should indicate the extent of repair necessary or advisable.

The situation, as it now exists, is considered dangerous to the safety of the spillway and dam. Should the water surface in the reservoir inadvertently reach a level above the bottom of the spillway channel at the downstream end, the entire structure should be observed closely to ascertain any percolation into the channel, any distress in the lining, or any movement of parts of the structure.

Erosion of the riverbed below the spillway stilling pool resulted from the high discharge through the outlet tunnel during the 6 hours required to drain the reservoir after the failure at the upstream end. This degradation appears to be of sufficient magnitude to lower the tail water and leave the stilling pool unprotected by backwater. The hydraulic jump may sweep out of the pool at low to intermediate flows. The baffle blocks and the rise in floor level at the downstream end of the pool may be effective in retaining a hydraulic jump in the stilling pool for low flows.

A tail water-jump height study similar to that recommended for Hatori Spillway is recommended for Sokishiba.

Horizontal curvature of the tunnel may cause the flood flows to enter the stilling pool with a poor horizontal velocity distribution. Velocities entering the right side of the pool will, very probably, be higher than those on the left side. If there is appreciable difference in velocity, a backflow may develop along the left side of the pool. This condition would cause the pool to sweep out at a lower discharge than if the entering velocities were well distributed across the upstream end.

It is recommended that flow conditions in the stilling pool be observed and recorded, at least photographically, over as wide a range of flows as is available in order that the need for corrective measures may be evaluated.

Other points which should be observed are: the effectiveness of the trashrack at the upper end of the reservoir to keep large floating debris from approaching the spillway. If good protection is not afforded, a log boom in front of the spillway may be necessary to prevent possible clogging of the bays of the spillway or the conveyance tunnel.

The cushion pool at the junction of the shaft from the intake gates and the outlet tunnel should be observed periodically to determine if the concrete in this area is being eroded or damaged. The cushion pool is shallow, and the water falling from the intake shaft and turning to flow down the outlet tunnel could cause erosion at this point.

The use of short trashracks over the intake gates at this and other dams should probably be made the object of a long period study to determine if longer racks would not be more satisfactory. The longer racks should permit easier cleaning. Additional protection would be afforded to the cables, chains, or rods provided for moving the gates. No change is suggested unless the study shows some benefits.

Narugo Dam

Narugo Dam was designed and constructed by the Ministry of Construction for flood control and power generation storage. Inspection of this dam was included in the itinerary in order that the expert might observe design practices followed by other government agencies.

In addition to the flood control pool in the reservoir, two spillways have been provided to pass a total flow of 2,000 cubic meters/second. The primary spillway has a gated control and a tunnel discharge carrier. No energy dissipating device is provided at the discharge end of the tunnel, since sound rock was assumed and the flow enters the river some distance below the dam. The auxiliary spillway is an uncontrolled crest section over the top of the arch dam. Approximately 100 cubic meters per second had been released through the primary spillway for a limited period of time. There had been no flow over the auxiliary spillway prior to the inspection.

Many points of design of the structures were discussed with the engineers of the Ministry of Agriculture and Forestry while at the site. It was suggested that periodic visits be made to the structure to observe a number of conditions. More important among these were:

1. Flow conditions at the entrance to the gated control. - The entrance appeared well designed, and good flow conditions should result.

2. Flow conditions in the tunnel downstream from the gates, if possible to make observations. - There is a short-radius horizontal bend combined with a short-radius vertical bend below the gates. The flow will probably be very rough, and there may be a tendency for the tunnel to fill at high discharges.

3. Flow conditions at the discharge end of the tunnel. - Some indication of the effect of the bends should be evident here. The jet from the tunnel may strike the left canyon wall and cause erosion.

4. Erosion below the tunnel portal. - The small flow previously released had eroded a hole about 6 meters deep. At the time of the inspection, a concrete cutoff wall was being installed to protect the tunnel outlet. Large floods may cause serious erosion in the riverbed and on the left canyon wall. It was suggested that a concrete deflector so shaped to throw the jet away from the rock wall and with a slight upward slope to cause the jet to strike the riverbed some distance from the tunnel portal would have been a better solution. It was also pointed out that such a deflector could easily be added later if a serious erosion and maintenance problem develops. A satisfactory shape for design could be developed from a simple hydraulic model.

5. The conditions of the concrete surfaces in the tunnel. - The concrete in the lower vertical bend of the spillway tunnel had been smoothed and left in a very good condition. It is probable that this smoothing is adequate to maintain the tunnel surfaces without damage from the high velocity flow. The tunnel surfaces downstream from the bend were not as smooth as those in the bend proper. Some cavitation erosion may develop in these areas. By observation of the two types of surfaces, considerable experience could be gained regarding concrete finishes for tunnels subjected to high velocity flows.

6. Flow conditions in the auxiliary spillway. - This design was developed with the aid of hydraulic models and should operate satisfactorily. An erosion problem may develop downstream from the cushion pool at the toe of the dam. Degradation of the riverbed by flows from the primary spillway will result in an appreciable drop from the floor of the cushion pool to the riverbed, and maintenance or additional construction will probably be required.

Tamayama Dam

Tamayama Dam is of concrete gravity type, with the spillway over the dam. The reservoir will include a flood pool. The lower level of this pool will be at the spillway crest and the upper level at the top of a 15.5-meter high gate controlling the crest section. The dam is in the early stages of construction, and spillway design has not been completed.

The energy of the dissipator proposed in the design is a hydraulic jump stilling pool with a level apron. A concrete arch dam is proposed downstream for a control to insure the necessary tail water depth for the hydraulic jump.

The design appears adequate in most respects. However, some savings in cost may be effected by further study. Consideration should be given to providing scour protection facilities below the secondary dam. Otherwise, a costly maintenance problem may develop.

It is recommended that a hydraulic model study be made of the stilling pool. The model should contain the small arch dam proposed for tail-water control and a short reach of river downstream from this structure. Some saving may be effected in providing an improved stilling pool of less length. The dimensions could be determined from the model. Some difficulty may be encountered in obtaining an effective stilling pool because of the high discharge per unit width of spillway; over 100 cubic meters per second per meter of width. The possibility of lowering the stilling pool should be investigated in the model. The height of the arch dam could thus be reduced. A possible saving in overall cost might result. Other types of energy dissipators, such as a flip bucket or a ski jump, should be studied on the model. Economic studies would determine relative costs. Careful evaluation of riverbed conditions, particularly geology, downstream would also be necessary in consideration of a ski-jump spillway.

Koromogawa No. 1 Dam

Koromogawa No. 1 is an earth dam in the early stages of construction. Design for the spillway has not been completed. Hydraulic model studies to assist in the design of the spillway are being conducted at Tohoku University at Sendai. A model of the preliminary spillway design was observed in operation prior to the site inspection.

The dam and reservoir have both a flood control and irrigation storage function. A gated control section and an open-channel discharge carrier are included in the preliminary design. The energy dissipator will act as a hydraulic jump pool for flows up to about 30 percent of the maximum and will sweep out and become a flip bucket for higher flows.

The site inspection and observance of the hydraulic model led to the following conclusions and recommendations:

1. Move the centerline of the spillway to the left at the downstream end. Alignment of the spillway on the ground placed the lower end so far to the right that the jet issuing from the spillway at high flows would strike the sandstone bluff on the right side of the river at an unfavourable angle. This would probably cause a large eddy in the river at the toe of the dam and subsequent erosion. This relocation of the centerline would not change the amount of excavation appreciably. Some re-alignment of the roadway to the left of the spillway may be necessary. Site inspection in the excavated areas indicated that the rock underlying the spillway location may not dip as sharply toward the river as assumed from the preliminary subsurface investigations. Moving the centerline to the left at the downstream end may be desirable for improved foundations. More exploratory drilling should be done prior to the final location. The centerline change had been considered previously, and the hydraulic model was constructed on a revised centerline.

2. Make economic, geologic, and hydraulic model studies of a 3-gate instead of the proposed 5-gate control structure. This would result in a narrower control structure but the gates would need to be higher to pass the design discharge. Examination of the rock in the excavated cutoff trench for the dam indicates that the foundation for the control structure will need to be lowered to rest on suitable rock. Considerable amount of concrete would be required in the overflow crest if 5 gates are used. If 3 gates are used, the top elevation can be held the same and the bottom elevation lowered, thus reducing the amount of concrete. More drill holes will be necessary to determine the physical characteristics of the rock. The higher gates will require a better foundation to withstand the increased head and the greater overturning moment. Better hydraulics in the discharge carrier will result if 3 gates are used, because the amount of convergence of the channel below the control will be considerably less. A more economical structure should result from the change in number of gates.

3. A drain should be provided under the discharge carrier. The shale seams in the foundation rock will provide slippage planes and percolation in the paths. The probability of movement will be greatly reduced if a drain is provided to remove accumulated water.

4. More study on the design of the entrance channel will be required. The radius of curvature of the presently proposed channel is too short, and an unequal horizontal velocity distribution in the flow will result. This was indicated on the hydraulic model. The narrower control structure will probably simplify the problem of intake channel design. Development of a good design for this channel should have high priority in the program of hydraulic model tests.

5. A cutoff wall and riprap or dry-rock paving should be provided downstream from the energy dissipator. When the energy dissipator is acting as a hydraulic-jump pool and during the transition period from this type of flow to the flip-bucket action, downstream velocities will be relatively high. Erosion is likely to occur in the area between the structure and the present river channel. Some studies on the hydraulic model are indicated to determine the extent of protection necessary.

6. Make extensive use of the hydraulic model to aid in overall design. The chute portion of the spillway is not on a steep slope. Therefore, the present angle of divergence should not be too great. The best angle can be developed on the hydraulic model. Different shapes for the downstream end of the energy dissipator should be tried in the model to determine which shape will give the best flow conditions to fit the downstream topography and the old river channel. Pressures on the training walls and on the floor of the structure can be measured in the model to provide data for structural design.

Gando Dam

Gando Dam is an earth and rockfill structure in the early stages of construction. The dam and reservoir will be operated to store water for irrigation and power generation.

Present plans for the spillway include an entrance channel, a gated control, an open-channel discharge carrier, use of a rock quarry excavation as an energy dissipator, and an outlet channel from the quarry to the river. The design, in general, is well formulated.

Site inspection and review of the plans and drawings led to the following conclusions and recommendations:

1. For best hydraulic conditions, the centerline of the control section should be changed so that it will be perpendicular to the centerline of the chute. The present centerline is a continuation of the centerline of the dam. Economic studies should be made to determine relative costs of the present and proposed new locations. With the present alignment, the flow in the entrance channel must first be turned away from the river, then toward the river, and again away from the river as it passes through the control structure and a short reach of channel immediately downstream. Unequal velocity distribution will result, and standing waves are likely to develop in the chute. Discharge through the control gates may not be the maximum possible, nor may it be that calculated because of the unequal entrance velocity distribution. Entrance channel design should be simplified somewhat by the change of the centerline location.

2. The left wall of the entrance channel should be curved. The straight wall upstream from the transition section will require more rock excavation, and flow conditions will not be as good as with a curved wall.

3. A curved section and some riprap or paving on the face of the dam should be provided on the right side of the entrance. Present design will permit flow along the face of the dam and cause bad entrance conditions and reduce discharge for the gate adjacent to the dam. Some scour on the face of the dam might result if velocities are high enough to move the proposed riprap material.

4. The angle of convergence of the training walls of the chute can remain as in the preliminary design. This conclusion is contingent upon rotating the control structure so that the centerline is perpendicular to the centerline of the chute. In the present design, standing waves, created by the changes in direction of flow and the pier in the control structure, may strike the training walls in the converging portion and cause overtopping.

5. The centerline of the chute should be straight through the converging section and to the quarry edge. The proposed horizontal bend near the downstream end may contribute to overtopping of the walls should standing waves be formed by the converging section.

6. Place a lip at the end of the chute to deflect the jet upward and away from the rock face of the quarry.

7. Make analytical studies of the path of the jet leaving the lip. These calculations should be made for a range of discharges to ascertain the location of the end of the structure. It is not considered necessary to extend the chute onto the shattered rock at the quarry edge.

8. If Recommendations 6 and 7 are carried out, there should be no need for a concrete protective slab on the quarry face. If deterioration of the face develops later, needed repair work can be done at that time.

9. A drain should be placed under the chute. This structure is on a relatively flat grade. The foundation rock appears sound. However, extensive freezing is reported in the area. The drain would remove excess water and offer a safeguard against damage from freezing and thawing, with consequent damage to the chute and the quarry face.

10. No special treatment of the concrete surface in the chute is considered necessary. The velocities will be relatively low because of the flat grade and the absence of vertical curves will maintain bottom pressures.

11. Use of the rock quarry for an energy dissipator should be satisfactory. This quarry is well removed from the toe of the dam and will be left isolated from the present river channel, except for the outlet channel which will be cut across a bend in the river. The rock exposed in the walls of the quarry at the time of the inspection appeared to be good except for some surface shattering from the blasting and should resist erosive action of the falling water.

12. The proposed plan for the outlet channel is sound. The exit will be at a considerable distance from the toe of the dam and around a bend of the river. Therefore, there should be no danger of erosion of the toe of the dam.

Sannokai Dam

Sannokai is an earth dam completed in 1952. Two side-channel spillways with tunnel discharge carriers lead the flood water to a common energy dissipator. A high sill across the pool forces a drowned hydraulic jump in the pool and in the twin tunnels. A second pool and sill provide erosion control below the high sill. No sizable flow was reported to have passed the spillways prior to the inspection and after the high sill was added to the pool structure.

Since this is a completed dam and spillway and is now in operation, no major structure changes are recommended at this time. Some changes have been made previously. Very close observation should be maintained of all flows passing the spillway. Any sign of inadequacy should be cause for immediate study on a hydraulic model of the entire spillway to develop capacity curves and assist in the design of corrective measures which may be necessary.

A site inspection and study of the plans lead to the following conclusions, suggestions, and recommendations:

1. It appears that a hydraulic jump will form in the tunnels at nearly all flows, with the possible exception of very high flows. Therefore, floating debris will collect in the forward roller of the hydraulic jump. This material will be thrown against the tunnel lining and may cause serious damage. Sufficient material could collect to cause the tunnel to jam. To lessen the danger to the spillway, it is recommended:

   a) That serious consideration be given to clearing the reservoir area. The reservoir was empty at the time of the inspection, and it was reported that it is drained each winter. This would facilitate clearing.

   b) A log boom should be installed at some distance from the twin spillways. The existing trashracks are short and located very close to the overflow crest where velocities are high. In the event of high flows, velocities would be sufficient to cause removal of material from the racks to be very difficult if not impossible.

   c) The fine grid should be removed from the present trashracks, leaving only a large grid. The present spacing will catch relatively small debris which cannot be removed because of high velocities and lack of removal facilities. It is possible that a sufficient amount can be collected to block the racks, and the structures could collapse onto the crest or be carried into the entrances of the tunnel and seriously restrict or block the flow. Small material passing the racks would probably not damage the tunnel lining to any serious extent.

   d) The tunnel outlet should be carefully observed during flood flows. Air carried into the flow by the hydraulic jump will be compressed in the downstream portion of the tunnels and may be released violently from the downstream portals. The action may be of sufficient magnitude to cause vibration and damage to the structure. If such action is observed, frequent inspections should be made to detect any structural damage.

Other observations made of the spillways, which pertain to design practice, were pointed out at the site. Among these were the following: the horizontal curves at the upper ends of the tunnels are too sharp for good flow conditions; the vertical curves at the entrances to the tunnels are also of very short radius; low pressure areas may develop on the inverts of the tunnels and cause damage to the lining; frequent inspections should be made to determine if damaged areas result from flood flows.

The irrigation outlet was inspected by members of the party. Cavitation erosion in the outlet tunnel just downstream from the control gate, which was evident in past years, was reported to have progressed considerably, notwithstanding the repairs made previously. An examination of the drawings for this structure and the reports of the damage in the tunnel indicate some changes would be helpful. It was suggested that a sudden enlargement from the 1.2-meter diameter control gate to the 1.35-meter diameter tunnel be used instead of the expander cone of reinforced gunite placed last year and subsequently seriously damaged. An air vent at least 20 centimeters in diameter should be drilled through the rock cover back of the intake tower to extend from above high water and enter the top of the discharge tunnel immediately downstream from the control gate. Air admitted in this area will be distributed around the jet from the control gate and relieve the low pressures on the boundary surfaces. The actual discharge through the outlet will be somewhat less for this arrangement because head losses at the sudden enlargement will be greater than for the expanding section. This is not considered to be a serious problem because of available head in the intake tower.

Erosion downstream from the end of the stilling basin was observed during the inspection. This has apparently been caused by releases through the irrigation outlet. Flood flows over the spillway will probably increase the amount of erosion in this area. It may be advisable to place some protective material in the riverbed downstream from the energy dissipator prior to any flood flows which might occur. In any event, the area should be carefully observed after each flood flow to determine if the erosion has progressed to a point where it might endanger the structure.

Ainono Dam

Ainono is an earth dam under construction. Approximately 70 percent of the fill had been placed in the dam at the time of the field inspection. The reservoir will provide offstream storage for irrigation and power. Because of the offstream location, large spillway capacity is not necessary. Hence, the outlet works and spillway are combined. The plans, which were well developed at the time of the inspection, include an intake tower with an uncontrolled overflow crest at the top for flood flows and a tunnel discharge carrier. No energy dissipator has been provided, because good rock exists at the outlet portal which is located at a considerable distance from the toe of the dam.

A hydraulic model of the preliminary design had been constructed and was being tested at the project office. Operation of this model was observed prior to and after the field inspection. Ample time was available to operate the model, both with the original design and with suggested changes.

Final designs for the spillway were scheduled for completion in early December 1957. Therefore, it was necessary to make decisions at the project during the visit, November 28, 29, and 30, 1957. Some drawings, revised to reflect changes decided on as a result of the discussions, were received in the central office in Tokyo prior to the expert's departure late in December. A summation of observations of the model and the discussions and conclusions are included here for record.

Review of the designs, observation of the model in operation, and study of the pressure data previously taken on the model indicated the major deficiency in design was the use of short radius bends. The two vertical curves in the 1.1-meter-diameter tunnel and the horizontal curve in the 2.0-meter-diameter tunnel connecting the intake tower and the existing 2.0-meter-diameter tunnel used for diversion of the river were too sharp. Low pressures existed at the entrance from the tower and in the bends. Extremely rough flow conditions prevailed in the large tunnel. A deflector was installed in the model in the top of the large tunnel to reduce the tendency for the flow to spiral and seal off the air supply entering from the downstream end. Although this deflector was effective for low flood flows, the tunnel sealed at high flows and reduced pressures resulted. The reduced pressures caused a siphoning action in the double vertical bend.

Time and materials were not available to reconstruct the model with the suggested changes. A discussion of all observations made on the model and in the field led to the following conclusions for changes in the design of the tunnels:

1. Lower the bottom of the intake tower and cushion pool the maximum amount permissible and still retain drainage by gravity flow. This amount would be about 0.6 meter.

2. Lower the centerline of the entrance of the outlets 2.25 meters. This change would reduce the head available for siphon action to 2 meters and permit lengthening the radius of curvature of each of the two vertical bends from 2.5 to 4.0 meters.

3. Increase the radius of curvature of the horizontal bend from 6 meters to about 18 meters. To retain an easement curve into the existing diversion tunnel, a short reach of 2.0-meter-diameter tunnel would be excavated, and the entrance to the outlet would be moved clockwise around the intake tower approximately 15 degrees.

4. A deflector would be placed in the top of the 2.0-meter tunnel in the horizontal curve to retard spiral flow at high discharges.

5. The connection between the small and large tunnels would be a sudden enlargement instead of the expanding conical section originally proposed.

6. Air vents at least 30 centimeters in diameter to enter the 1.1-meter-diameter tunnel downstream from the entrance and the 2.0-meter tunnel immediately downstream from the sudden enlargement would be provided.

The discussions also brought agreement in other modifications in design:

1. No trashrack should be installed on the spillway. A log boom would be more economical and afford safer protection.

2. The overflow crest should be extended toward the center of the tower to produce an overhang. This overhang would reduce the tendency for vibration of the overfalling nappe and prevent low discharges from flowing down the inside face of the tower and striking the openings for the irrigation inlets.

3. The piers should be extended outward from the crest. This would necessitate an overhang. Improved flow conditions on the crest would result.

Other considerations discussed were:

1. Reduction of the size of the tower and the thickness or the number of the piers on the crest might be possible but would require further study.

2. The possibility of damage to the tower caused by the jets from the irrigation outlets striking the opposite side. Since a single gate is never operated under a head greater than 3.0 meters, probably no damage will result.

3. The oil-piston-operated irrigation outlet gates should require less maintenance and provide more positive control than the chain- or cable-controlled gates used at many other installations.

Kinugawa Diversion Dam

Kinugawa Diversion Dam is in the planning and early design stages. This dam and a main canal will divert and serve water to a number of small irrigation systems now in operation, each having separate diversions from the river. Power development is included in the plan.

Examination of the overall plans indicated that the project is well laid out and is on a firm basis. The development should be of great benefit to the area.

Preliminary designs for the dam and headworks were reviewed at the proposed dam site. The site inspection and review reveal that certain modifications of plans would be beneficial:

1. Surface exposure shows good rock under the site of the headworks and sluiceway. Drill records show that this rock dips into a buried channel under the right portion of the diversion weir. This buried channel is filled with large boulders. Calculations of the seepage paths under the dam and apron has been made, using the Bligh formula. It was suggested that these calculations be repeated using the Lane formula as a check to insure a percolation path of adequate length.

2. Because of the powerplant in the canal system, it is recommended that a trashrack, which can be readily cleaned, be installed in the headworks.

3. Since designs are in the preliminary stage, it is recommended that hydraulic model studies be made to assist in completion and improvement. Studies should first be made on a sectional model of the weir and energy dissipator. These studies should include:

   a) A complete calibration of the crest. This crest, as designed, will probably be found to have a higher coefficient of discharge than that assumed in the calculations. The present crest is designed to pass 17 cubic meters per second per meter of length. Actual efficiency of the crest is necessary to determine the exact length of weir needed, the upstream heads, height of levees, etc.

   b) Determination of the adequacy of the proposed apron as an energy dissipator, with particular attention to accurately representing in the model tail water depths which will prevail at the site.

   c) Changes in the energy dissipator to develop the most economical and satisfactory design to meet specific conditions at the site.

   d) Determination of the need for dry-rock paving or other protection downstream from the energy dissipator in the right portion of the river.

   e) Other observations to develop data for the final designs.

A model should be constructed of the entire diversion weir, sluice, and headworks (exclusive of the proposed desilting device in the canal) to include an area on the right bank, a reach of the river upstream, and a short reach of river downstream (possibly to include the highway bridge if it appreciably affects the backwater). Studies on this model should include:

1. Determination of height and location of the levees on the right bank and the short levee on the left bank.

2. Determination of necessity for the two 20-meter river gates at the left end of the diversion weir. It was suggested at the site that one 20-meter gate could be deleted from the plan, the remaining 20-meter bay fitted with two 10-meter gates with a sill height the same as that for the two sluice gates.

3. Determination of the effectiveness of the two sluice gates to remove material from in front of the headworks.

4. Methods of excluding bed materials from the headworks. A skim weir, curved guide walls, serrated sills, etc. could be investigated in the model.

5. Determination of depths upstream of the dam for different discharges.

6. Other problems which arise in design.

Design of the structure for removal of the bedload from the canal should be checked with hydraulic model studies. These studies are being considered at the outdoor hydraulic laboratory and were discussed at quite some length at the time of the visit there. The sand-removal tubes will present the biggest problem. It was suggested that laboratory personnel make prototype observations on a similar sand and gravel removal structure in operation at Meiji headworks to obtain design data.

The site of the proposed settling basin in the canal above the powerplant was not visited. In connection with this structure, it was recommended:

(1) that samples of the suspended material in the river be obtained to determine size analysis and other physical properties, and

(2) that design of the settling basin be based on the fall velocity of the particles to be removed.

Additional study of the reach of canal upstream from the powerplant will be necessary:

(1) to design an overflow or other type spillway to care for the flow in case of a sudden rejection of load at the plant;

(2) adequate freeboard to handle the surge created by rejected load; and

(3) handling of trash, ice, or other debris at the entrance to the powerplant.

Yahagi Dam

Yahagi is a concrete gravity dam under construction. The reservoir will store water on a tributary to replace water diverted from the main stream at Meiji headworks. Approximately 60 percent of the concrete had been placed in the dam at the time of the inspection. The flood spillway is over the concrete gravity section and will be controlled by radial gates.

At the time of the inspection, the designs for the spillway were completed, and a considerable amount of construction was finished. Studies had been made on a hydraulic model to aid in the spillway design. In general, this design was good, and suggestions regarding some minor points were made.

It was suggested that the step in the bottom of the stilling basin may produce low pressures, and cavitation erosion could result. Since the step will be near or above water level during low flows, it can be easily inspected periodically to detect any damage which may develop. It was pointed out that pressures on the floor of the basin at this step could have been observed in the model and any indicated corrective measures incorporated in the design.

The training walls of the hydraulic jump stilling pool appears quite thick. It was pointed out that pressures could have been measured in the hydraulic model, and some saving of concrete might have been effected.

The designers were also cautioned in regard to the jump height curve with relation to the stage-discharge curve of the river for formation of a satisfactory hydraulic jump in the stilling pool.

The floating intake for the irrigation outlet appeared to work well as observed in a small model at the project office. However, the many moving parts in this device may be a source of maintenance in actual operation.

Designs for the irrigation outlet include a 1.25-meter-diameter cone dispersion valve for control. Discharge from this valve will enter a 2.5-meter-diameter discharge pipe. The downstream conduit appeared small in relation to valve size, and it was recommended that the design be checked, using information in S. Morgan Smith Company publications for this type valve and Transactions, American Society of Civil Engineers, 1953, Paper No. 2567, by Rex Elder and Gale B. Daugherty. Both references were said to be available in the Tokyo office of the Ministry of Agriculture and Forestry. It was recommended that an air vent of minimum diameter of 20 centimeters be installed immediately downstream from the control valve. This air vent will be necessary, regardless of the size of the downstream conduit used, because of the bends near the outlet end.

Meiji Headworks

Meiji headworks is a gate-controlled, concrete diversion weir, sluice, and intake. The structure had been in operation two seasons prior to the inspection. This headworks shows good workmanship and presents a good appearance.

The brief visit disclosed no apparent deficiencies in design. It was noted that observations were being made on the apron of the overflow section to check design assumptions. This type of work should be carried on more extensively.

The adequate sluice capacity, the guide walls upstream from the sluice openings, and the relative elevations of the sills of the sluice, the intake, and the crest of the dam suggest that a schedule of operation of the sluice gates could be developed to keep a high percentage of the bedload of the stream from entering the canal. It was recommended that such a schedule be developed in the prototype. Observations should be made and samples should be taken in the stream, sluice, and canal to determine the effectiveness of each schedule tried during operations.

The structure in the canal to remove bedload should be very effective and work quite well. It was reported that it had not been used, because material had not entered the canal during the two seasons of operation. When the pool above the dam becomes completely filled and stabilized, material in quantity may enter the headworks if a successful sluicing schedule cannot be developed. In such case, the desilting structure may be very necessary.

It is possible that silt removal facilities at this headworks may be overdesigned. A suggestion was made to initiate a sediment sampling program and a study of this installation to establish more facts for future design. Similar desilting structures are planned for other locations, Kinugawa headworks, for example.

The prototype testing was later discussed in some detail with the staff of the Ministry of Agriculture and Forestry Hydraulic Laboratory. A program of sampling, determination of amount of material sluiced, amount of water used for sluicing, and ratio of water diverted to water used for sluicing was suggested. Prototype testing should be a function of the Hydraulic Laboratory.

Tsuburo Dam

Tsuburo is a concrete gravity dam. Approximately 10 percent of the concrete had been placed in the structure at the time of the inspection. The spillway will be a controlled overflow section of the dam.

Preliminary designs for the spillway were first completed and hydraulic model studies then made to develop the details. This is an excellent procedure. The model studies had been completed at the time of the visit to the dam. However, final decisions had not been made on some design details. These decisions were urgently needed to avoid delays in construction. Considerable foundation difficulty had been encountered in the abutment areas of the dam and work in the stilling pool area was contemplated to adjust construction schedules.

Careful examination of the area downstream from the stilling pool was made during the visit. Final recommendations were not made at the site, pending review of the results of the model studies at the hydraulic laboratory at a later date. After all information was considered, the following conclusions were drawn:

1. The length of the stilling basin is ample. In fact, it is probably longer than necessary to contain the hydraulic jump if tail water heights are as anticipated.

2. The model studies show that the secondary weir downstream will control the tail water to the necessary depth for a hydraulic jump to form in the stilling basin.

3. Model results favour the upstream location for the secondary weir. From surface observations, there appears to be good foundation rock at either location. For best hydraulic conditions, the location favoured by the model should be used.

4. No outcrop of rock was apparent in an area on the right bank of the bend in the river immediately downstream from the stilling basin. This area extended to the left from a point in line with the projection of the right training wall. There is also some embayment in this area. Rock outcrop on the bank was noted both upstream and downstream. This indicates that the shattered rock zone under the dam and the right portion of the stilling basin may extend downstream. If such condition does exist, erosion will probably occur in this area, because it is directly in line with the discharge from the stilling basin and only a short distance away. Erosion and an increase in the size of the present embayment will probably result in a large eddy at the bend in the river and a backflow toward the left portion of the stilling pool. No corrective measures are recommended during initial construction, but the area should be kept under close observation. Removal of some rock downstream from the present embayment or protection of the bank in the embayment by riprap or a concrete wall may be necessary at a later date.

There is one alarming report in regard to the spillway. The design capacity is 265 cubic meters per second. It was reported that in September 1956 a rainfall intensity in the watershed of some 4 inches

per hour for a short period produced a flood flow at the dam site estimated to be in the order of 400 cubic meters per second. No measurements were obtained. The capacity of the diversion tunnel was greatly exceeded, the work area completely flooded, and considerable damage resulted. Reported conclusions of a conference regarding spillway capacity were that the reservoir would be low during the typhoon season, and the flood peak could be absorbed in the reservoir; hence, additional capacity for the spillway was not warranted, and construction of the smaller spillway was continued.

It is recommended that flood routing studies be made to determine the safe operating level of the reservoir for the maximum expected flood based on the recent observations and estimates. It is further recommended that the determined safe level be strictly adhered to in operating the reservoir.

It is recommended that precipitation gages be placed in the watershed, and a river gaging station be established a short distance downstream from the dam site. Data collected from these facilities will provide information to adjust and revise calculations made of flood flows and flood routings. Enlargment of the spillway or reservoir may be indicated.

Discussion of the extraordinary flood which occurred during construction of the dam offered an opportunity to emphasize the importance of establishing precipitation and gaging stations in the area early in the planning stage. This was one of those rare occasions where data of extreme importance to spillway design could have been obtained in time to be used in the final designs.

Kanayama Dam

Kanayama is an earth dam in the early construction stage. The spillway design includes a straight overflow control structure, a sharply converging reach of open channel on a relatively flat grade, a reach of open channel having a lesser convergence, a reach of open channel with parallel walls, followed by a reach having diverging walls. The last three reaches are on approximately the same slope which is rather steep. A hydraulic-jump stilling pool forms the energy dissipator. The centerline of the structure is straight from control to end of pool. A sandstone bluff extending about 20 meters above the riverbed blocks the path of the flow a short distance beyond the end of the stilling pool. Water leaving the stilling pool must turn rather sharply to the left to enter the river channel. Farm buildings and paddy fields occupy the land on top of the bluff.

Inspection of the spillway location at the site, study of the drawings, and discussions with the designers led to the following recommendations:

1. Use of an overflow crest, curved in plan, instead of the proposed straight crest. The topography lends itself better to the curved structure.

An equal length of crest can be provided with less hillside excavation. A better foundation for the structure should result. The sharply converging reach of discharge carrier at the upper end can be replaced with a reach having much less convergence. Flow entering the carrier from the curved crest will be directed toward the center, and hydraulic conditions will be generally improved.

2. Study of a ski-jump energy dissipator so located that the issuing jet will strike in the riverbed or on the left bank before it reaches the riverbed. The hydraulic-jump stilling pool is costly, and flow conditions at the exit may not be entirely satisfactory. The quality of the rock in the valley appears adequate for use of the ski jump. It is understood that strong political pressure by residents on top of the bluff has already been exerted against construction of this type of energy dissipator. However, the ski-jump solution may offer as good or better insurance to their safety than the stilling pool.

3. Make hydraulic model studies of the altered design for development of the most economic and satisfactory structure. Full use of the model should be made to develop an efficient crest shape, good crest and channel alignment, and the best shape for the ski-jump to avoid damage to the sandstone bluff or the improvements on top. Pressure should be measured at critical places in the model to develop design data. A very good use of the model and one which might well repay the entire cost of all the studies is assistance in the solution of the political question. The land owner on top of the bluff should be convinced, after viewing the model and demonstrations of the flow conditions, which of the two energy dissipators would afford him the most protection. This would probably necessitate construction in the model of both types of energy dissipators.

4. If the political question is not resolved and it is necessary to retain the hydraulic-jump stilling pool, a hydraulic model study is strongly recommended because of the proximity of the pool to the bluff. Because of the adverse angle through which the flow must turn, severe eddies may form in the river, one flowing toward the toe of the dam and others flowing both clockwise and counterclockwise downriver from the outlet of the pool. Wave reflection from the bluff might adversely affect the action of the stilling pool.

Maruyama Dam

Maruyama is an earth dam in the planning stage. Exploratory work is being done at the site, and preliminary designs have been made. A side-channel spillway with a tunnel discharge carrier traversing a bend in the river is proposed. Because of developed areas in the valley near the tunnel exit, a hydraulic-jump stilling pool is included. An outlet channel will carry the water from the stilling pool to the river.

The following suggestions are made regarding the plans for the spillway:

1. Make an early study of the overflow crest shape and side channel with the object of shortening the structure. Because of the steep hillside and nature of the topography, any shortening will appreciably reduce costs.

2. Make studies of the effect of moving the spillway location upstream, using the crest length developed from 1, above. It appears that the side channel could be better adapted to this upstream location.

3. Retain the hydraulic-jump stilling pool for the energy dissipator. The topography, geology and improved areas at the site all indicate this to be the best solution.

4. Study tail-water conditions in the river as related to the depth necessary to form the hydraulic jump. The proposed outlet channel will serve as a control, and the backwater curve at the end of the stilling pool can be calculated with reasonable accuracy.

5. Make hydraulic model studies of the complete spillway to further develop the design. These studies should include:

   a) A calibration of the overflow crest and channel to determine exact length needed.

   b) Use of a longer radius connecting curve between the side channel and tunnel. A slight curve should be permissible, but the preliminary layout of the curve is too sharp.

   c) With a curve of longer radius, study elimination of the drop in the bottom of the side channel at the beginning of the transition to the tunnel. Eliminate this drop if possible. If some change in grade is necessary, make a smooth transition.

   d) Use a curved backwall at the upper end of the side channel to improve efficiency of the upstream end of the crest.

   e) Make observations of flow conditions and pressures in the tunnel. The entrance curve may induce spiral flow.

   f) Make studies of movement of the exit of the tunnel to the right a slight distance. This would give a new alinement to the tunnel and improve the entrance curve.

   g) Other studies which will provide additional data for design.

The preliminary designs include an inclined intake structure for irrigation releases. Gates are provided at 4-meter vertical increments.

In connection with this design, it was suggested:

(1) that an air vent of minimum diameter of 15 centimeters be placed at the top of the inclined conduit; and

(2) that the intersection of the inclined conduit and the diversion tunnel be rounded to avoid sharp corners at this junction.

Other Structures

From time to time during the field trips, designs of structures other than those visited were presented for opinions and suggestions. These discussions were conducted on an instructional basis. Conclusions for two of the more important discussions are included in this report.

Plans for the Totsu and Kino River Project include a dam at the Osako site. Originally, a concrete gravity dam was proposed. Preliminary work was being done in the project office at Gyodo on designs for an arch dam. The plans proposed a spillway over the top of the 71-meter-high arch dam. Logs of drill holes showed shales interspersed with hard sandstones in the area where the falling water would strike. This geologic structure would probably need considerable protection to prevent scour. Solutions suggested were:

1. Provide a deep cushion pool by construction of a secondary dam. A model study should be made to develop the best pool. The designs should be complete before issue of specifications because of the possibility that the secondary dam forming the cushion pool could be used for a downstream cofferdam for construction of the main dam.

2. Orifices through the arch might be used. A similar solution was used by Kansai Electric Power Company of Osaka at Tonoyama Dam. This design was developed by an American consultant and should be available for study.

3. Two chute spillways on the abutments of the dam, with ski-jump energy dissipators. Topographic sheets showed this might be a possible solution.

4. An auxiliary spillway separate from the dam for extraordinary floods. Time did not permit sufficient study of the topographic sheets to determine if this solution was feasible.

5. Two gloryhole or side-channel spillways, using diversion tunnels for discharge carriers. Studies for this solution should be made early to permit maximum use of the facilities provided for care of the river during construction.

6. Economic studies should be made to evaluate the cost of raising the dam to create a flood pool, thus reducing the size and cost of the spillway.

Because of the limited time available for inspection of spillways in the Kyoto area, a discussion period was arranged at the Kyoto Regional Office. Recent failures of the two earth dams in the Prefecture had prompted a program of study and actual enlarging and rehabilitating existing spillways. During the discussion period, the program was outlined, the damages caused by one of the failures were reviewed, and preventive measures to be undertaken were studied and proposed.

The most important portion of the discussion centered around the enlargment of the spillway for Mawari Dam from 25 cubic meters per second to 127 cubic meters per second, to provide additional security for this 32-meter-high earth structure. A tee-shaped structure which fitted the topography and made maximum use of construction works in the old spillway had been sketched. Two side-channel spillways formed the cross of the tee and an open-channel discharge carrier extending to portions of the old structure to be used as cushion pools for the energy dissipator formed the leg of the tee. Discussion of this plan led to a number of suggestions. Important among these were:

1. Hydraulic model studies should be made to establish the length of the overflow crests and side channels. The preliminary plan for 50 meters of crest length appeared more than necessary if an efficient crest shape were used.

2. The entrance curves to the discharge carrier were probably too short in radius for good hydraulic conditions. The best curve could be developed on the hydraulic model.

3. Based on descriptions of the quality of the rock and condition of portions of the old structure proposed for use, the plan for cushion pools as an energy dissipator should be satisfactory.

4. Careful attention should be given to the end of the side channel adjacent to the dam. If the crest length can be shortened the problems will be reduced. Proposed plans place the extreme end of the right side channel on the end of the earth dam. Foundation might be a problem. With this location, possible damage to the upstream protection of the dam could result during high flows.

The tee-shaped spillway would probably be rather expensive, although cost figures were not available. It was suggested:

1. That economic studies be made of the cost of raising the dam to store a portion of the flood and construction of a spillway of lesser capacity. The calculated flood hydrograph showed that the high discharges continued for only a very short period of time, some 4 hours. The present dam, with a height of 32 meters and a length of only 50 meters, forms a reservoir of 850,000 cubic meters in capacity. Since the dam is short, the cost of raising should not be excessive.

2. That a plan including a large capacity emergency spillway, and rehabilitation of the present spillway to safely carry 25 cubic meters per second be considered. An existing road will be a factor in this consideration, but total cost may be decreased.

At the close of the conference, carrying capacity of tunnels was discussed. Because of the uncertainty of the exact value of the friction factor which will be attained in construction of a lining, the fact that there are a number of formulas for calculating capacity of conduits and all do not give identical results, the type of entrance and exit and many other considerations involved, the best policy is to design for ample capacity. This will necessitate a slightly larger conduit than might be necessary if all factors are as good or better than assumed, but added security will be attained.

Hydraulic Model Studies of Spillway, Koromogawa No. 1 Dam

Hydraulic model studies for design of the spillway of Koromogawa No. 1 Dam being conducted by the Civil Engineering Department of Tohoku University at Sendai were reviewed on 21 November 1957. Initially, Dr. Toshio Iwasaki and Dr. F. Kawakami of the University staff reviewed the designs for the spillway, described the test facilities, scale ratio of the model, and the problems involved. The model was then viewed in operation at a number of discharges. A closing conference was held to discuss the observations and future test program. These discussions are summarized as follows:

The model, built on a scale ratio of 1:40 Froude relationship, was adequate for the studies contemplated. Laboratory procedures being followed conformed to standards of good practice.

Entrance flow conditions on the right side of the gated control structure were unsatisfactory. The extreme right gate did not carry full capacity except at very low flows. It was recommended that the long straight guide wall on the right side of the entrance channel be shortened and the upstream end curved outward. It was suggested that Portuguese practice of providing windows in guide walls be tried in the model.

The convergence of the channel below the gate structure was too abrupt. Diagonal standing waves developed in the flow in the chute and the training walls were overtopped at higher discharges. A converging section with curved walls was suggested. Suggestions were made for a procedure to be followed to effect rapid changes in the model for development of converging and diverging reaches of the discharge carrier.

The rough flow conditions in the chute caused an uneven velocity distribution across the entrance of the energy dissipator. Because of this condition, the energy dissipator did not operate at maximum efficiency and at high flows an irregular jet was formed. Improvement of flow conditions in the entrance and discharge carrier should reduce this problem.

The action in the pool for flows below sweepout discharge, 187 cubic meters per second, was generally satisfactory except for the conditions noted above. With these flow conditions, the discharge passing across the excavated area between the end of the pool structure and the river channel may cause erosion. During the transition of flow from pool action to flip bucket action there will be considerable turbulence and possible erosion beyond the end of the pool. Examination of the excavated area may be necessary to determine the extent of protection needed. However, much information can be obtained from the model.

For flows exceeding 187 cubic meters per second, the energy dissipator acts as a flip bucket. Some of the water strikes the left side of the excavation downstream from the structure. It could not immediately be determined whether the unequal distribution of entering velocity or the shape of the downstream end of the structure was the cause. For this flow condition, a large eddy sweeping upstream and across the toe of the dam is formed in the river channel.

It is recommended that the future test program includes the following in the order given:

1. Studies to improve flow conditions in the entrance channel.

2. Studies of the discharge carrier to develop a design with curved training walls and a lesser angle of convergence.

3. Studies of the lip at the downstream end of the energy dissipator to shape the jet so that (a) it will strike in the most desirable location in the river; (b) it will avoid the left bank of the excavation; and (c) eliminate the large eddy flowing upstream and across the downstream toe of the dam.

4. Studies of the excavated area downstream from the energy dissipator to assist in determining the protective measures necessary.

The visit to the university was made prior to inspection of the dam site. Resultsoof this inspection and the discussions which followed resulted in recommendations for certain changes in design. It was understood that these changes would be incorporated in the model before an extensive test program was started. The design changes should relieve a number of problems apparent in the original model and the test program would thus be shortened.

VI. RECOMMENDATIONS FOR HYDRAULIC LABORATORIES OF THE MINISTRY OF AGRICULTURE AND FORESTRY

The Laboratories

The facilities which have been provided at the two hydraulic laboratories of the Ministry of Agriculture and Forestry are adequate to perform many studies to aid in design. The equipment is very good. The staff should be ample until the number of studies are increased, but a training program should be carried on for replacement personnel and additions to the staff.

Suggestions relating to each of the studies being made in the laboratories were made during the visit and need not be repeated here. A number of proposed studies were similarly discussed. Such subjects as: construction of the models, materials to be used for construction, scale ratios, movable bed materials, conduct of the tests, analysis of results and reports, were discussed.

Suggestions for Improvement

The laboratories are included in the design section. Therefore, the remarks regarding possible means of improvement are directed toward the ultimate goal of obtaining better design of hydraulic works. As previously stated, improved hydraulics usually result from experiment. Comments in regard to model studies have been made in a previous section "Problems in Hydraulic Model Studies" and some suggestions have been made.

In summary, the suggestions for improvement may be briefly stated as follows:

1. Designers should make maximum use of the laboratories. Work done in the laboratories should be considered an integral cost of the design. Therefore, adequate financial support should be available. Experience will show that expenditures in the laboratory will be returned, sometimes many times over, in savings in construction and in added safety.

2. Designers and laboratory staff should work together in close cooperation and make maximum use of models to confirm calculations, obtain data which are not easily calculated (for example, pressures on overfall crests, in energy dissipators, etc.) and extend the general knowledge of hydraulics. The result will be the most economical structure to meet conditions existing at the site and one which will operate satisfactorily and with safety.

3. Models should be employed to make applied studies and such basic studies as are immediately necessary to solve design problems. Such a course is now being followed at the laboratories but could be expanded.

4. The results of a number of applied studies should be generalized when possible to provide data which can be used in design of similar structures. For example, the extensive use of side-channel spillways in Japan should warrant a number of studies of particular structures. The results from these, combined with a limited amount of additional research, should yield valuable information for improvement of design procedures.

5. Testing and observation of completed structures in the field should be a function of the hydraulic laboratory. There are limitations in what can be done with models. Prototype observations will greatly increase the value of model work.

6. Improved techniques can be obtained by continually training personnel. Visits to laboratories in other countries by members of the staff will prove very helpful in this training.

7. Periodic reviews of techniques and consultations by competent experts will permit more rapid and sound development of the laboratory facilities.

VII. GENERAL RECOMMENDATIONS FOR IMPROVEMENT OF DESIGN

In past years, flood spillways have been designed for many relatively low earth dams in Japan. The transition to higher structures and use of other construction materials requires changes and improvements in design procedures to obtain safe and economical spillways. In this transition period, many problems are encountered by the Japanese engineers. Many of these problems have been satisfactorily solved by engineers of other countries. Exact solutions for some are still being sought.

Japan will not experience the difficulties in improving her design practices that other countries have in the past because of the vast store of knowledge, gained primarily by experiment, now available in other parts of the world.

Careful evaluation of all observations made of present spillway design practice leads to the following recommendations for improvement.

General

1. Greater consideration be given to construction of multi-purpose projects. It has been found, broadly speaking, that cost-benefit ratios for the planned purposes may be improved by multi-purpose construction over those for single-purpose construction. Inclusion of a flood control function in irrigation reservoirs should be of great economic benefit in Japan because of high intensity rainfall and short duration runoff.

2. Economic studies be made of flood handling facilities at each dam to determine relative costs of providing: (a) a primary spillway of large capacity; (b) a higher dam with some flood storage capacity in the reservoir and a primary spillway having a smaller capacity than in (a); (c) a primary spillway to accommodate usual floods and an auxiliary spillway for unusual floods; and (d) possible combinations of the above. Large capacity spillways are required to handle high peak runoff's if no other facility is provided. Such construction is very expensive. When site conditions are favourable, considerable savings should result from use of a solution other than (a), which is now used almost exclusively.

3. The costs of various operations and materials which go into construction of spillways should be studied, using the economic base prevailing in the area of construction. These studies, based on prior records of construction, should indicate proportionate cost and specific item costs. For instance, in Japan, it appears that rock excavation has a high relative cost and may be one reason for high overall spillway costs. If cost studies show this to be true, then designs which involve the least rock excavation may result in lower total cost. Changes in type of spillway originally proposed may be necessary to avoid high cost items.

4. Include a sediment program in the investigations of storage projects. There is much evidence of erosion in the watersheds and sediment transport in the streams. Sediment is acknowledged as a problem at diversion dams and handling facilities are provided as needed. Loss of valuable irrigation storage may result from deposits of material in the reservoirs. The possibility of storage loss and the economic effect on the project should be studied as part of the investigation. Corrective measures and a program of observations should be developed as needed to protect the investment. Large changes in reservoir capacity can affect spillway capacities.

5. Give more consideration to use of gated control sections for the spillways. An uncontrolled structure requires a higher dam and a longer overflow crest. Both items involve increased cost. Economic studies will show which solution, controlled or uncontrolled crest, involves the least cost. It is admitted that lack of properly trained and dependable operators has caused adoption of the present policy of using uncontrolled crests. Steps should be taken to correct this deficiency so that decisions can be made on economic and technical considerations.

6. Utilize the vast store of knowledge on spillway design available in the world by seeking the advice and counsel of prominent hydraulic engineers who are working in those countries which have gained the experience. This is the best method by which to profit from the experience of others. Periodic reviews of Japanese design practice by such experts would accomplish a great deal. The reviews should include the methods and procedures employed in the hydraulic laboratories since much of the design work can be accomplished there. Review of world literature and affiliation with international technical societies will also be helpful.

7. Selecting and training suitable personnel in other countries. Although consultants can accomplish a great deal toward training local personnel, normally the time is limited and details cannot be covered. Until such time as the transition period has passed, the facilities and knowledge of other countries should be fully utilized to acquire details and stimulation of thought. Fellowships, scholarships and similar programs should be utilized to provide this training for hydrologists, designers and hydraulic laboratory personnel abroad and in Japanese universities and colleges. This will hasten the day when well qualified hydraulic engineers for spillway design can be supplied locally.

Projects in the Planning Stage

1. Make maximum use of all existing data needed for design.

   a) Establish the best possible relationships between rainfall and runoff by intensive study of all existing data obtained in the area or in areas similar to those being considered. Initially, these relationships may not be well defined, but will nevertheless be of great assistance.

b) Study all available rainfall records to provide information on probable maximums in different areas of Japan. Subdivide these areas as additional information becomes available. Where runoff data are available, correlate for maximum expected.

c) Give the designer the best information possible as a result of the above studies in regard to expected flows, infiltration rates, concentration time, etc.

2. Obtain additional hydrologic data.

a) Establish precipitation gages in the watershed area very early in the investigation stage.

b) Establish stream gaging stations early in the investigation stage at the dam site and on the tributaries in the watershed if necessary to develop adequate data. The important station is one far enough below the dam site so it will not be affected by changes during construction, by rough water from the spillway or other works after construction, or diversion flows during construction and yet close enough to the dam site to establish a tail-water rating curve for spillway and outlet works design.

3. Constantly adjust and improve the basic hydrologic data and methods of analysis by using the accumulated records and results of studies. This should apply to each project and to general design procedures.

Design Criteria

In view of the very limited data available on rainfall and runoff and the relationship between the two for areas in which much of the development is being done:

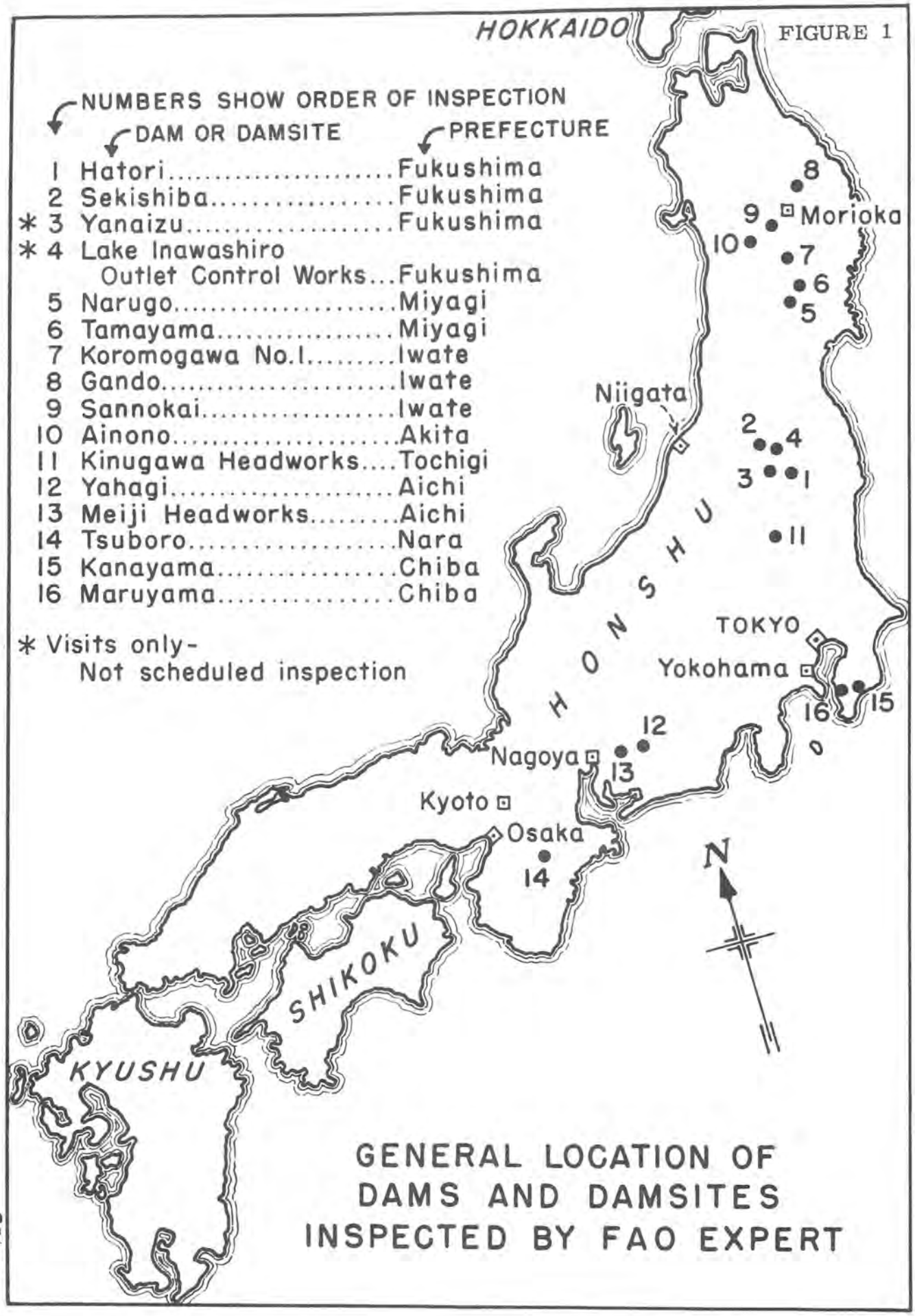
1. The maximum probable flood should be developed by a rational analysis. Maximum probable floods calculated from meager data and based on a 200-year probability can easily be exceeded with devastating results.

2. Each element of the spillway should be designed for the maximum flow that it will be expected to carry. Because of the uncertainties in the hydraulic calculations, it is not good practice to design for a lesser amount and extrapolate the results to greater flows.

3. Use general hydraulic formulas with caution.

a) These formulas very probably have been developed from experiment and are valid only for the range of conditions for which they were developed.

b) Examine the conditions under which each was developed and do not exceed those limits unless facts indicate this is permissible. An example is the use of the Hinds formula for the design of side-channel spillways. This formula was developed for straight channels.


HOKKAIDO
FIGURE 1
NUMBERS SHOW ORDER OF INSPECTION
DAM OR DAMSITE
PREFECTURE
1 Hatori.....Fukushima
2 Sekishiba.....Fukushima
* 3 Yanaizu.....Fukushima
* 4 Lake Inawashiro
Outlet Control Works...Fukushima
5 Narugo.....Miyagi
6 Tamayama.....Miyagi
7 Koromogawa No.I.....Iwate
8 Gando.....Iwate
9 Sannokai.....Iwate
10 Ainono.....Akita
11 Kinugawa Headworks....Tochigi
12 Yahagi.....Aichi
13 Meiji Headworks.....Aichi
14 Tsuboro.....Nara
15 Kanayama.....Chiba
16 Maruyama.....Chiba
* Visits only-
Not scheduled inspection
Morioka
Niigata
TOKYO
Yokohama
Nagoya
Kyoto
Osaka
HONSHU
SHIKOKU
KYUSHU
N
GENERAL LOCATION OF
DAMS AND DAMSITES
INSPECTED BY FAO EXPERT

8F/1381

When curved, tee-shaped, ell-shaped, or other irregular channels are considered, the formula may not provide a satisfactory solution. Use of the formula in making preliminary layouts may be justified but final designs should be based on additional studies, preferably by hydraulic models.

Design Stage

As aids in conducting the design work and improving completed designs:

1. Make extensive use of hydraulic models. Many hydraulic problems cannot be completely solved by rational analysis. Many solutions can be obtained more quickly and more economically by the use of models than by lengthy calculations. The hydraulic models should be utilized to the maximum to provide information on pressures, calibrations, and data on other physical dimensions necessary to the designer. Close cooperation and liaison should be maintained at all times between the design and laboratory staffs.

2. Make studies of overflow control sections to select or develop shapes which have high discharge coefficients and be consistent with structural design. Appreciable shortening of the crest length may be possible. Length is an important cost item on rock hillsides. Hydraulic model studies provide a dependable means for calibrating the crests and insuring that maximum design discharge can be safely passed.

3. Use bends of a longer radius of curvature in both open channels and tunnels designed to flow partly full. As observed both on plans and on completed structures, there is a general tendency to use short radius bends. Such practice may result in very undesirable hydraulic conditions under certain circumstances. Considerable reduction in safe discharge capacity can easily result.

4. Make more comparative cost studies of types of spillways other than side channels. The side channel has been used extensively and no doubt is well fitted to many locations. A certain confidence has also been built up in this type of design; however, some sites may be developed more economically with other types. More extensive use made of diversion tunnels may be possible with other types.

5. Air vents to tunnels and outlet conduits should be used more extensively. Cavitation erosion has occurred at some installations and more may be experienced. Admission of air to areas of low pressure will relieve these conditions, reduce maintenance costs, and insure greater safety.