

Public Works Research Institute
Technical Memorandum No. 2115

PUBLIC WORKS RESEARCH INSTITUTE TECHNICAL MEMORANDUM
SAFETY CONTROL FOR DAMS

March 1984

Dam Department
Public Works Research Institute
Ministry of Construction
Government of Japan

Copyright © 1982 by P.W.R.I.

All rights reserved. No part of this book may be reproduced by any means, nor transmitted, nor translated into a machine language without the written permission of the Director of P.W.R.I.

Preface

The safety of dams is required by society, and therefore dams are designed and constructed carefully with the best technology. After the construction, they should be monitored carefully and their safety should be controlled with special attention given to prevention of collapse. While no dam has failed in Japan, most reports on dam collapses abroad indicate that abrupt change of leakage or deformation etc. occur before collapse. This means that suitable monitoring of dam behavior and quick deployment of prevention measures in time of emergency can prevent the disasters caused by dam collapses. Importance of everyday's safety control should be therefore emphasized.

Dams managed by the Ministry of Construction and related offices are as many as 221 (in 1981), and today's trend of labor saving requires the effective management of dams with a fewer people. Under these circumstances, the effective safety control of dams is also required. From the view point of the effectiveness, the following problems can be pointed out in consultations about measurements with dam control offices.

- 1) Unnecessary measurements hinder effective dam control.
- 2) Inadequate data analysis confuses the judgement of conditions of dams.

This booklet is prepared to show more adequate and more effective ways of safety control for dams. We hope this booklet will be of help for the safety control for dams.

March 1984

Dam Department, Public Works Research
Institute, Ministry of Construction

CONTENTS

	Page
1. OUTLINE	1
2. MEASUREMENT ITEMS	2
3. FREQUENCY OF MEASUREMENT	4
4. SOME REMARKS ON MEASUREMENTS	9
4.1 Leakage of Water	9
4.2 Deformation	10
4.3 Uplift or Pore Pressure	10
5. DATA PROCESSING	11
5.1 Leakage of Water	11
5.2 Deformation	14
5.3 Uplift or Pore Pressure	20
5.4 Other Measurements	21
6. DATA ANALYSIS TO EVALUATE SAFETY OF DAM	22
6.1 Leakage of Water	22
6.2 Deformation	25
6.3 Uplift or Pore Pressure	26

1. OUTLINE

This booklet is mainly concerned with general measurement items and the data processing necessary for checking the safety of the dam body and its foundation rock after filling water, and the way to judge the safety of the dam body and its foundation rock from the obtained data. The methods described in this booklet are considered to be also effective for a dam during the test filling of water, but the data should be examined with larger and more detailed figures than in the case mentioned in this booklet.

This booklet shows the general methods of measurement for safety control, but other methods of measurement and data processing can be also utilized when it is necessary. However, application of different methods to different dams is irrational from the viewpoint of safety control, and it is also undesirable for the establishment of safety control standards. Safety control of the dam is therefore expected to be performed in reference to the measurement plans, measurement methods and data processing described in this booklet.

2. MEASUREMENT ITEMS

For the safety control of dams, many items such as leakage of water, deformation, uplift (pore pressure), stress, strain and temperature are measured, and dam bodies are also inspected. However, these items do not have the same importance, and all the items are not necessary for every dam. Table 1 shows the list of required measurement items for four types of dams.

Table 1 Measurement Items for Safety Control

Item Type of dam	Leakage of water	Deformation	Uplift or pore pressure	Surface line of seepage	Temperature	Stress or earth pressure	Strain or shear deformation	Inspection of dam body and other facilities	Earth- quake
Concrete gravity dam	⊙	⊙	⊙	—	△	△	△	⊙	○
Concrete arch dam	⊙	⊙	⊙	—	⊙	○	△	⊙	○
Rock fill dam	⊙	⊙	⊙	—	—	△	△	⊙	○
Earth dam	⊙	⊙	⊙	⊙	—	△	△	⊙	○

Note: ⊙ indicates indispensable measurement items.

○ indicates relatively important measurement items.

△ indicates desirable measurement items for large scale dams.

Measurement of leakage of water, deformation, uplift (pore pressure) and surface lines of seepage, and the inspection of dam bodies and other facilities are the most important and reliable to judge the safety of the dam body and its foundation rock. These items should be measured or performed at all dams. In the case of arch dams, temperature should also be measured beside these items, because large deflection or strain occurs with temperature changes.

The measurement of stress and strain is unnecessary except for large or important dams, because accurate measurements are not always expected for these items and the unusual measured values of these items do not necessarily have effects on the safety of the dam. In the case that such measured values have effects in the safety of the dam body and its foundation rock, it will appear in the measurements of the indispensable measurement items. Omission of the measurement of stress and strain does not

influence safety control.

The inspection of the dam body is not a kind of measurement, but it is important to judge the safety of the dam body and its foundation rock.

The seismograph is utilized to judge the necessity of measurement or inspection after the earthquake. The seismograph should be chosen carefully, because its data are utilized not only for the safety control but also for the structure analysis and for future dam design.

3. FREQUENCY OF MEASUREMENT

Measurements for the safety control should be performed frequently enough in order to check the unusual condition of the dam body and its foundation rock as soon as possible. However, too frequent measurements are unnecessary. As the stability of the dam body and its foundation rock depends on the type and the scale of the dam, the age after filling water and other factors, the frequency of measurement should be determined according to these factors.

The frequency of measurement should be determined for each measurement item, because how to judge the safety of the dam body and its foundation rock is different for each measurement item.

In order to judge the safety of the dam body and its foundation rock, the period of measurement can be divided into the following three terms.

- 1) From the beginning to the end of the first filling of water, and a certain period thereafter (first term).
- 2) After the first term and until the behavior of a dam and its foundation rock reaches a steady state (second term).
- 3) After the behavior of a dam reaches a steady state (third term).

Here, the steady state is the state when measured values become constant if external factors such as water level and temperature in a dam are constant.

Table 2 shows the desirable frequency of measurement for each term.

Table 2 Frequency of Measurement for Safety Control

- (1) After the completion of dam construction and until the dam starts its function through the first filling of water (during the test filling)

..... First term

Item Type of dam	Leakage of water	Deformation	Uplift or pore pressure	Surface line of seepage	Temperature	Stress or earth pressure	Strain or shear deformation	Inspection of dam body and other facilities
Concrete gravity dam	Once/ 1 day	Once/ 1 day	Once/ 1 day	-	Once/ 7 days	Once/ 7 days	Once/ 7 days	Once/ 1 day
Concrete arch dam	Once/ 1 day	Once/ 1 day	Once/ 1 day	-	Once/ 3.5 days	Once/ 7 days	Once/ 7 days	Once/ 1 day
Rock fill dam	Once/ 1 day	Once/ 7 days	Once/ 1 day	-	-	Once/ 7 days	Once/ 7 days	Once/ 1 day
Earth dam	Once/ 1 day	Once/ 7 days	Once/ 1 day	Once/ 1 day	-	Once/ 7 days	Once/ 7 days	Once/ 1 day

Note: Once/3.5 days means twice a week.

- (2) Five years after filling water Second term

Item Type of dam	Leakage of water	Deformation	Uplift or pore pressure	Surface line of seepage	Temperature	Stress or earth pressure	Strain or shear deformation	Inspection of dam body and other facilities
Concrete gravity dam	Once/ 7 days	Once/ 7 days	Once/ 7 days	-	Once/ 1 month	Once/ 1 month	Once/ 1 month	Once/ 1 month
Concrete arch dam	Once/ 7 days	Once/ 7 days	Once/ 7 days	-	Once/ 0.5 month	Once/ 1 month	Once/ 1 month	Once/ 1 month
Rock fill dam	Once/ 7 days	Once/ 1 month	Once/ 7 days	-	-	Once/ 1 month	Once/ 1 month	Once/ 1 month
Earth dam	Once/ 7 days	Once/ 1 month	Once/ 7 days	Once/ 7 days	-	Once/ 1 month	Once/ 1 month	Once/ 1 month

(3) After five years Third term

Item Type of dam	Leakage of water	Deformation	Uplift or pore pressure	Surface line of seepage	Temperature	Stress or earth pressure	Strain or shear deformation	Inspection of dam body and other facilities
Concrete gravity dam	Once/ 1 month	Once/ 1 month	Once/ 1 month	-	-	-	-	Once/ 1 month
Concrete arch dam	Once/ 1 month	Once/ 1 month	Once/ 1 month	-	Once/ 1 month	-	-	Once/ 1 month
Rock fill dam	Once/ 1 month	(Once/ 3 months)	Once/ 1 month	-	-	-	-	Once/ 1 month
Earth dam	Once/ 1 month	(Once/ 3 months)	Once/ 1 month	Once/ 1 month	-	-	-	Once/ 1 month

Note: () indicates that the interval of the measurement can be elongated according to conditions.

(4) When the unusual condition is detected from the measurement (the period until the safety is confirmed or recovered by some measures).

Item Type of dam	Leakage of water	Deformation	Uplift or pore pressure	Surface line of seepage	Temperature	Stress or earth pressure	Strain or shear deformation	Inspection of dam body and other facilities
Concrete gravity dam	Once/ 1 day	Once/ 1 day	Once/ 1 day	-	Once/ 7 days	Once/ 1 day	Once/ 1 day	Once/ 1 day
Concrete arch dam	Once/ 1 day	Once/ 1 day	Once/ 1 day	-	Once/ 3.5 days	Once/ 1 day	Once/ 1 day	Once/ 1 day
Rock fill dam	Once/ 1 day	Once/ 7 days	Once/ 1 day	-	-	Once/ 1 day	Once/ 1 day	Once/ 1 day
Earth dam	Once/ 1 day	Once/ 7 days	Once/ 1 day	Once/ 1 day	-	Once/ 1 day	Once/ 1 day	Once/ 1 day

Note: Refer to chapter 4 for the definition of the unusual condition.

(5) One week after the flood control

Item Type of dam	Leakage of water	Deformation	Uplift or pore pressure	Surface line of seepage	Temperature	Stress or earth pressure	Strain or shear deformation	Inspection of dam body and other facilities
Concrete gravity dam	Once/ 1 day	Once/ 1 day	Once/ 1 day	-	Once/ 7 days	*	*	Once/ 1 day
Concrete arch dam	Once/ 1 day	Once/ 1 day	Once/ 1 day	-	Once/ 7 days	(Once/ 7 days)	(Once/ 7 days)	Once/ 1 day
Rock fill dam	Once/ 1 day	*	Once/ 1 day	-	-	*	*	Once/ 1 day
Earth dam	Once/ 1 day	*	Once/ 1 day	Once/ 1 day	-	*	*	Once/ 1 day

Notes: 1) For dams with no automatic measurement system, the term of the completion of flood control can be regarded as the time when the measurement becomes possible after flood control.

2) () indicates desirable measurement items.

3) The same frequency of measurement as in (1) ~ (3) can be applied for *.

(6) One week after an earthquake.

Item Type of dam	Leakage of water	Deformation	Uplift or pore pressure	Surface line of seepage	Temperature	Stress or earth pressure	Strain or shear deformation	Inspection of dam body and other facilities
Concrete gravity dam	Once/ 1 day	Once/ 1 day	Once/ 1 day	-	Once/ 7 days	*	*	Once/ 1 day
Concrete arch dam	Once/ 1 day	Once/ 1 day	Once/ 1 day	-	Once/ 7 days	(Once/ 7 days)	(Once/ 7 days)	Once/ 1 day
Rock fill dam	Once/ 1 day	*	Once/ 1 day	-	-	*	*	Once/ 1 day
Earth dam	Once/ 1 day	*	Once/ 1 day	Once/ 1 day	-	*	*	Once/ 1 day

Notes: 1) The earthquake mentioned here is one whose seismic intensity is more than 4 in the Japan Meteorological Agency's scale or more than 1/3 of design seismic intensity.

2) () indicates desirable measurement items.

3) The same frequency of measurement as in (1) ~ (3) can be applied for *.

Five years after filling water are considered as a tentative period when a dam body and its foundation rock reaches a steady state. If the steady state is not reached within five years, the same frequency of measurement should be kept thereafter. On the other hand, if the steady state is reached within five years, the frequency of measurement can be reduced to the level of the third term.

The measurement after the flood control is listed in the table to confirm the safety, because the dam body and its foundation rock rarely experience such load condition. The measurement in this period should be performed according to that of the case of test filling.

Measurements of each item are not necessarily performed at all measuring points. Especially during the latter half of the second term and during the third term, the number of measuring points can be reduced, and it is desirable to avoid unnecessary measurements. The measurement items which can be omitted are as follows.

- (1) A part or all of the measurements of stress or earth pressure, strain or shear deformation and temperature, which have already reached a steady state, or when the accuracy of measurement is unreliable.
- (2) Thermometer for construction use, or thermometer at point where the measurements of deformation and stress are not influenced by temperature or where the measurements can be substituted by measurements at other points.
- (3) A part of the measurements of leakage of water and uplift (pore pressure) which have already reached a steady state, when the water leakage is small.
- (4) A part of the deformation measurements of a fill dam which has reached a steady state.

Table 2 shows the measurements for safety control, and therefore the frequency of measurement for other purposes such as structure analysis differs from the table.

4. SOME REMARKS ON MEASUREMENTS

Leakage of water and deformation, and uplift (pore pressure) are measured for safety control of dams, but the safety of a dam cannot be judged accurately without proper measurements of these items.

Attention should be paid to the following points for accurate measurements.

- (1) Proper maintenance is necessary to keep measuring devices in a good condition. Especially when leakage of water and deformation, and uplift (pore pressure) are measured by remote control devices, the electric circuits and calibration should be checked periodically.
- (2) Measuring methods should be selected to reduce measurement errors as much as possible.
- (3) Reading should be recorded after the measured value becomes stable.

Some remarks on the primary measurement items are as follows.

4.1 Leakage of Water

Triangular weirs are usually used to measure the amount of water leakage. Special attention should be paid on the accretion of lime or the damage to a knife edge, especially when remote control devices are used. They disturb measurements. The accretion of lime in a drain hole sometimes reduces the measured value.

The amount of water leakage from each drain hole is usually measured by a graduated cylinder. When the amount of water leakage is so large that the graduated cylinder cannot be utilized, a large container should be used to avoid large measurement errors.

At the measuring holes of seepage flow for fill dams or at the drain holes for concrete dam which are also utilized for the measurement of uplift (pore pressure), large discharge may occur temporarily just after the valve is opened. Reading should be made after the discharge becomes stable. In the places where piping may occur, the repetition of opening and closing of the valve may induce piping. In this case, the frequency of measurement should be reduced, or only uplift (pore pressure) should be measured.

4.2 Deformation

The measurement of deformation is very delicate, and it requires special care. Especially when a plumb line is used, special attention should be paid to door opening and shutting, because only slight breeze can swing a pendulum. In the case that remote control devices are used, the dispersion of data should be checked.

4.3 Uplift or Pore Pressure

Bourdon-type pressure gauges or pore pressure meters are used for the measurement of uplift (pore pressure). In the case of Bourdon-type pressure gauges, the amount of leakage of water is also measured simultaneously. Uplift (pore pressure) is not stable directly after closing the valve after the measurement of leakage of water, and in extreme cases it will take more than a day until pore pressure becomes stable. Therefore, the time to reach a steady state should be examined beforehand. However, the steady state is not necessarily required and setting regular time span before measurement is enough for safety control. The condition of valves in adjacent measurement holes should be kept constant at the time of measurement, because it has some effect on the measurement.

In the case that uplift (pore pressure) is measured by a pore pressure meter, it should be noted that filter clogging sometimes reduces pore pressure.

5. DATA PROCESSING

In order to utilize the measurement data effectively for safety control, the data should be processed properly. Although the arrangement of data in the form of the table is indispensable to reuse the data, it is not enough for safety control of a dam body and its foundation rock. Data should be expressed in the form of the graph.

There are two ways of expressions in the form of graphs, one is the plot of data with time sequence, and the other is the plot of correlations.

The plot of data with time sequence is excellent to visualize the change in the behavior of a dam body and its foundation rock, but it is usually difficult to find the unusual conditions quickly and accurately when external factors such as water level change.

The plot of correlations to water level or other factors is effective to find the unusual conditions of a dam body and its foundation rock accurately and quickly, if suitable factors are chosen. However, in certain cases, such as in the deformation of an arch dam which is affected by many factors like water level or temperature, the judgement becomes difficult.

The way of data processing for each measurement item is described below.

The forms of graph can be referred at the end of this booklet.

5.1 Leakage of Water

There are two ways to measure the amount of leakage of water, the measurement of leakage of the individual drain hole and the measurement of total leakage. Generally, for the purpose of safety control, graphs of total leakage and of some relatively large leakage of the individual holes are enough. Graphs at the points of small leakage can be omitted. The data of total leakage of water are more desirable to be divided into some blocks, such as left bank, right bank and river bed, than to be plotted in a figure as a whole. Such a division of blocks is more desirable for the early confirmation of places of unusual conditions. In the case of the concrete dam, the measurement data of leakage water from the foundation rock should be processed separately from those of joints.

Examples of graphs are shown in Fig. 1 and Fig. 2. Fig. 1 shows the plot of data with time sequence. Daily precipitation is also plotted in

Leakage of water (Time sequence)

Name of dam: x x x dam

Measuring point: River bed

Leakage of water
(whole, (section), hole)

Period of measurement:

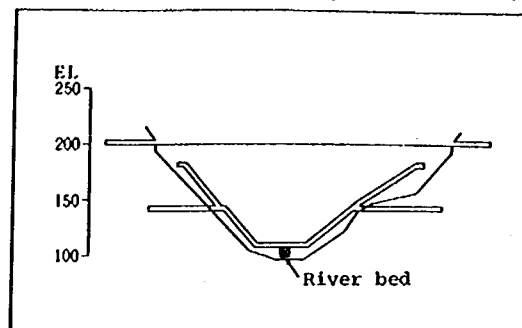
from January, 1981

to December, 1981

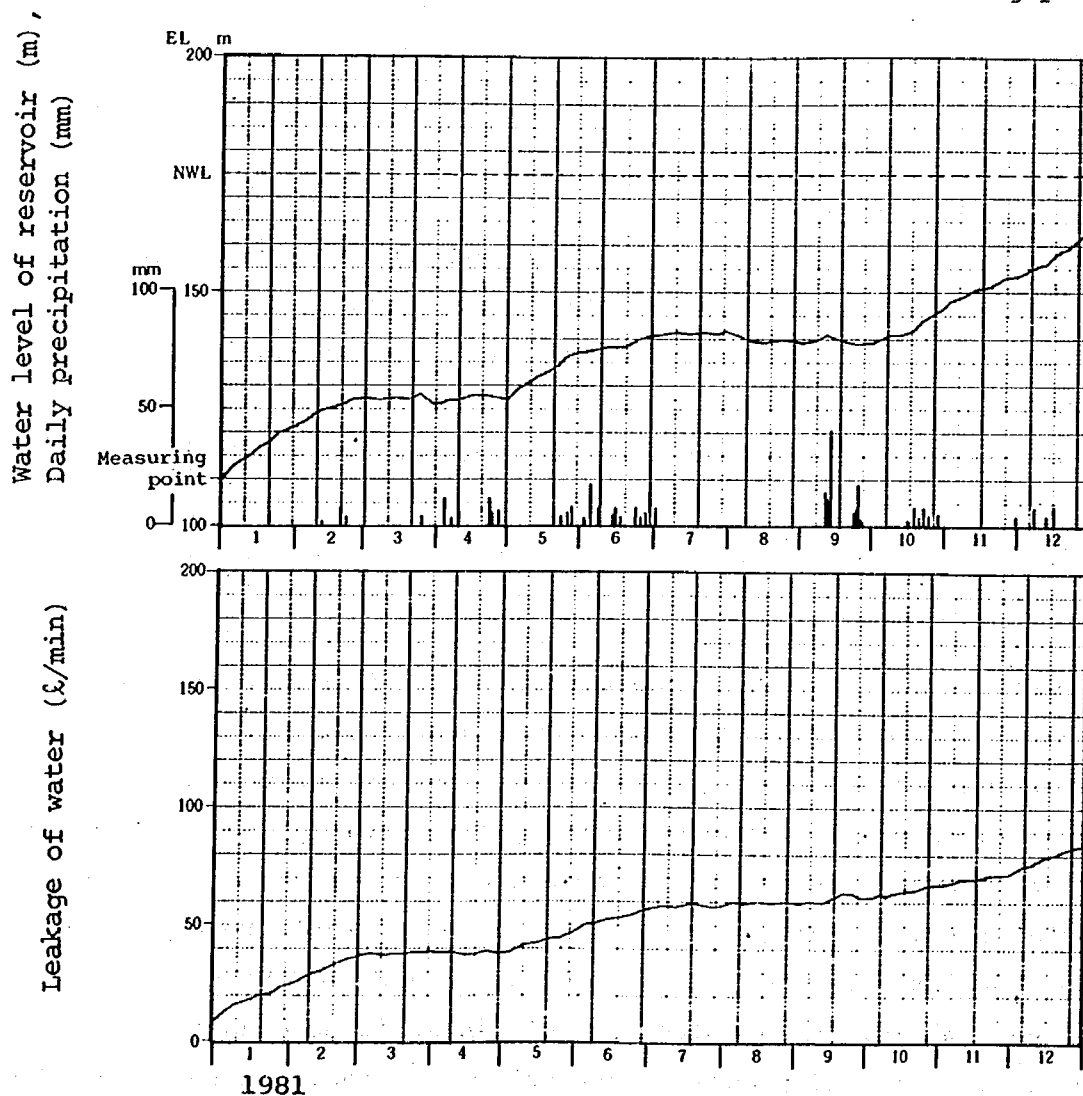
Start of filling water:

December, 1980

Measurement form 2
(Leakage of water)



Location of measuring point



Note) The elevations of normal water level and the drain hole should be indicated clearly in the graph.

Fig. 1 Example of the Plot of Leakage of Water with Time Sequence

Leakage of water (Correlative to water level of reservoir)

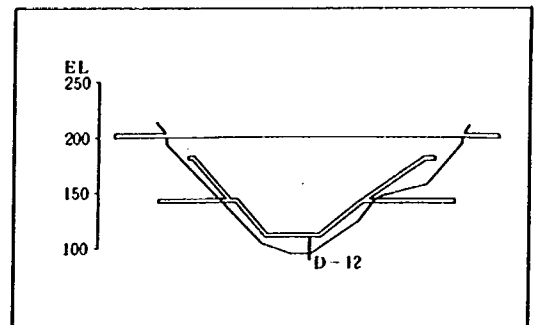
Measurement form 1
(Leakage of water)

Name of dam: × × × dam

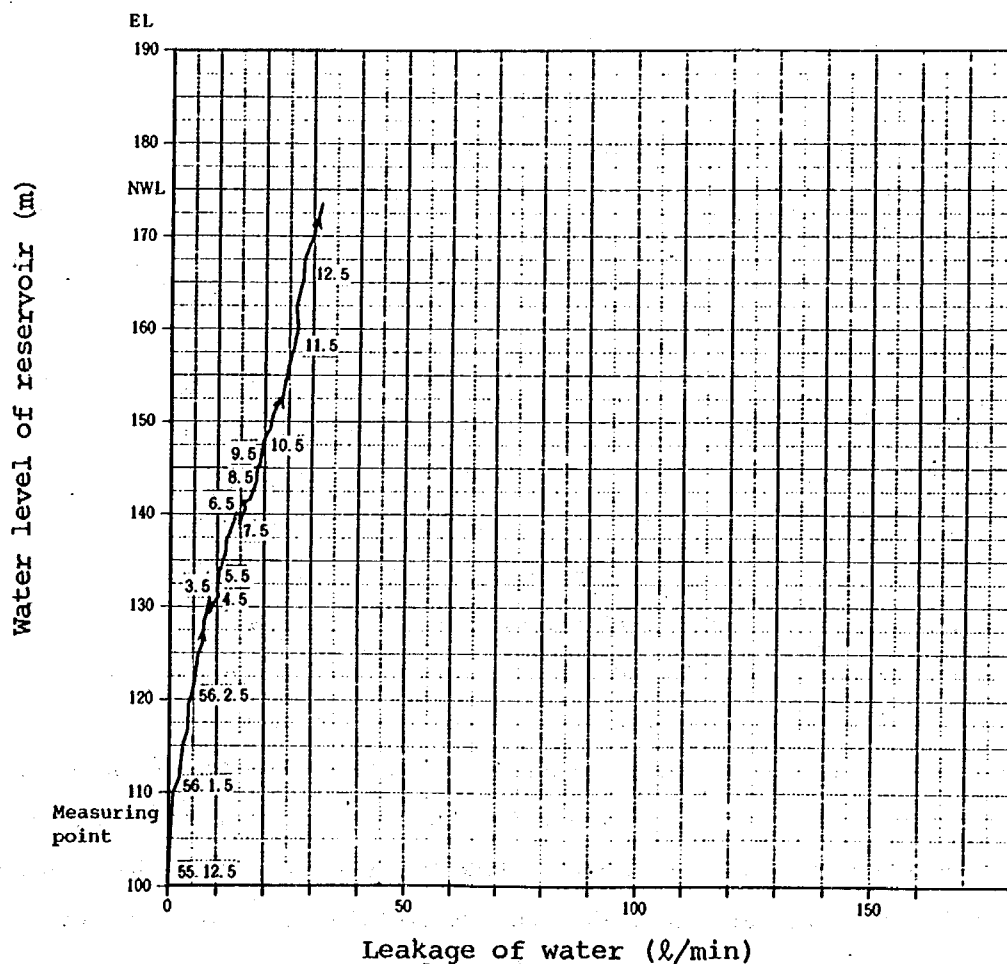
Measuring point: D-12
Leakage of water
(whole, section, hole)

Period of measurement:
from December, 1980
to December, 1981

Start of filling water:
December, 1980



Location of measuring point



- Notes) 1. Arrows should be put in the graph to show the time sequence.
2. Date of measurement should be indicated in the graph periodically.
3. The elevations of normal water level and the drain hole should be indicated clearly in the graph.

Fig. 2 Example of the Plot of Correlation Between Leakage Water and Water Level of Reservoir

the figure to check whether the amount of leakage of water is affected by the precipitation. The measurement of daily precipitation is necessary for fill dams. Fig. 2 shows the correlation between the amount of leakage of water and the water level of the reservoir.

The graph showing the amount of leakage of water with time sequence (Fig. 1) should be plotted on a new sheet every year. The graph showing the relationship between the amount of leakage of water and the water level of the reservoir is desired to plot data for some years on the same sheet. When the graph becomes too complicated to read, a new sheet of paper should be used. In Fig. 2, it is not necessary to plot every day's measurement data even during the first term. If all the data are listed on a data sheet, one plot in the graph per week is enough to evaluate the relationship between water level and water leakage. The date of measurement should be written periodically in the figure to see seasonal changes.

5.2 Deformation

If deformation cannot be measured at once as in the case of a plumb line in an arch dam, data should be arranged as absolute displacement against the fixed point instead of relative displacement among measurement points. Examples of data processing of deformation in the form of graphs are shown in Figs. 3, 4 and 5. Fig. 3 shows an example of data processing with time sequence. Changes of the temperature in a dam body are also recorded in the graph to see whether the deformation of the dam body is affected by the temperature change. Ideally, 2 ~ 3 embedded thermometers are necessary near the deformation measuring sections. These thermometers should be embedded in the higher part for the concrete gravity dam because almost no temperature change occurs in the lower part. For the concrete arch dam, only thermometers embedded in the middle part of the dam are considered to be enough because they stand for the average temperature. Thermometers should be embedded inside of the section to avoid the direct effect of the ambient temperature change. Measurements of thermometers at the upper and the lower elevations, and near the upstream and the downstream surfaces should be plotted in the graph to analyze precisely.

Deformation (Time sequence)

Name of dam: × × × dam

Measuring point: PL-2

Period of measurement:

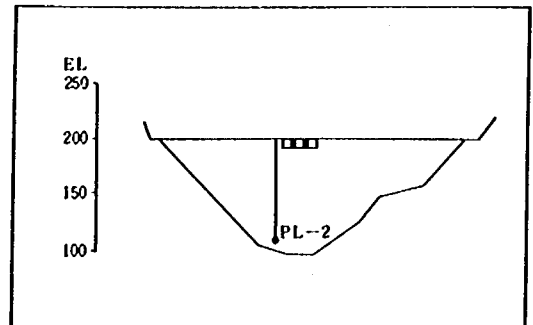
from January, 1981

to December, 1981

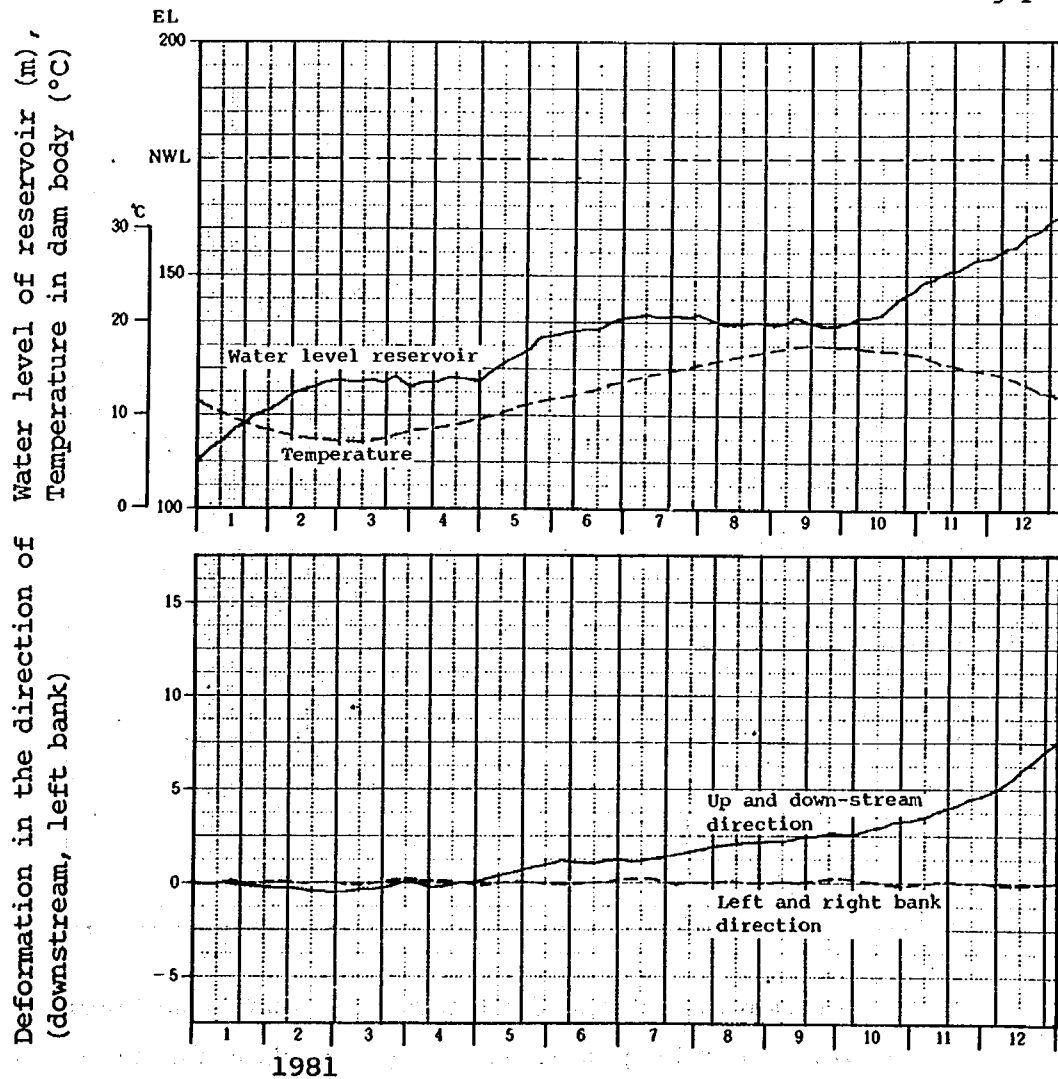
Start of filling water:

December, 1980

Measurement form 2 (Deformation)



Location of measuring point.



- Notes)
1. The temperature which represents the average temperature in the dam body should be plotted.
 2. The amount of deformation should be plotted for all the directions.
 3. The elevation of normal water level should be indicated clearly in the graph.

Fig. 3 Example of the Plot of Deformation with Time Sequence

Deformation (Correlative to water level of reservoirs)

Name of dam: x x x dam

Measuring point: PL-2

Period of measurement:

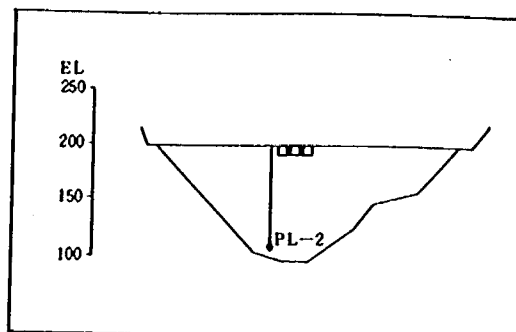
from December, 1980

to December, 1981

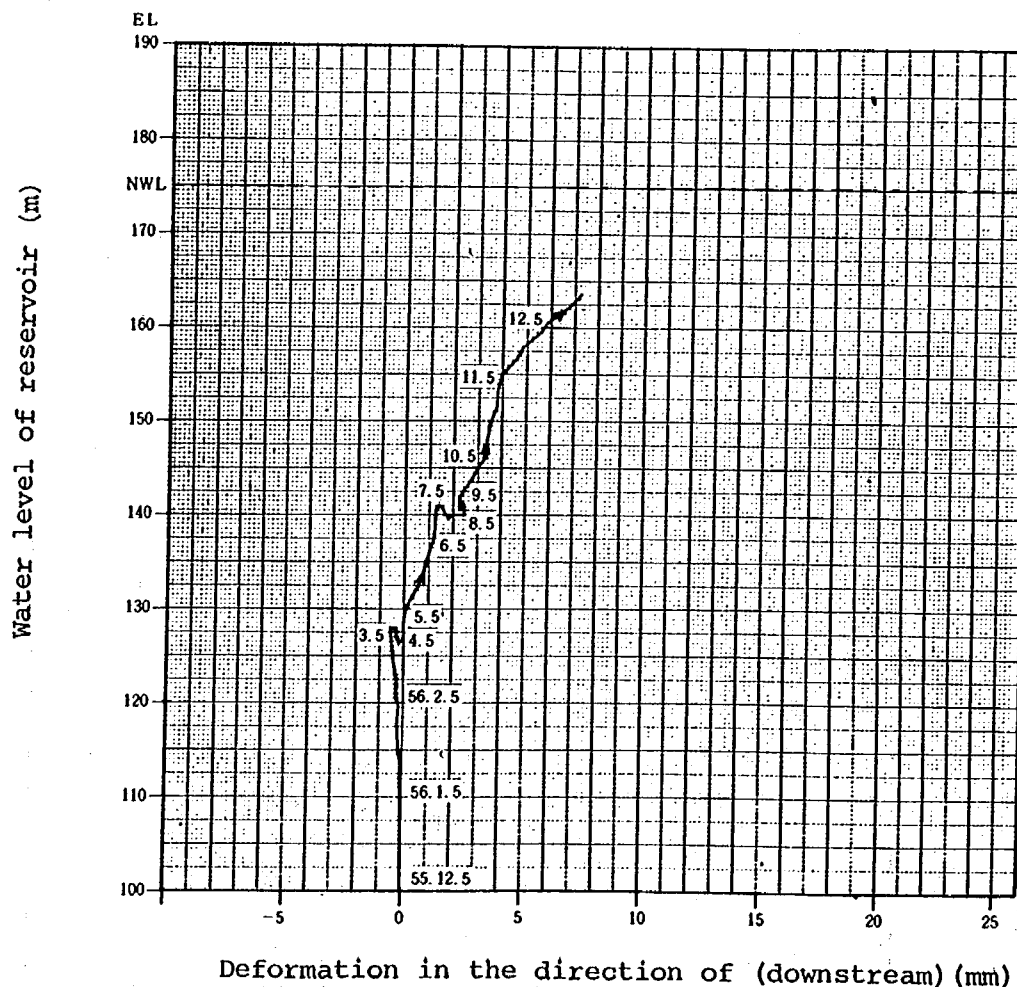
Start of filling water:

December, 1980

Measurement form 1
(Deformation)



Location of measuring point



- Notes)
1. Arrows should be put in the graph to show the time sequence.
 2. Date of measurement should be indicated in the graph periodically.
 3. The elevation of normal water level should be indicated clearly in the graph.

Fig. 4 Example of the Plot of Correlation Between Deformation and Water Level of Reservoir

Deformation (Distribution map)

Name of dam: dam

Elevation of measurement: EL 405.0 m

Period of measurement

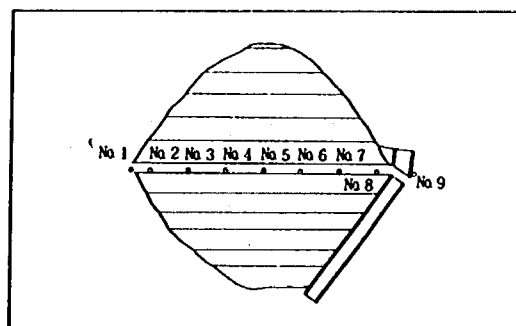
from September, 1979

to September, 1982

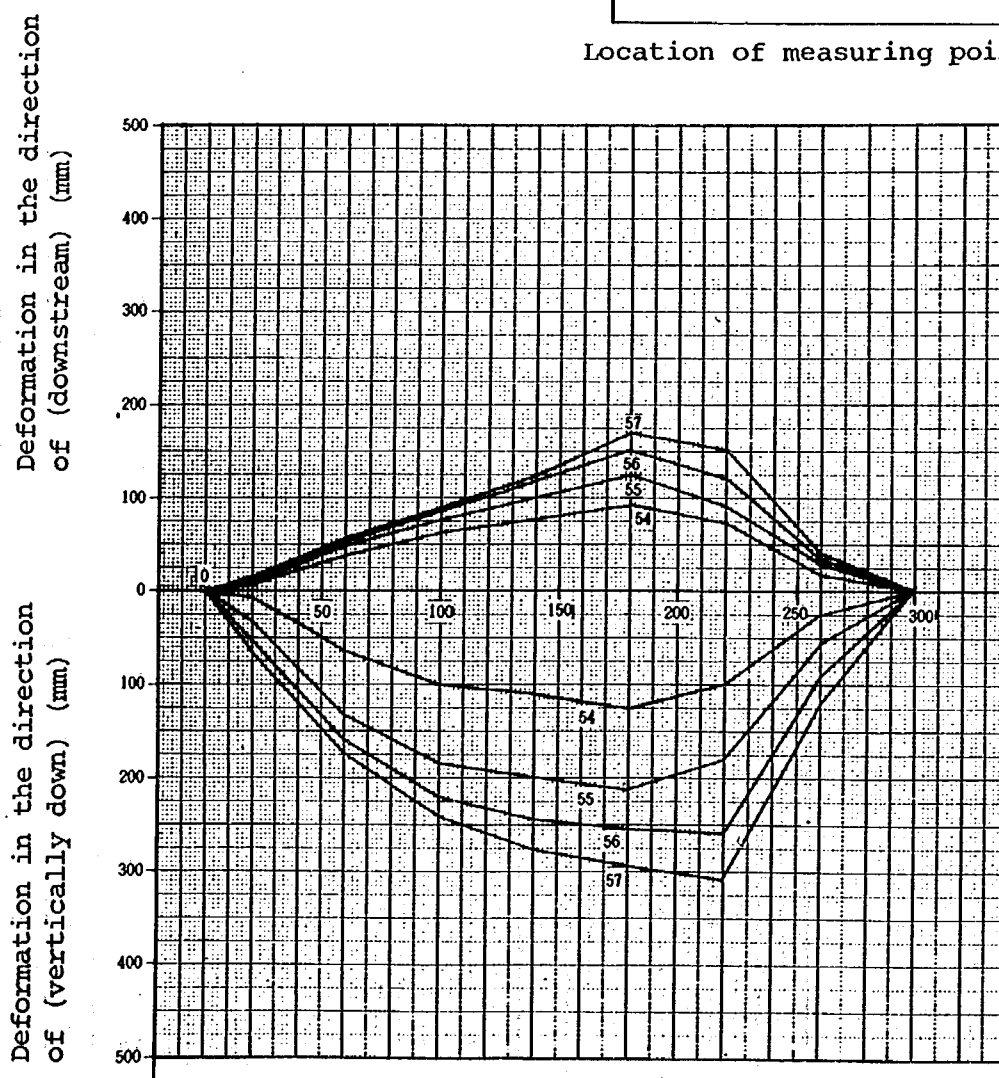
Start of filling water:

September, 1979

Measurement form 3 (Deformation)



Location of measuring point



Location of measuring point (m)

Fig. 5 Example of Distribution Map of Deformation

Uplift (Time sequence)

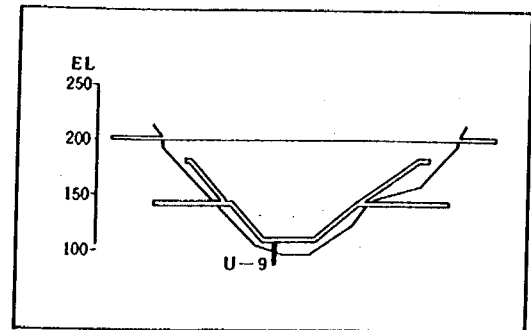
Name of dam: x x x dam

Measuring point: U-9

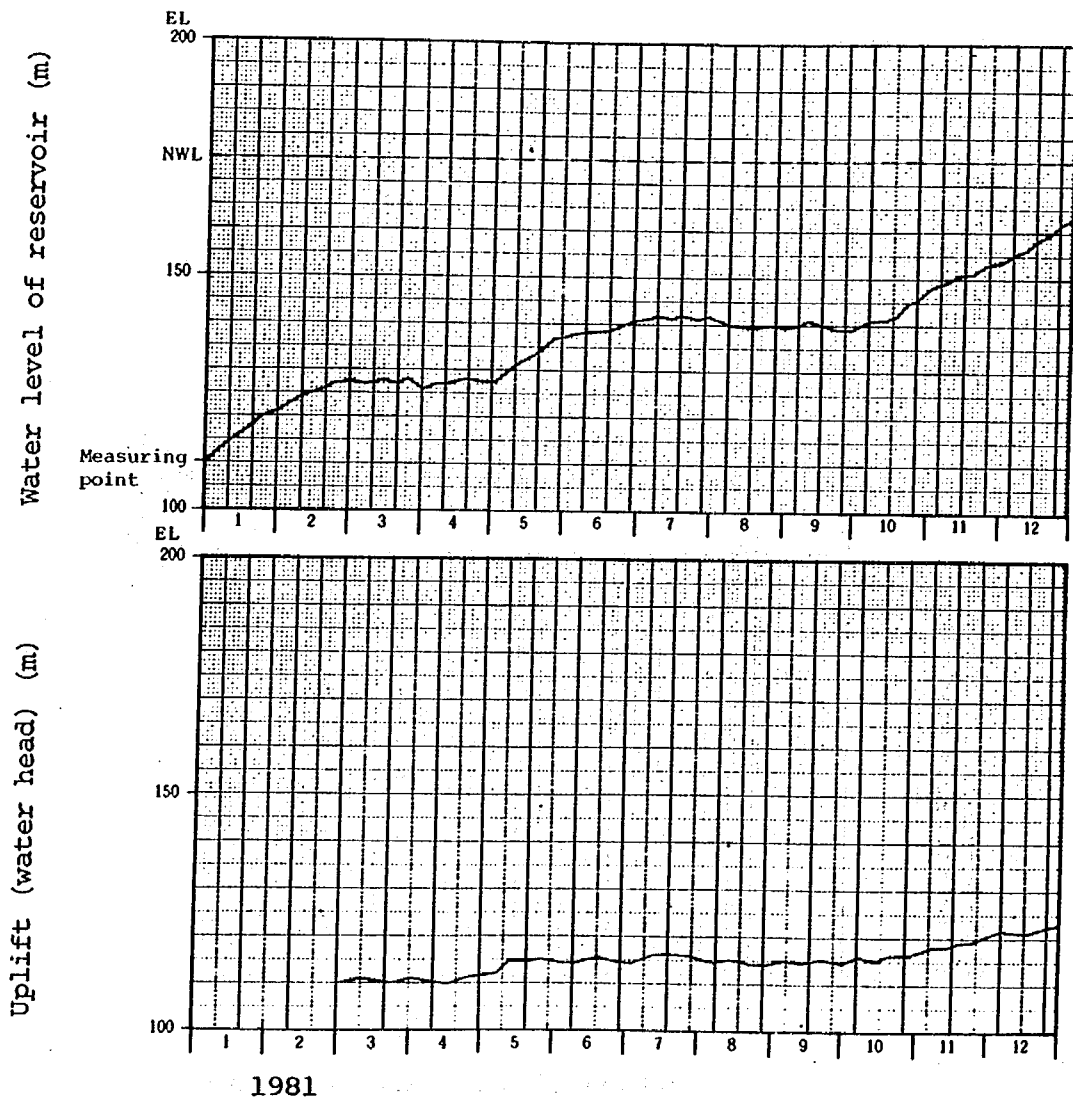
Period of measurement:
from January, 1981
to December, 1981

Start of filling water:
December, 1980

Measurement form 2
(Uplift)



Location of measuring point



Note) The elevations of normal water level and measuring point should be indicated in the graph.

Fig. 6 Example of the Plot of Uplift (Pore Pressure) with Time Sequence

Uplift (Correlative to water level
of reservoir)

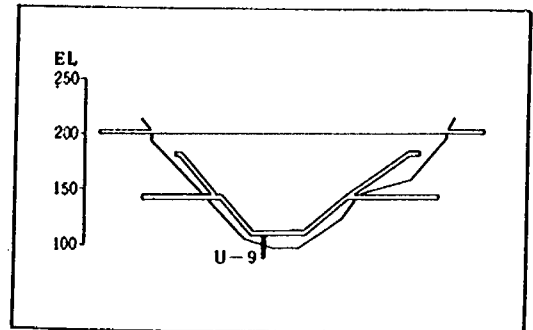
Measurement form 1
(Uplift)

Name of dam: X X X dam

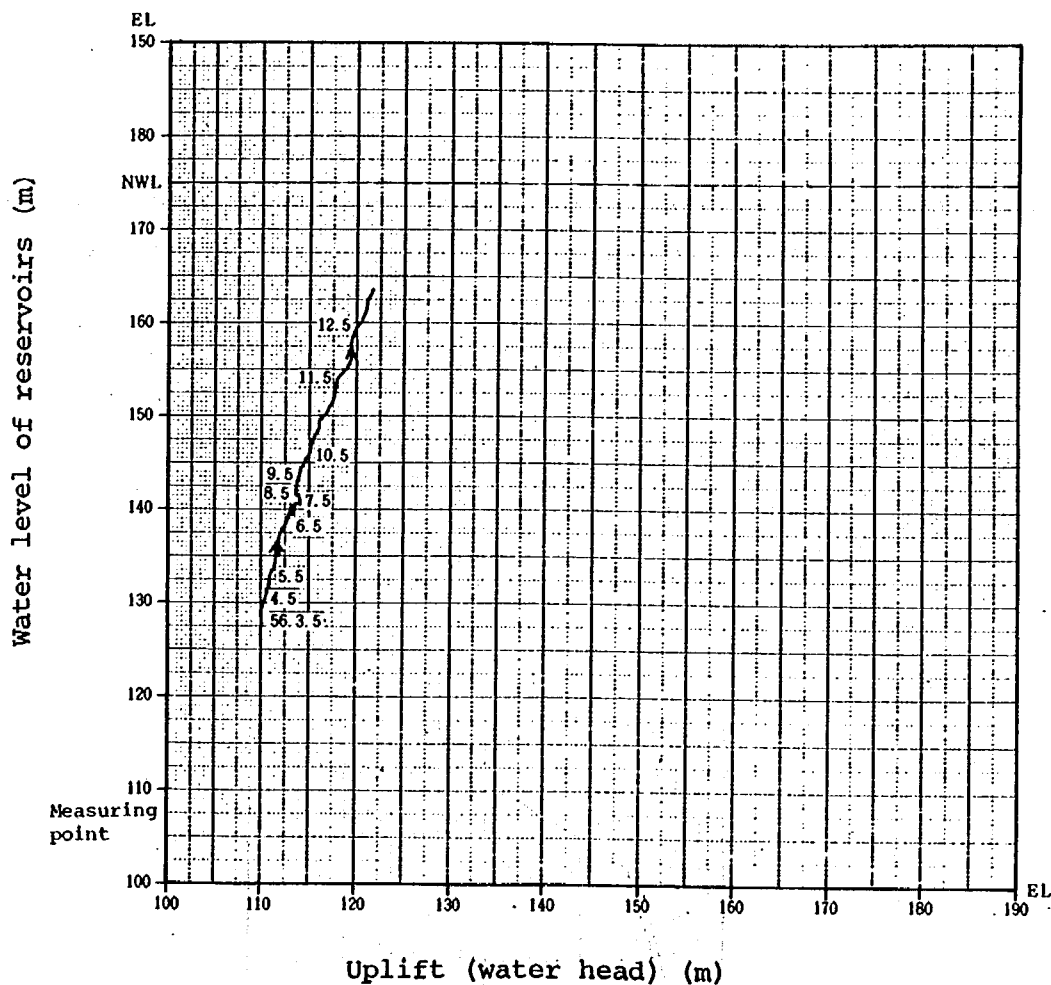
Measuring point: U-9

Period of measurement:
from December, 1980
to December, 1981

Start of filling water:
December, 1981



Location of measuring point



- Notes)
1. Arrows should be put in the graph to show the time sequence.
 2. Date of measurement should be indicated in the graph periodically.
 3. The elevations of normal water level and the drain hole should be indicated clearly in the graph.

Fig. 7 Example of the Plot of Correlation Between Uplift
(Pore Pressure) and Water Level of Reservoir

Fig. 4 shows the correlation between deformation and water level.

Fig. 5 shows creep deformation of a fill dam. The graph should be drawn with a plot per year on the condition of constant water level.

Other remarks should be referred to [5.1 Leakage of Water].

5.3 Uplift or Pore Pressure

The measurement of uplift or pore pressure is generally expressed by the unit of pressure (kg/cm^2), but it is more convenient to use the unit of water head (m) to judge the correlation to reservoir water level.

Examples of data processing of uplift (pore pressure) in the form of graphs are shown in Figs. 6 and 7. Fig. 6 shows the uplift (pore pressure) with time sequence, and Fig. 7 shows the correlation between uplift (pore pressure) and reservoir water level.

Refer to [5.1 Leakage of Water] in further detail.

In the case that measuring devices are embedded to obtain the distribution of uplift (pore pressure) in the up and downstream direction, the distribution map of uplift should be drawn. In this case, the data should be arranged with a constant water level, or they should be arranged as percentage to hydrostatic pressure. An example of the distribution map of uplift (pore pressure) is shown in Fig. 8.

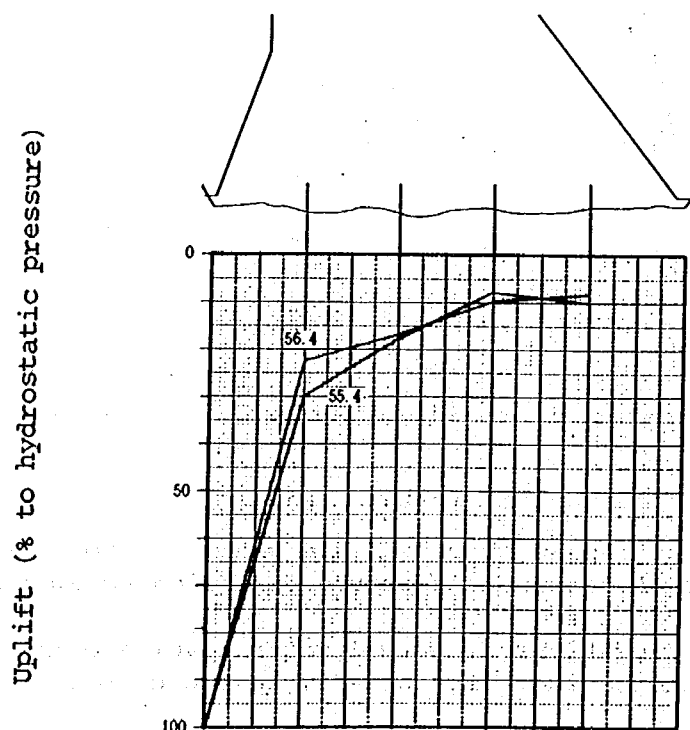


Fig. 8 Example of the Plot of Uplift Against Hydrostatic Pressure

5.4 Other Measurements

The same graphing as deformation can be utilized for other measurement items, such as stress or earth pressure, and strain or shear deformation.

6. DATA ANALYSIS TO EVALUATE SAFETY OF DAM

The "unusual condition" of a dam body and its foundation rock means the condition that the normal function of the dam will be damaged by a large amount of water leakage or that the structural stability of the dam will be lost by piping or a large deformation, unless proper prevention are taken. It does not mean the actual occurrence of serious functional or structural problems. However, when the unusual condition appears in various measurement data, a detailed analysis of the data will make it possible to predict more seriously unusual condition of the dam body and its foundation rock in advance.

6.1 Leakage of Water

The unusual leakage of water can be judged from the correlation between water level of the reservoir and amount of leakage of water. In the normal condition, the leakage of water per hole has a linear correlation with water level of the reservoir, and the total amount of leakage of water can be approximated by a linear or a quadratic equation of reservoir water level. Accordingly, a rapid increase of the amount of leakage of water compared to the change of water level indicates the unusual condition as shown in Fig. 9. In this case, it can be judged that a water leakage path was formed from the elevation where leakage of water increases rapidly to the drain hole. For the rapid increase of leakage of water in the foundation rock, further investigation is necessary referring to the geological condition of the area or the results of grouting.

The water leakage more than 100 l/min per hole possibly indicates unusual condition and special attention is required.

Prevention works should be employed immediately after unusual water leakage is observed, or if mud is recognized in the leakage water even when the amount of leakage water is small. The muddy flow indicates the enlargement of the path.

The relation between leakage of water and rain fall should be carefully considered in the observation of leakage of water in fill dams, because the permeation of rain water sometimes has large effects on the amount of leakage water.

Leakage of water (Correlative to water level of reservoir)

Measurement form 1
(Leakage water)

Name of dam: X X X dam

Measuring point: D-12

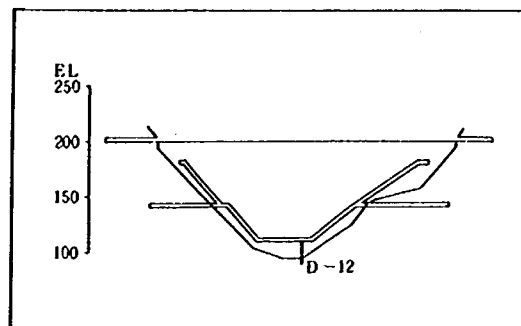
Leakage of water
(whole, section, hole)

Period of measurement:

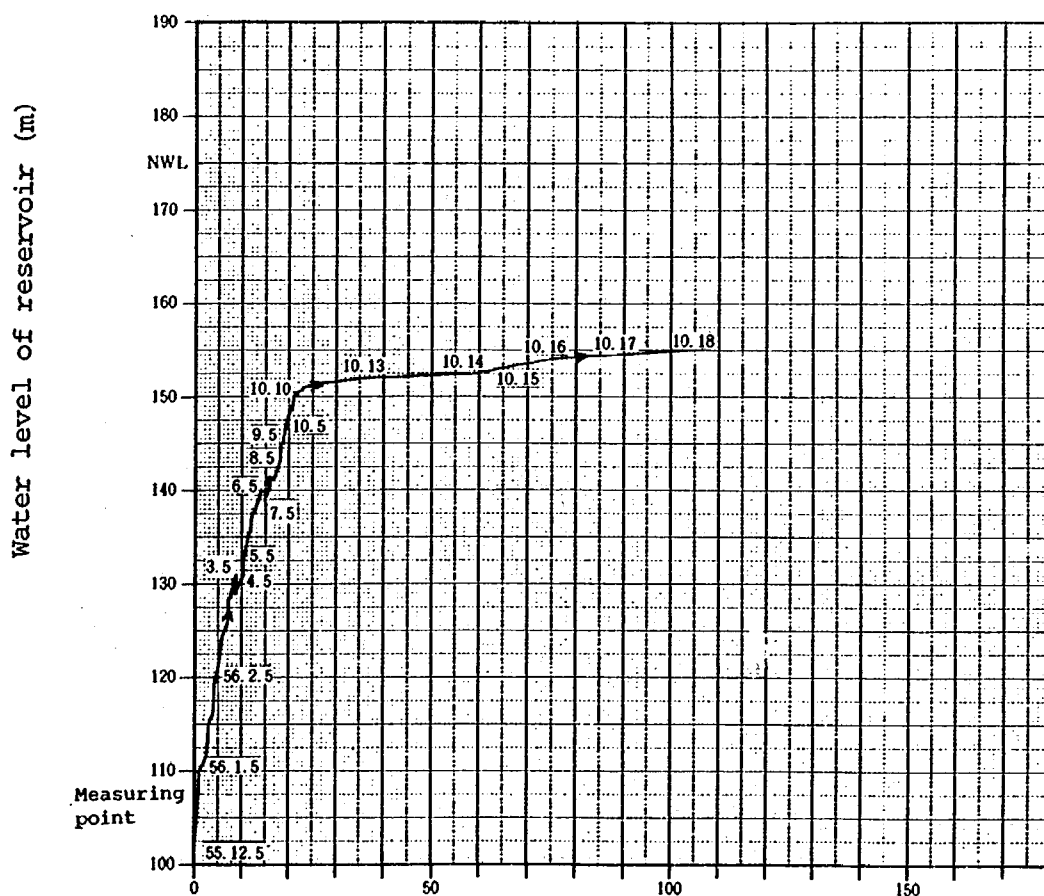
from December, 1980
to October, 1981

Start of filling water:

December, 1980



Location of measuring point



Leakage of water (l/min)

- Notes) 1. Arrows should be put in the graph to show the time sequence.
2. Date of measurement should be indicated in the graph periodically.
3. The elevations of normal water level and the drain hole should be indicated clearly in the graph.

Fig. 9 Example of Unusual Leakage of Water

Deformation (Correlative to water level of reservoir)

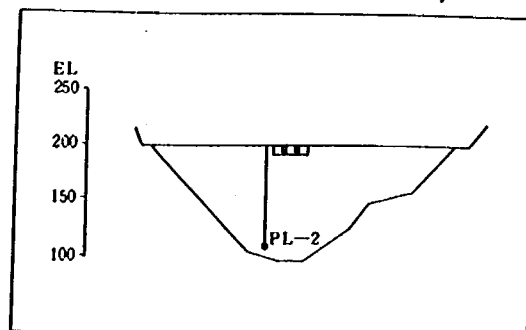
Name of dam: x x x dam

Measuring point: PL-2

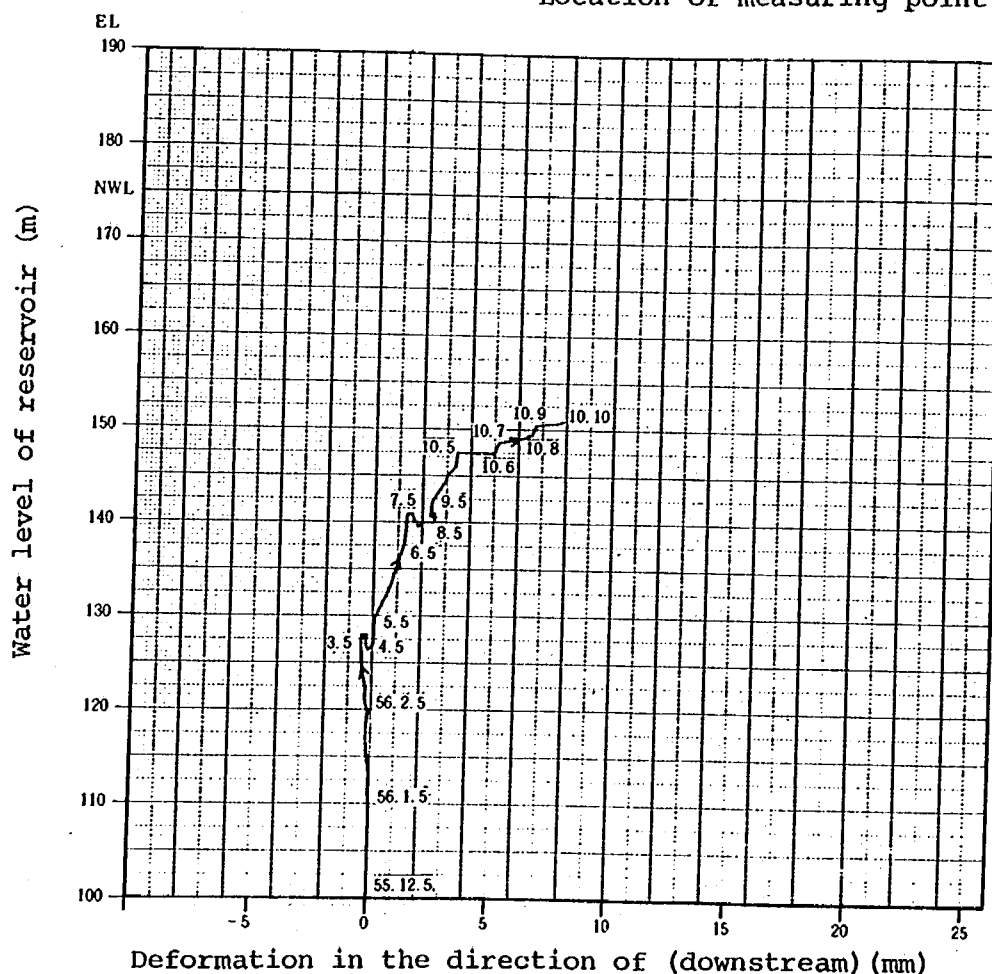
Period of measurement:
from December, 1980
to October, 1981

Start of filling water:
December, 1980

Measurement form 1
(Deformation)



Location of measuring point



- Notes) 1. Arrows should be put in the graph to show the time sequence.
2. Date of measurement should be indicated in the graph periodically.
3. The elevation of normal water level should be indicated clearly in the graph.

Fig. 10 Example of Unusual Deformation

6.2 Deformation

The unusual deformation is judged from the relation between reservoir water level and amount of deformation. The amount of deformation is approximated by a quadratic equation in the normal condition. As shown in Fig. 10 a rapid increase of deformation compared to the reservoir water level indicates the occurrence of unusual condition.

However, such unusual condition seldom occurs and the problem is usually in the creep deformation of the foundation rock or of the fill dam body.

The creep deformation is plastic or viscous behavior of the foundation rock or the fill dam bodies in the early stage, which does not recover with unloading. The deformation usually converges to a constant value as a result of compaction by the repeated or the long-term load such as water pressure and weight of the dam body. If the deformation does not converge to a constant value or if it shows an extremely large value, the unusual condition is expected in the dam body or in its foundation rock. However, there is no way to determine the allowable amount of deformation. The unusual deformation is generally judged by the change of the rate of creep deformation. The case where the rate of creep deformation increases with time (Fig. 11 (a) is clearly considered to be unusual. The case of Fig. 11 (b), in which the rate of creep deformation decreases, indicates that a stable condition will be obtained. Fig. 11 (c) which shows the constant rate of deformation indicates the transition stage to (a) or (b), and careful measurement are still necessary.

These judgements must be done with a special care, because the amount of deformation is affected not only by the change of water level of the reservoir and creep deformation but also by the change of temperature as in the case of concrete arch dams.

To divide the data, in which some factors are involved, for each factor, mathematical analysis like multiple regression analysis is generally effective. However, as a simpler method, the effect of temperature change on the deformation can be eliminated by selecting data at the time of nearly equal temperature. Creep deformation can be extracted by selecting data at the time of nearly constant water level and temperature.

The measured amount of deformation generally differs more or less from the designed deformation. This is caused by improper assumptions or inaccurate calculation, and therefore the absolute value of deformation is rarely utilized for the judgement of unusual conditions. The change of deformation with time or the amount of deformation which is independent of the water level or temperature, is generally utilized for this judgement.

Unusual deformation is generally accompanied by unusual leakage of water and unusual uplift (pore pressure).

A concrete gravity dam tends to deform toward upstream in the early stage of first filling of water and then deforms toward downstream. This is considered to be caused by the settlement of the upstream foundation rock with the reservoir water load or the change of temperature at the upstream face of the dam. In the case of rock fill dams, the upstream part of the dam body deforms upward, instead of downward in the early stage of first filling of water by the buoyancy. Then the settlement is induced and accelerated by the increase of effective stress by the lowering of water level. It becomes insensitive to the change of water level thereafter, and the rate of settlement decreases gradually with time.

6.3 Uplift or Pore Pressure

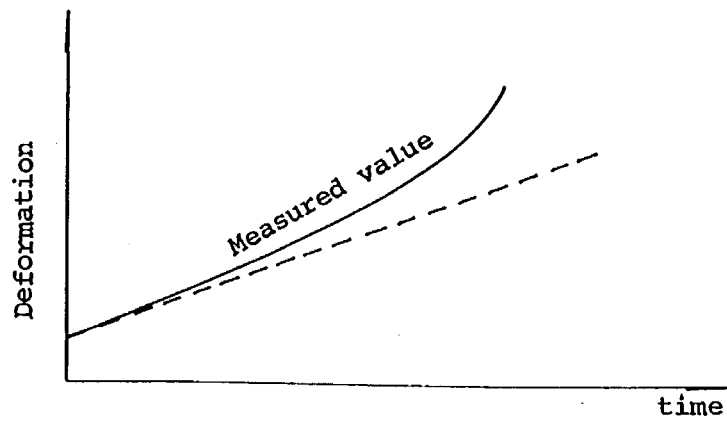
Unusual uplift (pore pressure) is judged from the relationship between water level of reservoir and uplift (pore pressure). The uplift (pore pressure) in a normal condition is linear to water level of the reservoir. Therefore, the rapid change of uplift (pore pressure) compared to the change of reservoir water level is considered unusual.

For the concrete gravity dam, it is desirable to check the stability of the dam when uplift larger than in design is measured. However, if the amount of leakage water and its change are small, large uplift does not cause a problem in the safety.

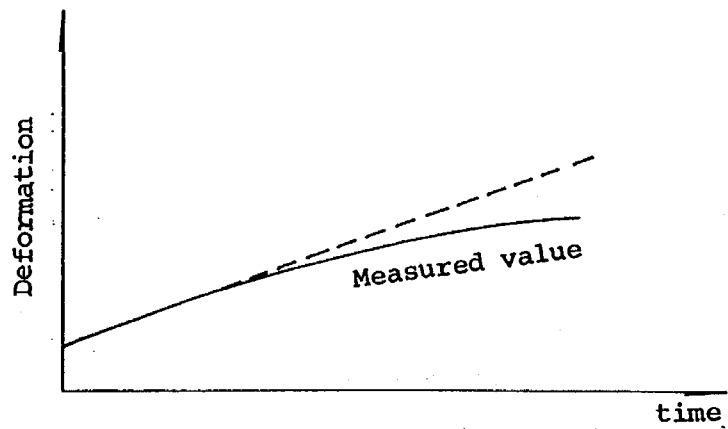
The fill dam is considered stable, if the distribution of pore pressure or the surface line of seepage is close to those in the design.

The uplift (pore pressure) in the foundation rock is sometimes higher than the reservoir water head because of groundwater in the foundation rock, when the water level of the reservoir is low.

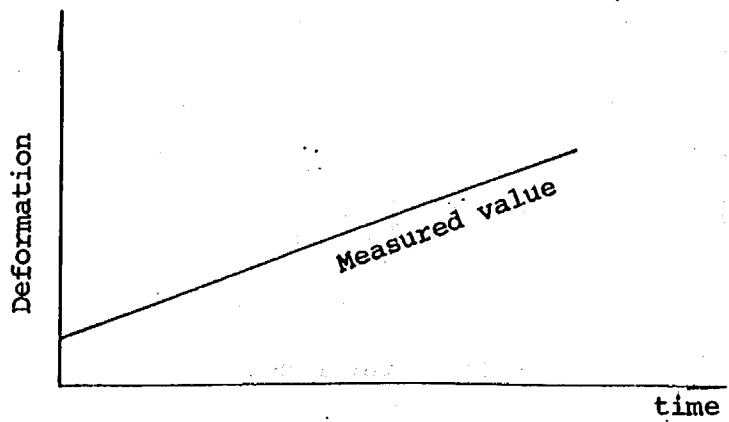
The unusual uplift (pore pressure) is sometimes accompanied by the unusual water leakage.



(a) Unusual condition



(b) Condition toward the steady state



(c) Transitional condition

Fig. 11 Changes of Deformation with Time

Uplift (Correlative to water level of reservoir)

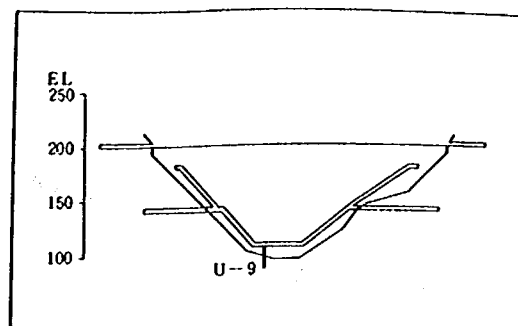
Name of dam: × × × dam

Measuring point: U-9

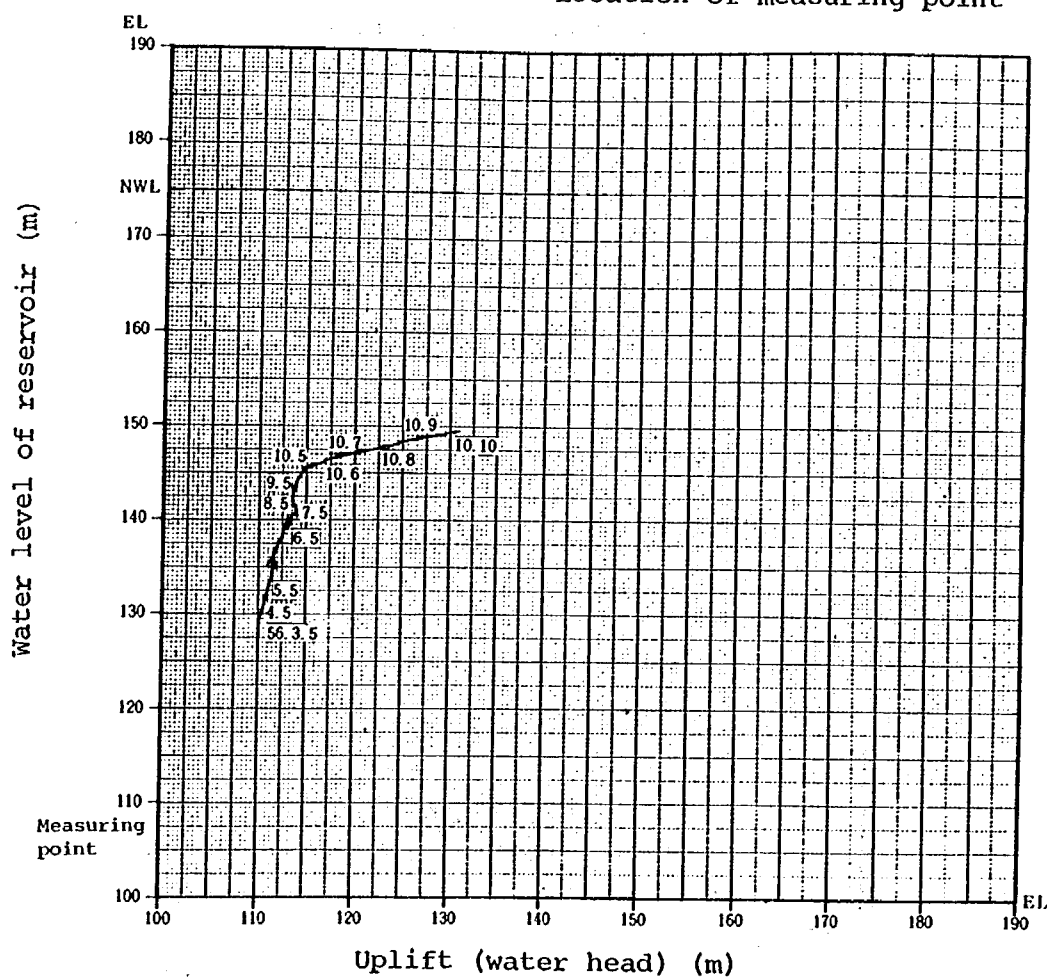
Period of measurement:
from December, 1980
to October, 1981

Start of filling water
December, 1980

Measurement form 1
(Uplift)



Location of measuring point



- Notes)
1. Arrows should be put in the graph to show the time sequence.
 2. Date of measurement should be indicated in the graph periodically.
 3. The elevations of normal water level and the drain hole should be indicated clearly in the graph.

Fig. 12 Unusual Uplift (Pore Pressure)

Leakage of water (Correlative to water
level of reservoir)

Measurement form 1 (Leakage of water)

Name of dam: _____ dam

Measuring point: _____

Leakage of water (whole, section, hole)

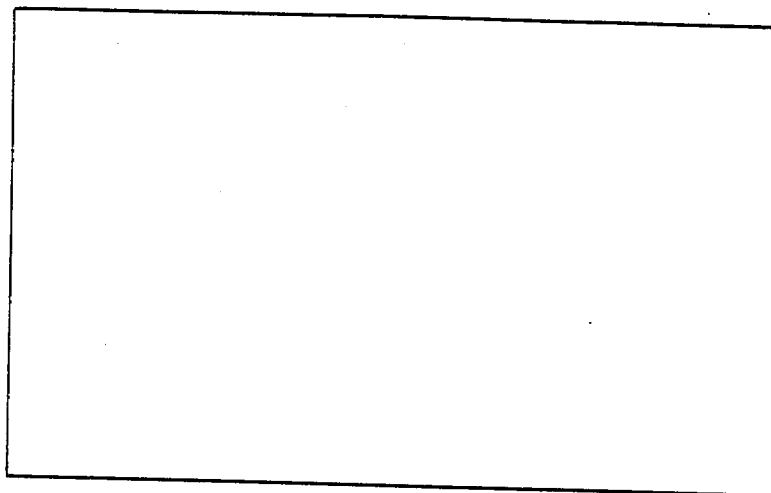
Period of measurement:

from _____ (month) _____ (year)

to _____ (month) _____ (year)

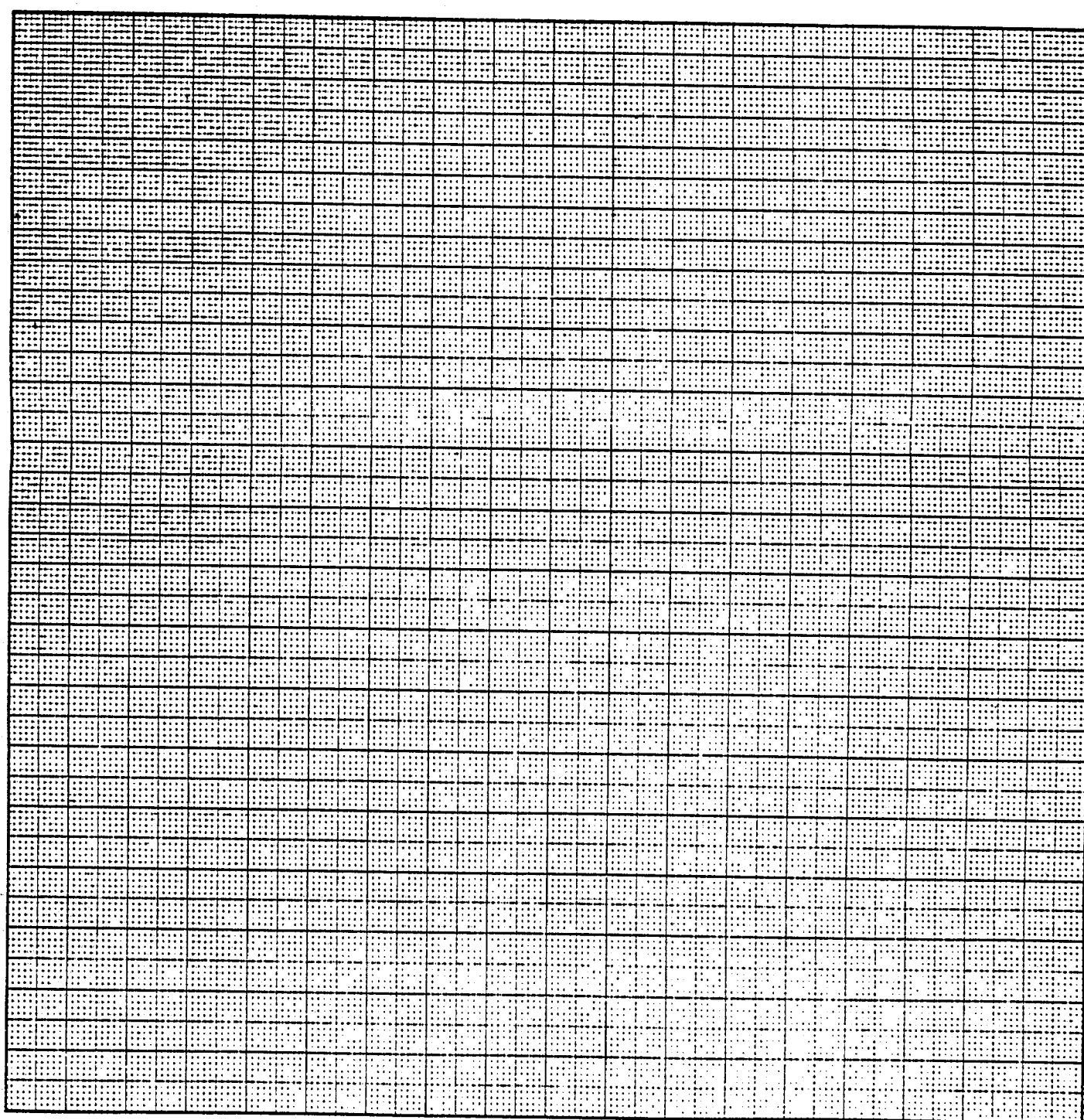
Start of filling water:

_____ (month) _____ (year)



Location of measuring point

Water level of reservoir (m)



Leakage of water (l/min)

- Notes)
1. Arrows should be put in the graph to show the time sequence.
 2. Date of measurement should be indicated in the graph periodically.
 3. The elevations of normal water level and the drain hole should be indicated clearly in the graph.

Leakage water (Time sequence)

Measurement form 2 (Leakage of water)

Name of dam: _____ dam

Measuring point: _____

Leakage of (whole, section, hole)

Period of measurement:

from _____ (month) _____ (year)

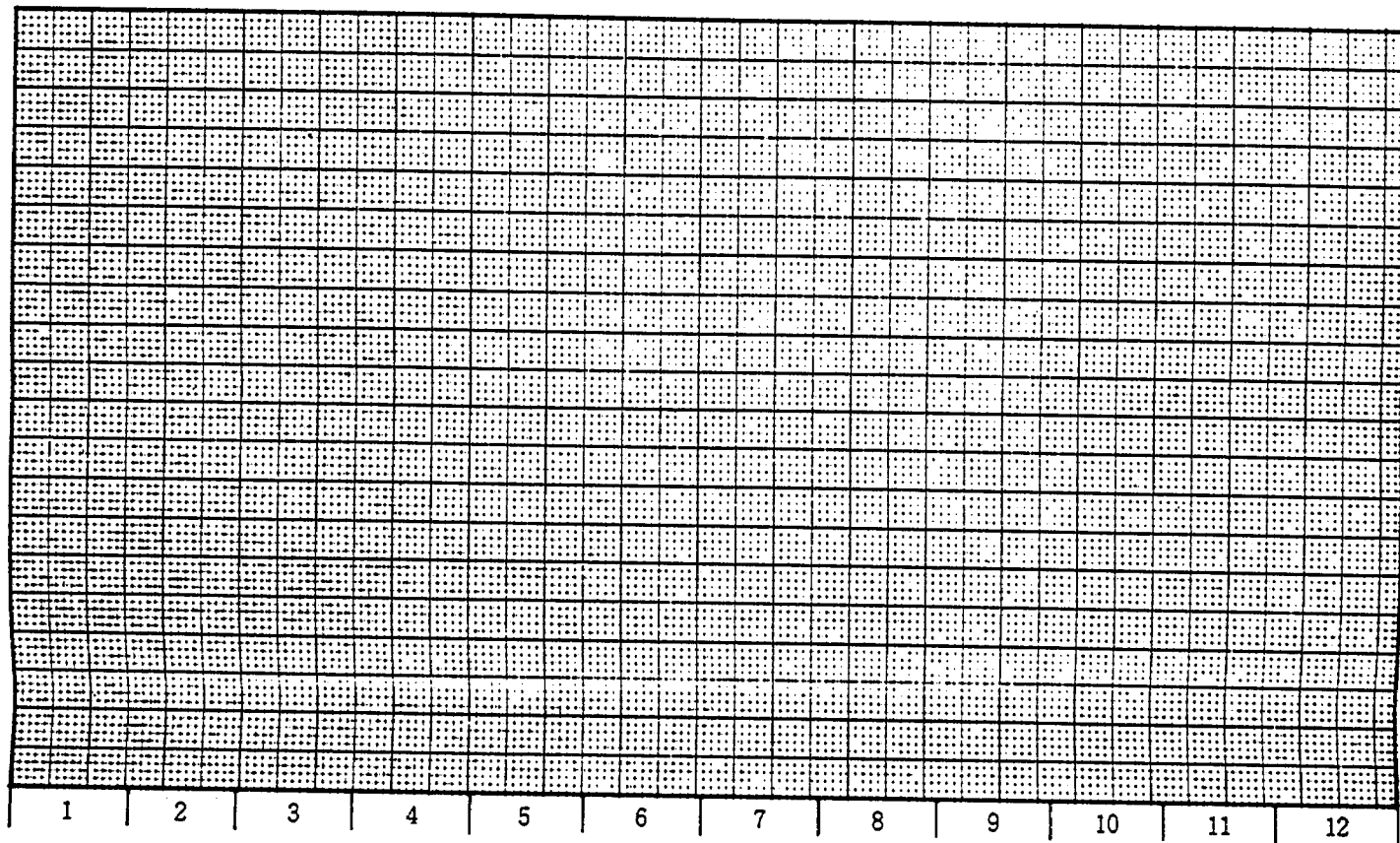
to _____ (month) _____ (year)

Start of filling water:

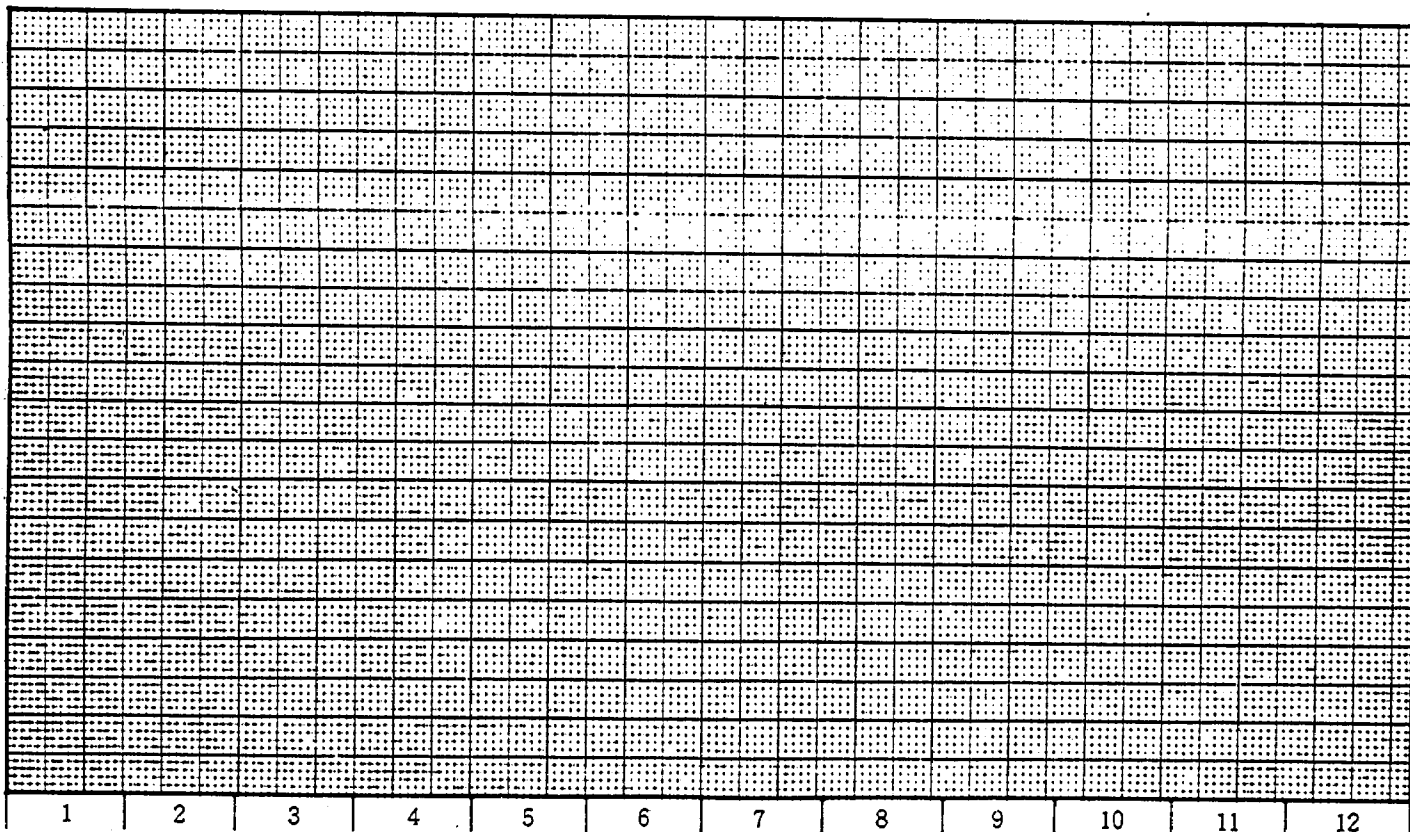
_____ (month) _____ (year)

Location of measuring point

Water level of reservoir
(m)
Daily precipitation
(mm)



Leakage of water (l/min)



Year

Note) The elevations of normal water level and the drain hole should be indicated clearly in the graph.

Deformation (Correlative to water level of reservoir)

Measurement form 1 (Deformation)

Name of dam: _____ dam

Measuring point: _____

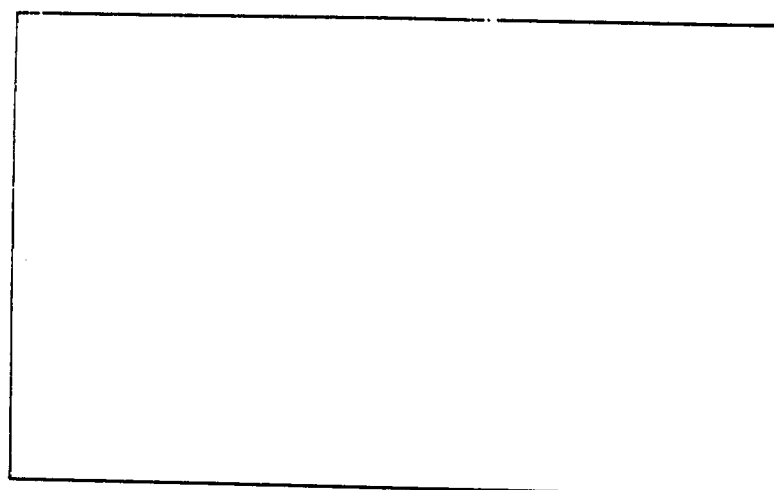
Period of measurement:

from _____ (month) _____ (year)

to _____ (month) _____ (year)

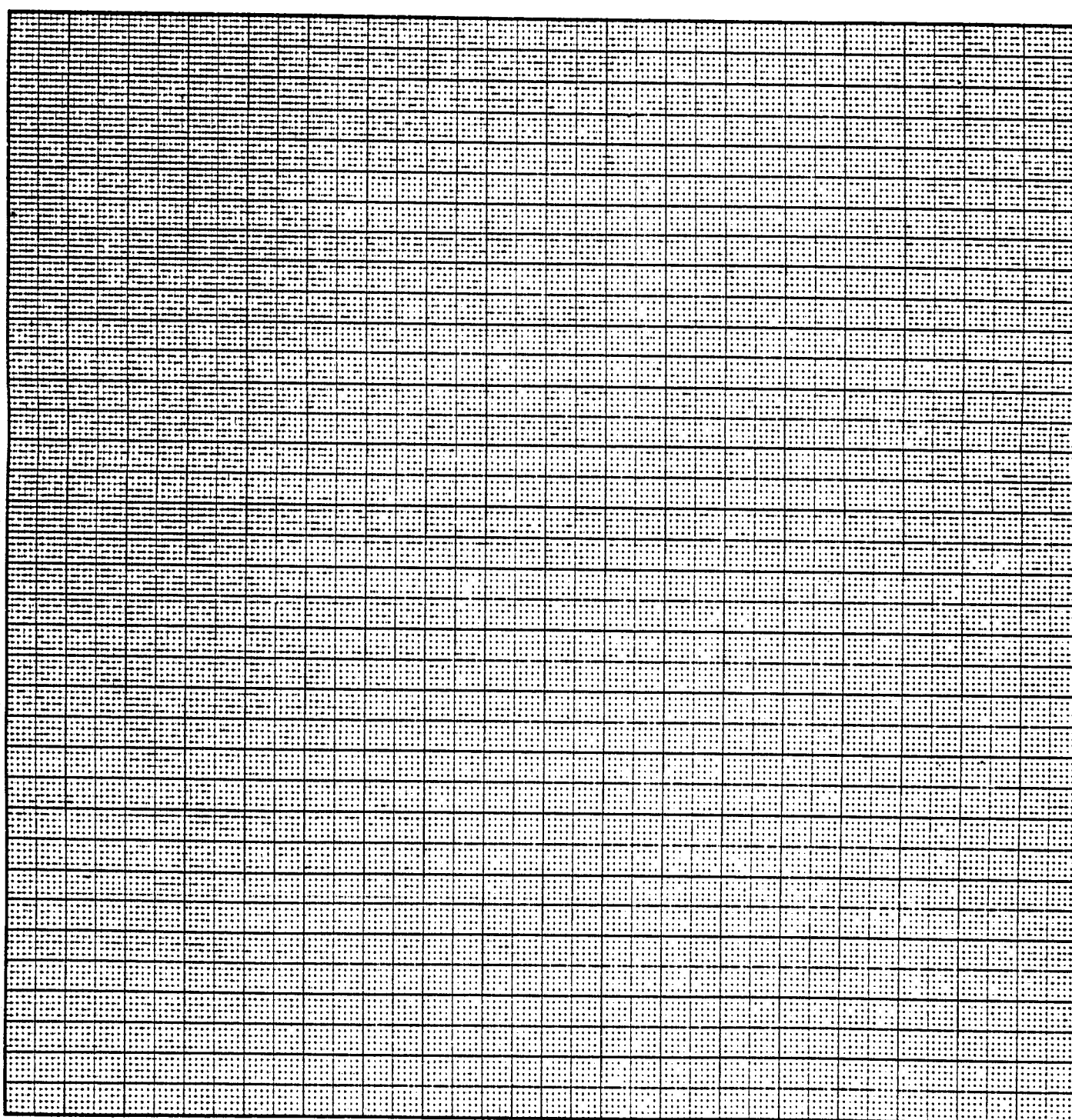
Start of filling water:

_____ (month) _____ (year)



Location of measuring point

Water level of reservoir (m)



Deformation in the direction of () (mm)

- Notes)
1. Arrows should be put in the graph to show the time sequence.
 2. Date of measurement should be indicated in the graph periodically.
 3. The elevation of normal water level should be indicated clearly in the graph.

Deformation (Time sequence)

Name of dam: _____ dam

Measuring point: _____

Period of measurement:

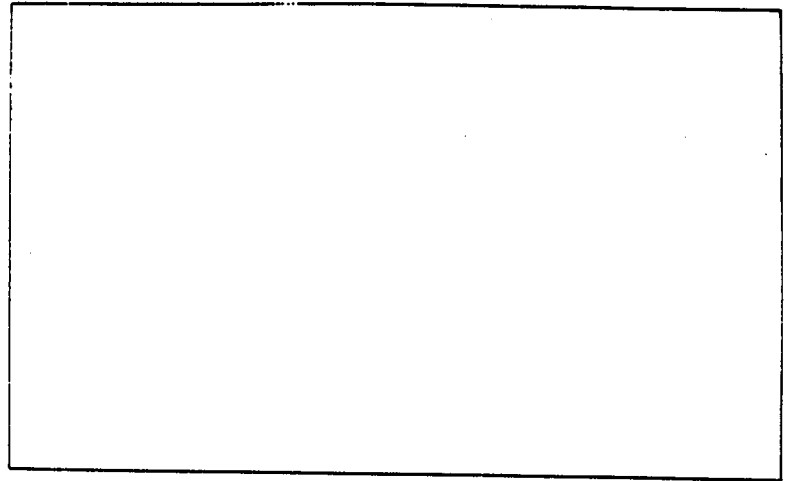
from _____ (month) _____ (year)

to _____ (month) _____ (year)

Start of filling water:

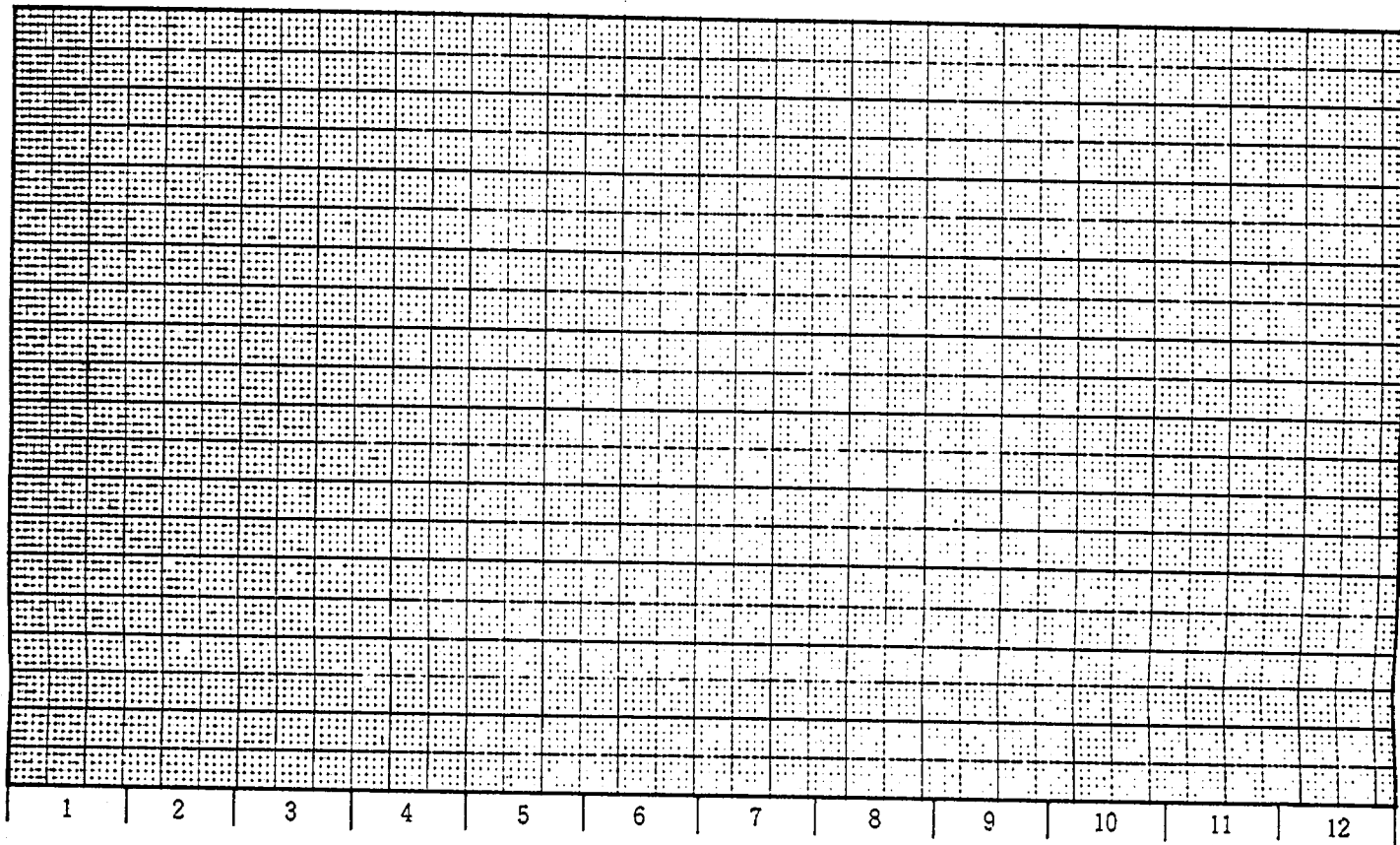
_____ (month) _____ (year)

Measurement form 2 (Deformation)

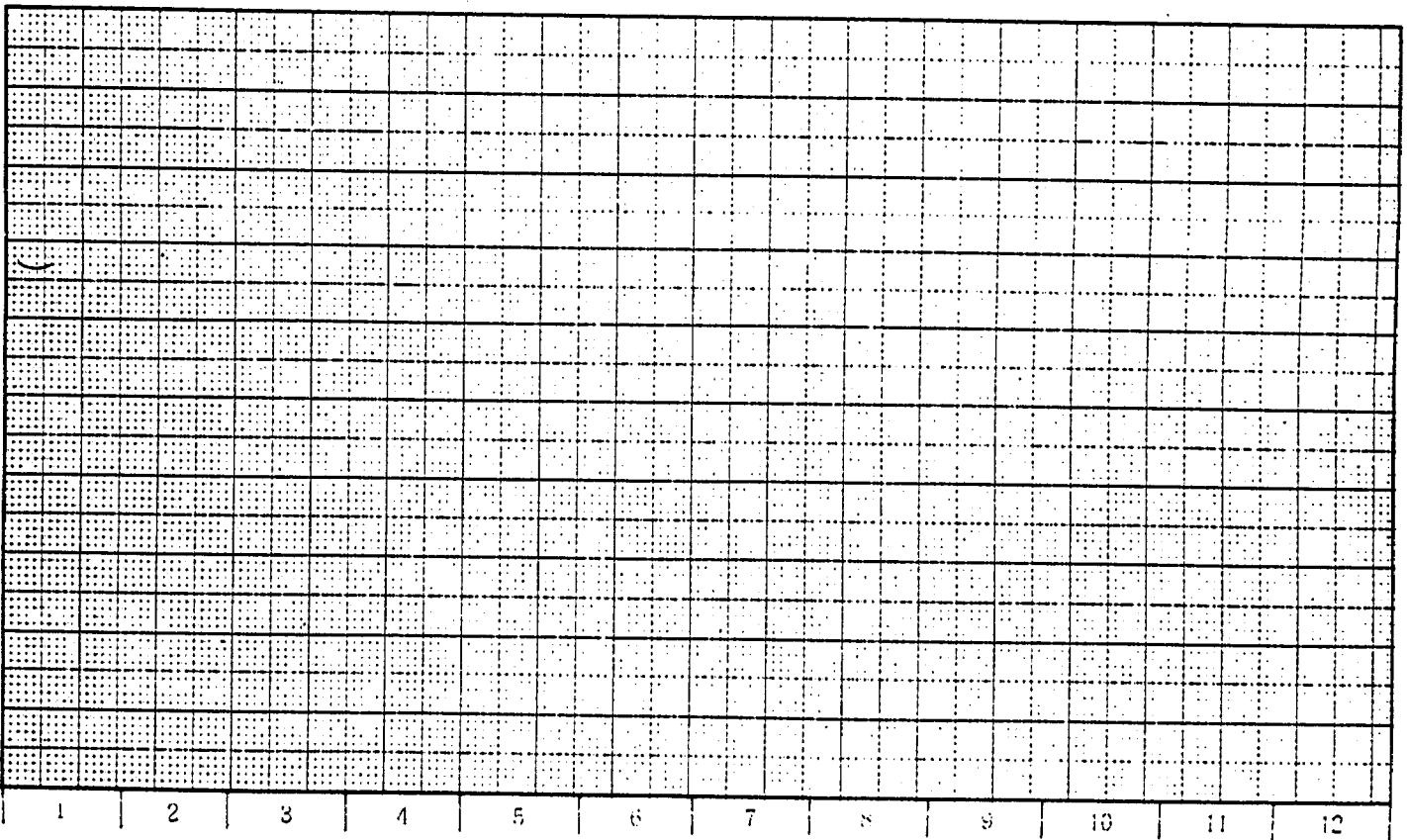


Location of measuring point

Water level of reservoir (m)
Temperature in dam body (°C)



Deformation in the direction of () (mm)



() Year

- Notes)
1. The temperature which represents the average temperature in the dam should be plotted.
 2. The amount of deformation should be plotted for all the directions.
 3. The elevation of normal water level should be indicated clearly in the graph.

Deformation (Distribution map)

Measurement form 3 (Deformation)

Name of dam: _____ dam

Elevation of measurement: EL _____ m

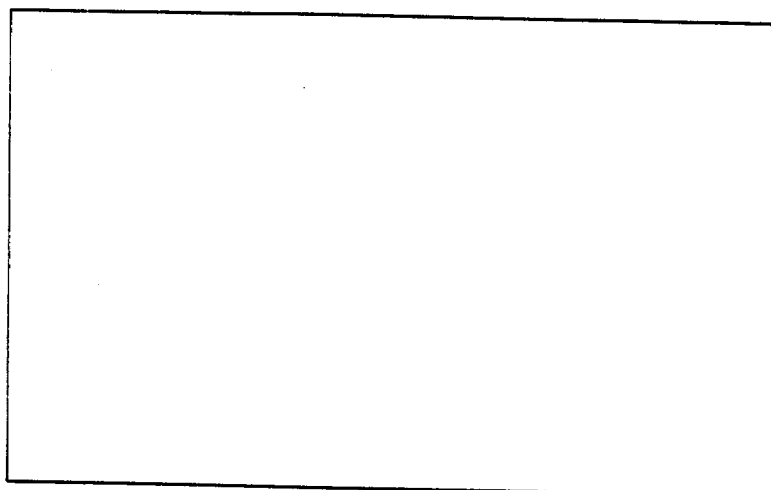
Period of measurement:

from _____ (month) _____ (year)

to _____ (month) _____ (year)

Start of filling water

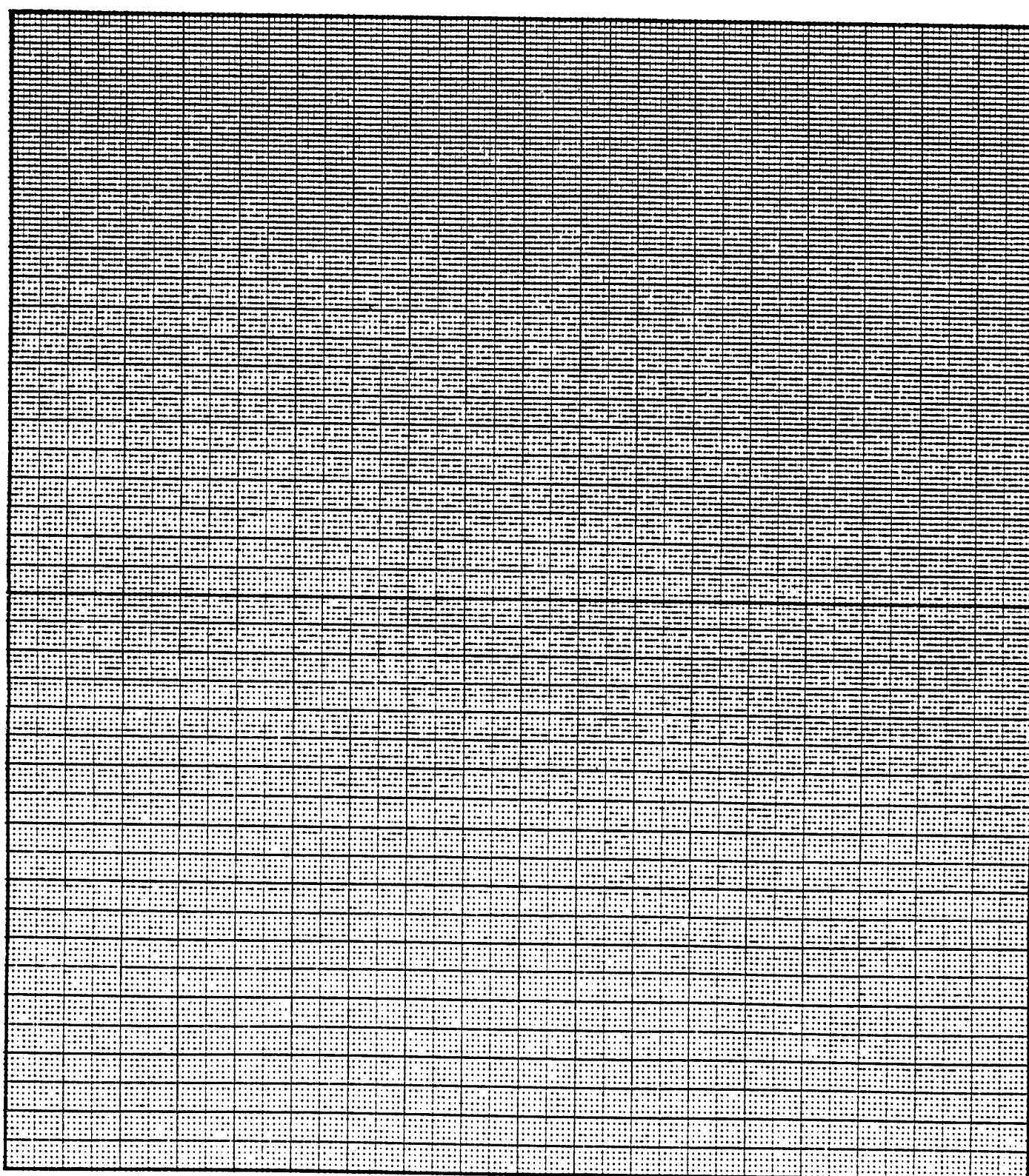
_____ (month) _____ (year)



Location of measuring point

Deformation in the direction of () (mm)

Deformation in the direction of () (mm)



Location of measuring point (m)

Uplift (Correlative to water level of reservoir)

Measurement form 1 (Uplift)

Name of dam: _____ dam

Measuring point: _____

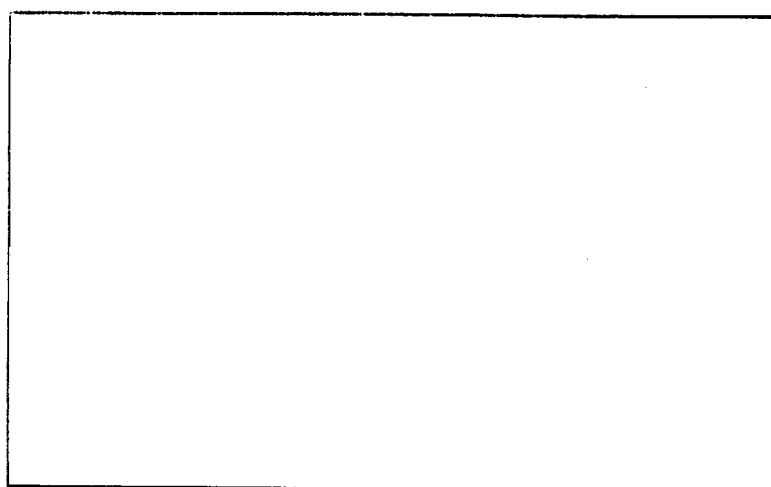
Period of measurement:

from _____ (month) _____ (year)

to _____ (month) _____ (year)

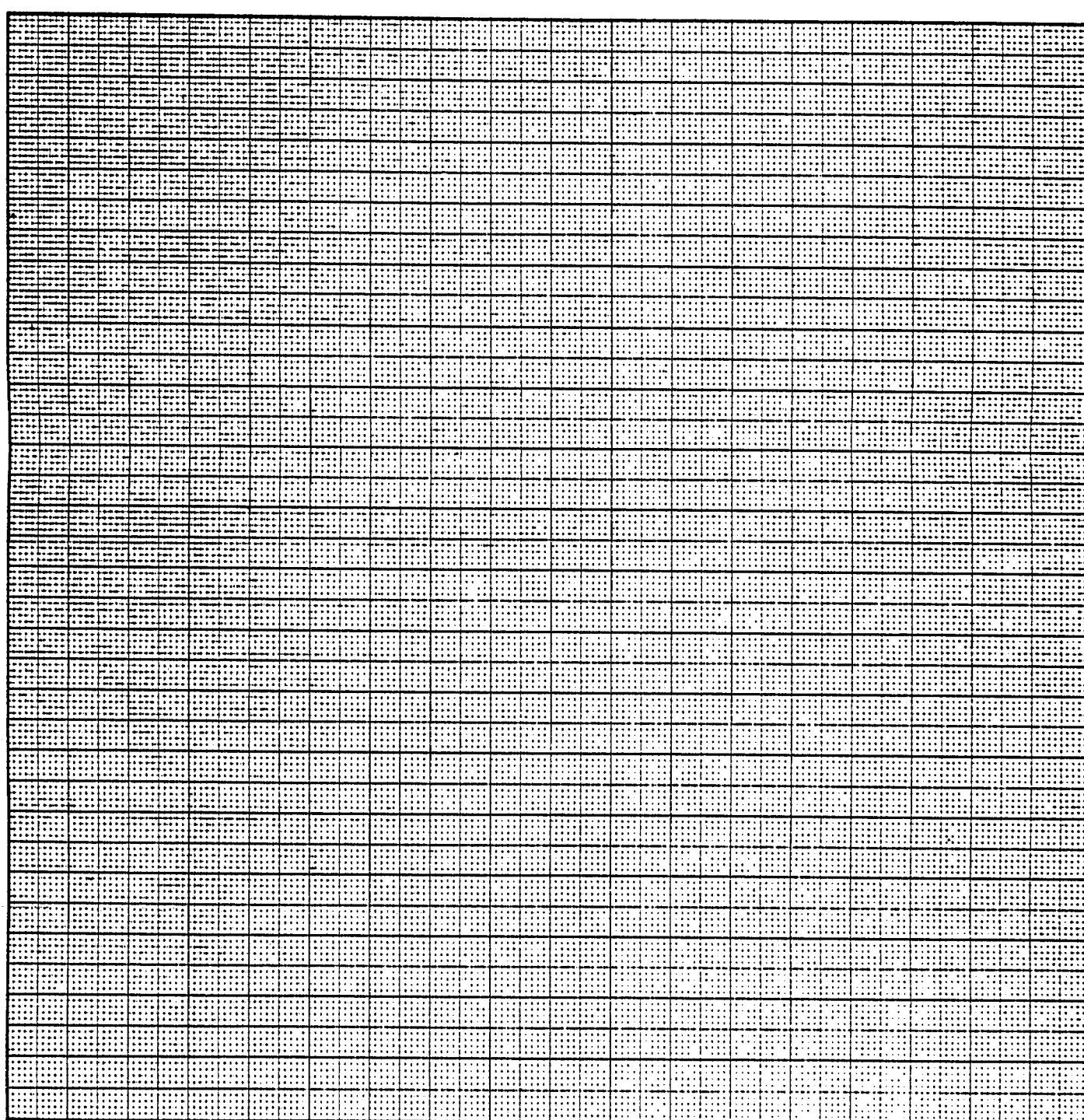
Start of filling water

_____ (month) _____ (year)



Location of measuring point

Water level of reservoir (m)



Uplift (Water head) (m)

- Notes)
1. Arrows should be put in the graph to show the time sequence.
 2. Date of measurement should be indicated in the graph periodically.
 3. The elevations of normal water level and the drain hole should be indicated clearly in the graph.

Uplift (Time sequence)

Measurement form 2 (Uplift)

Name of dam: _____ dam

Measuring point: _____

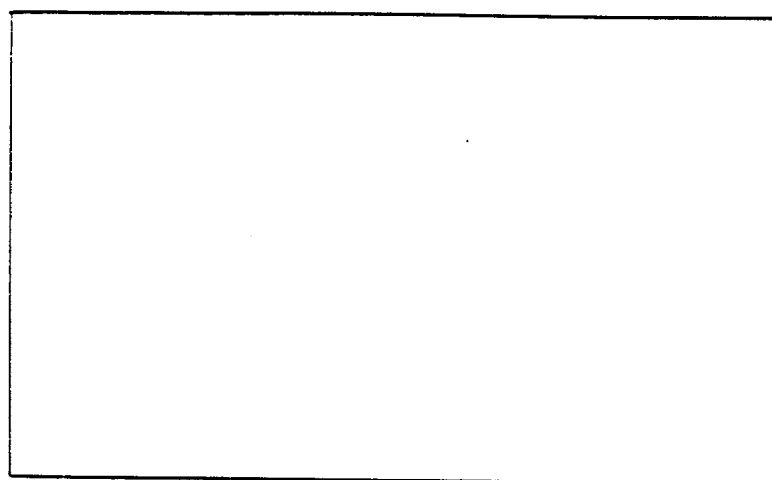
Period of measurement:

from _____ (month) _____ (year)

to _____ (month) _____ (year)

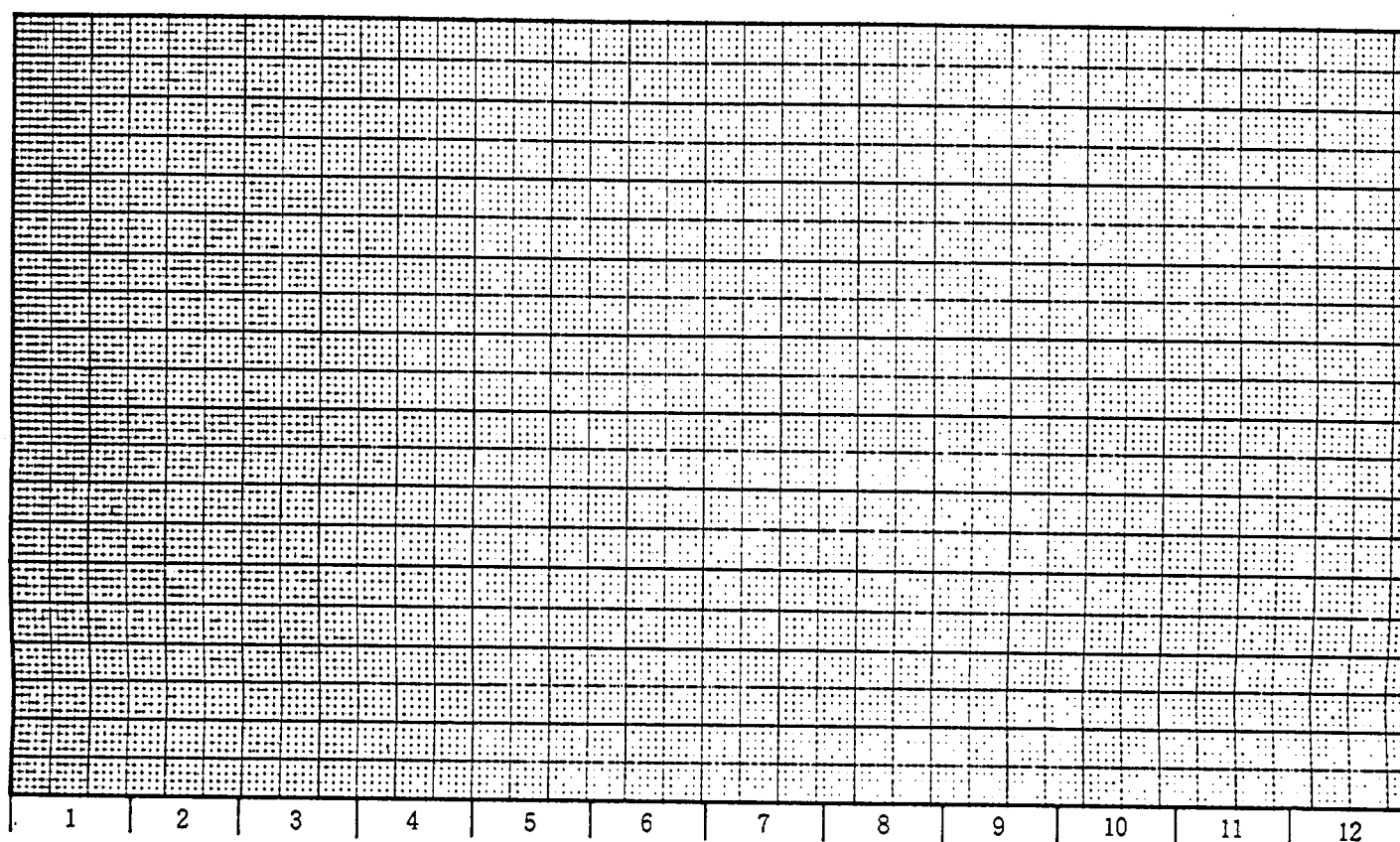
Start of filling water

_____ (month) _____ (year)

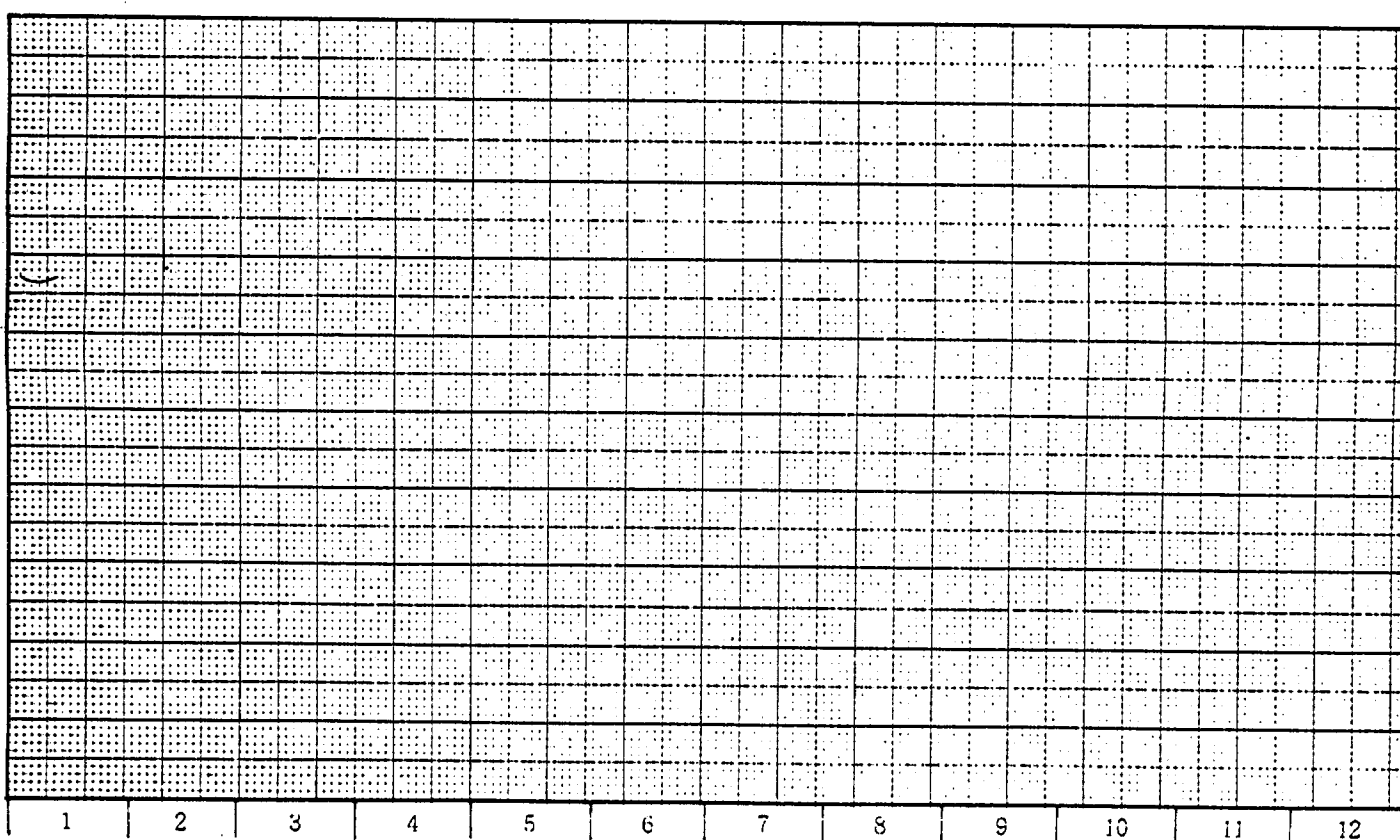


Location of measuring point

Water level of reservoir (m)



Uplift (water head) (m)



() Year

Note) The elevations of normal water level and measuring point should be indicated clearly in the graph.