DIKE ENGINEERING

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Preface

Some researches are already studied on dikes, and established consideration to many practical problems, but these are either insufficient or limited to special aspects. In this book, a clear explanation of fundamental principals of dike functions, dike boundary conditions, dike failure mechanisms, dike design, dike construction and dike management and maintenance are given. It is assumed that the designer has no prior knowledge of the subject, but has a good understanding of mechanisms and fluid dynamics.

The book has 9 chapters, and they are developed by Prof. Liu Hanlong (Chapter 1, 2, 3, 4 and 9) and Prof. Shu Yimin (Chapter 5, 7 and 8) from Hohai University of China, Prof. Zhao Zongji (Chapter 6) from North China Institute of Water Resource. All contents of this book are modified and unified by Prof. Liu Hanlong, and Prof. Jack Oostveen from Delft University of Technology.

The work presented in this book could not have been completed without the help and encouragement of many people. Deeply thanks to Professor J. K. Vrijling from Delft University of Technology, the Netherlands and Professor Suo Lisheng from Ministry of Water Resources, China, for their many valuable discussions and detailed comments on the book.

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December 1, 2003

Dr. Liu Hanlong
Professor of Civil Engineering
Geotechnical Institute (GeoHohai)
Hohai University
Nanjing, China

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1

Introduction

The alarming pictures of the disastrous flood of the Yangtze River and Songhuajiang River in the summer of 1998 recalled the last great flood of Yangtze River in 1917 and 1954. Not only were many lives lost but there was also considerable damage to property and to the land. A growing awareness arose that the safety of dikes along the major rivers left much to be desired. The awareness led to a decision to heighten and strengthen the river dikes.

A dike is an earth embankment constructed on the over bank along stream, lake or sea to protect land from being flooded by high stream flow or backwater or a storm surge. A typical dike is shown as Figure 1-1.

Figure 1. 1 A typical river dike

Dikes are amongst the world's oldest hydraulic engineering structures. The history of dike began many thousands years ago, which is proven by the remain founds in all centers of ancient culture, especially in China, Egypt and India. However, though the long history of this type of construction contributes to the progress in this particular field of civil engineering, neither modern scientific knowledge about soil mechanics, hydro-geology and hydrology, nor even experience in modern construction technology are taken sufficiently into account of designing dikes.

In the past, the design of dikes was mostly based on experience instead of generally accepted and validates calculation methods. The increased demand for reliable design methods for protective structures in China has resulted in an increased research in this field and, as a result, in the preparation of a set of design guidelines for the design and maintenance of dikes.

Flood disaster is one of the biggest and the most serious natural disasters in China. There are seven big basin systems in China, such as Yangtze River, Yellow River, and Pearl River, etc. At the middle-downstream and sea-along plain, about eight percent national surface area, forty percent population and thirty five percent national cultivated land, seventy percent national gross national products are distributed in this area. Here is also the most economic development and dense population distribution. Therefore, the dike engineering is the important part of flood defense systems in China. There are three characteristics for recent China dikes. The first is of poor condition for the base of dike, many dikes are constructed along rivers, so there is limit to choose the alignment of dike, many foundations are composed of sand and mostly have not been dealt with during construction. The second is of poor quality for the dike body. Many dikes, heighten and widen step by step with years, are constructed based on the old lower dikes, in which with poor quality. The last one is that there are many pools behind the dike, especially in the area of Yangtze River, Dongting Lake and Poyang Lake. Because, there is not enough dike fill material, the soil behind the dike was used up many years. Therefore, it is easy to result in the piping, slide, bank collapse, overtopping and dike damage when the flood comes.

The government has attached great importance to dike construction. By 1998, China has built 250, 000 km of dikes, of which about 65, 700 km dikes are located in the most important area for flood control. Due to some reasons, these dikes have many problems. It is estimated about 4300 km of dikes is in an urgent need of repairing. In the flood 1998, about 6100 dangerous cases happened in the middle and lower reaches of the Yangtze River. Therefore, the dike construction is a solution to flood control problems in China.

More attention should be paid following topics in future.

(1) The risk analysis and decision making system for dike safety assessment and dike strengthening planning, inclusive of the dike safety assessment standard, theory and methodology.

(2) The computer-aided decision making system for the comparative study of dike strengthening.

(3) Key technology development for seepage control and dike construction including the development of machinery for rock-fill dike construction, new structural type, materials and construction know-how of long-life pressure relief wells, strengthening dikes and protection slopes, and effect of the dike strengthening upon environment and its counter measures.

(4) The technology for dike breach repairing, inclusive of the optimization study of the base line of the breach gap, the threaded anchorage and other fast piling technology and equipment, the fast dumping of ripraps and comprehensive plugging methodology for dike breaches.

(5) Bank caving control technology.

(6) New technology for revetment of dike.

(7) Application of geosynthetics in dike engineering, such as reinforcement of slope stability, foundation improvement, revetment etc.

(8) Failure mechanism of dike under highest and lowest water level, the excitation of flood and rain infiltration.

(9) Detection and monitoring technology of hidden defects in dikes.

2

Function of Dikes

2.1 General

Dike is a structure constructed for an artificial watercourse. The main function of dikes is to protect the hinterland (population and economical values) against inundation due to flood and storm surges.

In the design of a dike, the requirements to be met can be formulated from several points of view. Obviously, the dike should offer the required extent of protection against flooding. Furthermore, it must be possible to manage and maintain the dike in a responsible manner. Except for this main function, there are some times secondary functions assigned. Those are transport, living, industry, agriculture, recreation, nature, cultural history and landscape etc. If one of these functions occurs, the user group or the manager has to define the objectives with regards to the main function and work out a comprehensive plan.

Transport. On the top of a dike often a road is planned (See Fig . 2. 1). Dike may require a maintenance road or a bicycle path. The functional demands for a top of road can be expressed for example as follows: Road suitable for safe transport of all vehicles up till x tones with an intensity of y vehicles per day. The engineer can express these demands in figures for width, stability, practicability and construction materials.

Living. It is near the water in high popular intensity at some economic development zones. Houses are being built near the riverfront or seafront. Construction of buildings on quays or along dikes, if it is in line with local regulations, so, will add

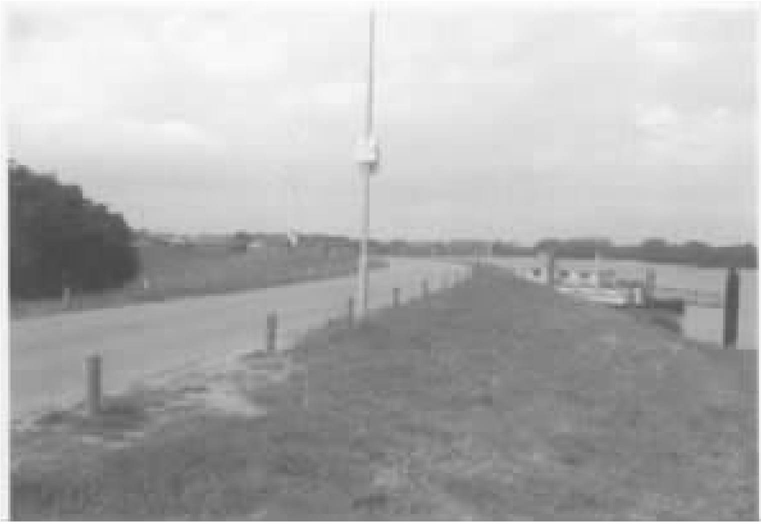

Figure 2.1 Function as transport

functional demands with regards to the stability, use of materials and the safe accessibility to the water (See Fig. 2.2).

Figure 2.2 Function as living

Agriculture. In agricultural, the practical use of dikes is pastureland and hay land. Functional demands of these are substrate for grass, practicable and safe for animals and accessible for agricultural machines. If properly managed, the agricultural use will enhance the quality of the dikes, and grass cover will reduce the erosion of the slopes.

Recreation. Various forms of recreation can be practiced on dikes and embankment, e. g. bathing, fishing, walking and cycling, surfing and boating (See Fig. 2. 3).

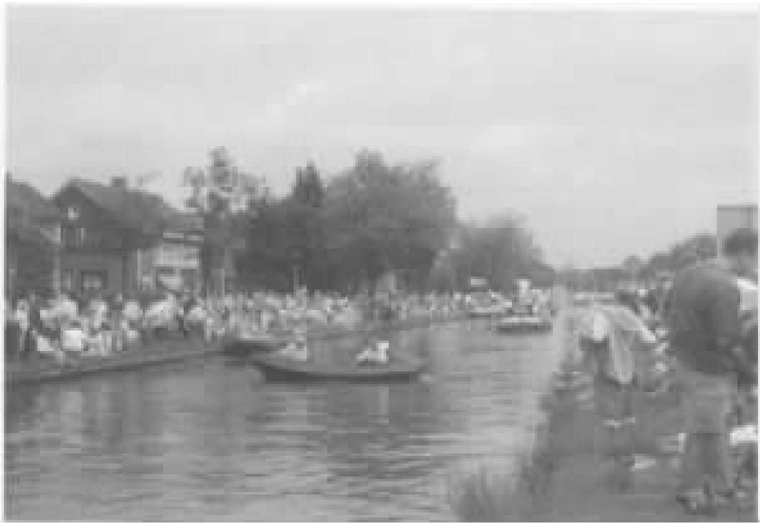

Figure 2. 3 Function as recreation

Each form of recreation has its particular demands for the design. For instance, bathing need safe access to the water, stimulation of sand sedimentation, comfortable surface to rest, shelter against wind and resistant to vandalism.

Based on these semands, the engineer may design alternatives with regards to the general construction with regard to the slope and with regard to the materials.

If fishing is the target, the functional demands for the bank of the canal could be safe access to deep water, accessibility of the embankment, place to sit and presence of vegetation.

Nature. The function nature in relation to banks has increasingly got attention in the world (See Fig. 2. 4). The various research projects are going on to improve the knowledge of the nature processes and development potentials, both for the banks of river. Much depends on local conditions such as the available space, hydraulic circumstance, water characteristics, water quality and presence of a foreland.

Landscape. It is related to the land use functions but not land use function by itself. It is an aspect that can be analyzed according to functional- and visual spatial criteria. A new construction should be in line with the functions of the surroundings. This can be realized such as by the choice of the materials.

If the dike crosses a salt marsh for example preference should be given to natural materials: wood or vegetated slopes. If the dike crosses an urban area, block construction would fit best in case of exist a visual relationship between dike and town.

Figure 2.4 Function as nature

Culture history. Dikes, for example at China river landscape have historical value. Their location, curves, construction materials, vegetation on dike, buildings along the dikes and other features related to the dike are elements of the history of China. So if renovation is planned these values should be taken into account.

In the above functions, the functions landscape, nature and cultural history play important roles in the dike reinforcement works, however, the functions of recreation and nature may conflict.

If for a particular part of a dike various functions are applicable, all these functions do have their own functional demands. Only in an ideal case these demands are complementary, mostly however one or several of demands are conflicting. Even if the compliance with the functional demands is equal for two designs, there may be a difference in costs. This means that, a good choice has to be made.

2.2 Type of dikes

Dikes can be broadly classified according to the type of lands protection (urban or agricultural), according to their use or purpose (mainline, tributary, ring, and setback dike, sub dikes, and spur dikes), or according to their method of construction (compacted, semi-compacted, and un-compacted). Classifications by use can be defined as follow:

Main dikes are dikes along a mainstream river, lake and sea and protect against flooding at highest water levels.

Auxiliary dikes are the extension of the mainline dike along the mouth of a tributary.

Setback dikes are built landward of existing dikes that are endangered by stream bank erosion or that have been breached.

Ring dikes are built to protect a single farm or house or hamlet from floods. They are of local importance only.

Sea dikes protect seaside area from flooding with storm surges and sea waves, due to the tides and sea winds.

City floodwalls are special dikes for keeping the safety of city facilities from flooding.

Sub dikes are for the purpose of under seepage control. They encircle an area behind a mainline dike that is subject to high uplift pressure and possibly sand boils during high stages. They are rarely used except in emergencies because the problem can be better solved by relief wells or seepage berms.

3

Boundary Conditions

3.1 General

For dike design, the following content should be taken into consideration as boundary conditions. Those are hydraulic boundary conditions, geotechnical boundary conditions, social, economic and environment, location conditions and other load conditions.

It is clear that the boundary conditions for dikes follow mainly from water levels. In general, these are called the natural boundary conditions, important for the construction of a dike are:

—the maximum water levels and the height of waves;

—the magnitude of the water level difference between the inner side and the outside of the dike;

—the magnitude of the water level difference along the dike, like current;

—the time between higher and lower water;

—the number of times that this water level difference occurs during the lifetime of the construction;

—the rising and falling of the water, in how much time the water-level rise from normal to extreme.

A lot of relevant information at water levels can be drawn from files and existing maps.

In view of the function of water defenses, the load will obviously be mostly due to the actions of long and/or short waves. In broad outline the following wave phenomena can be distinguished:

—low frequency water level changes, such as flood waves, tidal waves, and wind set-up gradients;

—wind waves and swell;

—ship's waves in navigable waterways.

In addition to this, a field reconnaissance and a land survey are indispensable, as well as photographic recording of the characteristic points in the area. The composition of the existing dike body and geologic structure of the subsoil are also very important. When these data are not available the soil mechanical investigation should be considered.

The quality of subsoil, important for the geotechnical stability and settlement, is also called a boundary condition. The most important geological aspects are:

—geological stratification, formation and history;

—ground water regime;

—seismicity.

The main questions which geotechnical investigation has to answer are:

—what kind of soil is found and at what depth, i. e. soft soils such as sand, clay and peat or hard soils such as limestone and calcareous sandstone, or very hard soils such as quartzite and basalt;

—what are the mechanical properties of the various soils with respect to their strength and deformation characteristics;

—is the soil fissured or weathered;

—will the soil degrade in time by weathering.

The first step is to organize and design the site investigation. The field program as part of site investigation is complemented by the laboratory testing and geotechnical calculations. The last and perhaps the most difficult step is the integration of the result of the investigations and structural design, resulting in the final foundation. At the set-up and organization of soil investigation program, the geotechnical engineers is confronted with the following questions:

—which soil data have to be collected;

—at which locations (number and depths);

—which site-investigation techniques and laboratory tests should be performed;

—when is the program to be carried out, and

—who will take care of the contracting work in the field, laboratory test and the interpretation of the results.

The answer to these questions will depend on, for example:

—the boundary conditions stipulated by the client (time and money schedule);

—the knowledge, judgement and experience of the geotechnical engineer;

—the availability of existing data, for instance topographical, geological and geotechnical maps;

—the phase of design: for a preliminary design only general information about a wide area is needed to recognize the main geotechnical problems; in the final design phase or during the construction period, detailed information on engineering soil parameters is needed;

—the type of geotechnical failure mechanism involved;

—the availability and restrictions (including the terrain accessibility) of the investigation tools and the quality of personnel to handle these tools.

3.2 Hydraulic boundary conditions

Water level on a river is determined by the river's discharge regime and, in addition, for the lower reaches by tides and also wind set-up.

Design water level. The water level, occurring during the so-called determinant discharge at one river is applied as the design starting point for dikes in the upper river area. The water level in summer and winter beds for steady flow conditions are determined by means of a computer model for two-dimensional flow based on the determinant discharge and on certain established river levels on the lower border of upper river area.

The peak of the discharge wave is, smoother as a consequence of the unsteady character of the discharge, examined separately. The computed water levels at a steady discharge rate are adjusted to the results of this examination.

The actually occurring water levels can be higher as well as lower due to uncertainties in the employed computer model, or in the input data especially regarding the hydraulic roughness of the riverbed and the discharge distribution at the branching points.

When determining the design water levels, no account is taken for raising of the water in case of the presence of a solid ice cover or by ice embankment. In the past, these used to be important causes of high river levels but, due to improvement regarding the riverbed, probability of the development of a solid ice cover or of ice embankment in river seems to have diminished considerably. It is recommended that the design water levels should be recorded per hectometer post.

Extreme water levels. For sea and river it is relevant not to determine the once in N-years water level, but the once in N-years discharge of the river. This makes the hydraulic computations much more simple. In the Netherlands, for the Rhine River the design flood has a probability of 1:1250 per year. For the Rhine River this is a discharge of 15,000m^3/sec (Boertien, 1993).

Using the discharges at the places, one may calculate the water level along the river. One should of course take into account the effects of bifurcations, barrages, weirs, etc. The general water level and discharge pattern is calculated using a one-dimensional computer model with many branches, the detail water level is conducted with the use of a two-dimensional computer model. The accuracy of these models is in