ERDC/GSL SR-09-2

Geotechnical and Structures Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Classification Systems for Earthen Levees: A Worldwide Review

Lillian D. Wakeley and Joseph B. Dunbar

February 2009

ERDC/GSL SR-09-2
February 2009

Classification Systems for Earthen Levees: A Worldwide Review

Lillian D. Wakeley and Joseph B. Dunbar

Geotechnical and Structures Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

Prepared for U.S. Department of Homeland Security
Washington, DC 20528

Abstract: Most nations of the world rely on levees in complex flood-control systems to protect hundreds of billions of dollars' worth of homes and businesses, and the lives of uncounted millions of people. With continuing urban growth and economic development, flood-control systems have been expanded and modified repeatedly to protect changing assets. The safety and reliability of a flood-control system depends on the condition of each individually built component. Yet there is no shared or standard system in the United States, and certainly not worldwide, for defining levee-management reaches, assessing levee condition, or predicting performance.

A unified system of levee classification should be based on best current practices. This report summarizes levee classification systems in use in the United States, in the European Union, and in Japan. A review of these systems revealed three approaches to levee classification. Approach 1 defines levee-management segments based on geographic location. This type of classification system allows easy identification of each entity of the system under discussion, but provides minimal additional information. Approach 2 defines segments or reaches based on some aspect of condition or materials. This type of classification system identifies the geographic location for each reach and also provides useful information about fixed properties, which either do not change or change slowly relative to a human timescale. In Approach 3, segments are defined dynamically for a particular time frame by some parameter of vulnerability that incorporates risk. The geographic identifier of a reach remains constant while its condition-related or risk classification changes as physical conditions change with time. A dynamic classification system is a powerful levee management tool, with space and time integrated into a predictive system.

Contents

Figures

Figures

Preface

This report documents a review of the classification systems used to define segments of earthen levees in the United States, the European Union, and Japan. Some systems also define levee condition or establish library systems for maintaining levee data. In addition, the report presents three approaches to levee classification identified by the authors.

The work was performed for the U.S. Department of Homeland Security (DHS) Critical Infrastructure Vulnerability Analysis and Mitigation Program. Program Manager for DHS was Wil Laska. Dr. Michael K. Sharp, Technical Director for Water Resources Infrastructure, Geotechnical and Structures Laboratory (GSL), U.S. Army Engineer Research and Development Center (ERDC), provided liaison between the ERDC and DHS. Joseph B. Dunbar, Research Geologist, Geosciences and Structures Division (GSD), GSL, was Work Package Manager for Rapid Levee Assessment, the project within which this work was performed.

Dr. Lillian D. Wakeley, Research Geologist, Engineering Materials and Systems Division (ESMD), GSL, identified and reviewed the classification systems and defined the three approaches to classification. Dr. Wakeley and Dunbar prepared this report.

The project was completed under the direct supervision of Dr. Larry N. Lynch, Chief, ESMD; Dr. Monte L. Pearson, Chief, Geotechnical Engineering and Geosciences Branch, GSD; Dr. Robert L. Hall, Chief, GSD; Dr. William P. Grogan, Deputy Director, GSL; and Dr. David W. Pittman, Director, GSL.

COL Gary E. Johnston was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

Unit Conversion Factors

Multiply	By	To Obtain
feet	0.3048	meters
miles (U.S. statute)	1,609.347	meters

1 Levees in a Complex Flood-Control System

Background

Flood-control systems consist of earthen levees plus several other types of structures such as dikes, walls, canals, drains, and spillways built over time to restrain and store floodwaters, or direct floodwaters away from occupied or other protected areas. The total system may include hundreds of linear miles of levees, making it difficult to define the geographic extent of a particular levee (usually actually a levee reach or segment) under discussion. This document focuses on earthen levees as the structure type representing most of the system.

A levee classification system is a tool or model to divide levees into manageable segments or reaches. The classification system becomes more useful if it also includes information about the materials, performance, or condition of the levee. Levees are constructed where they are needed, and not necessarily on a foundation that is ideal for a structure that must impound water. Because a given segment of levee is a fairly simple, low structure that will be dry most of the time, it is unusual for the foundations of levee systems to be subjected to focused geotechnical investigations and ground improvement prior to construction. Components of a system may cross many poorly characterized or unknown zones of weakness in the subsurface, and the vulnerable locations along a levee system may not be visible at the surface from traditional visual inspection methods.

With continuing urban growth and economic development, flood-control systems have been expanded and modified repeatedly to protect changing assets. The various segments or reaches of a flood-control system commonly are built to different standards, as requirements and the state-of-practice change over time. The ability of the complex system to perform its function is determined by the performance of its weakest component, which may be a single levee reach only tens of meters long. So when someone says “the levee failed,” he means that one limited reach of a levee system failed.

Purpose of this study

In the United States, no standardized methods exist for defining levee-management reaches, assessing levee condition, or predicting performance. The combination of different components, materials, foundations, standards, and changes over time creates a situation in which it is difficult to classify the levees of a flood-control system into meaningful units relative to their condition and vulnerability. This report offers three approaches to levee classification derived from study of existing systems and describes several levee classification systems currently in use.

Large current efforts in the United States focus on compiling a national inventory of levee data and on classification and characterization of specific levee systems of limited geographic extent in urbanized regions. The U.S. Department of Homeland Security (DHS) supports the concept of a unified system to improve and streamline condition assessment of levees, for which a classification system is a necessary prelude. Knowledge of current practices and systems of levee classification worldwide is useful input to development of a new or widely applied system.

Systems for classification of levee segments in use in the United States, Europe, and Japan were reviewed for this project. From that review, three approaches to classification were identified, as described in the following section.

Types of classification systems

The first component of a levee classification system is division of miles or kilometers of levees into geographically identifiable segments, using logical and easily explicable criteria. Ideally, the system should go beyond mere cataloging to include information about the condition of each segment or reach, and its level of vulnerability. The following paragraphs explain the three approaches to levee classification that resulted from this study, described in the order of increasing complexity.

Approach 1

This approach defines levee-management segments based on geographic location. This type of classification system is similar to numbering power poles in an electrical grid. It allows easy identification of each entity of the system under discussion, but provides no additional information.

Management segments may be arbitrary lengths of levee, or reaches defined by adjacent property ownership. Some levee libraries define units according to projects as understood by the levee-owning organization, conveying only limited meaning to a broader interest group. Ownership-based systems and arbitrary lengths generally have seams and discontinuities, both on the ground and in databases. A structure that appears to an outsider to be one levee many miles long may host invisible material boundaries, jurisdictional boundaries, and incompatible classification changes over its length. Accommodating pre-existing, inconsistently identified, arbitrary-length reaches can complicate a system-wide flood- or risk-management plan.

Approach 2

This approach defines segments or reaches based on some aspect of condition or materials. This type of classification system identifies the geographic location for each reach and also provides useful information about fixed properties, which either do not change or change slowly relative to a human timescale. Some examples of fixed properties are material used to construct a particular segment of levee; levee height at geospatially known locations; type of structure (e.g., earthen levee with a certain ratio of slope and height, T-wall or I-wall); or type of investment protected by the reach (farmland versus urban). Most of the classification systems described in this document are of this type. As long as the classification is supported by digital georeferenced data, this type of classification system provides excellent input into regional or system-wide plans.

Approach 3

This approach defines segments dynamically for a particular time frame by some parameter of vulnerability that incorporates risk. Although the geographic identifier of the reach would remain constant, its condition-related or risk classification would change as physical conditions change with time. That is, after segments are defined geographically, a dynamic classification system is applied to individual segments and is reviewed periodically to determine changes to levee condition, land use, or flood hazard.

Dynamic classifiers may represent a wide range of timescales for change. For example, as the projected maximum water level increases during a flood flight, the risk classifier for particular reaches would increase for the short term: water up, risk up. On an intermediate timescale, a levee reach may be eroded or its height found to be lower than expected, increasing the flood risk for certain reaches: levee height lower, risk up.

On a longer timescale, new components may be added to a flood-protection system, or new information may become available about negative and visually obscured aspects of levee condition, indicating increased vulnerability to levee failure. Demographic changes may increase the value of assets and number of people at risk if certain reaches fail. Many types of changes could cause the condition-related classifier to change in such a system. But the dynamic classification system would provide powerful levee management, with space and time integrated into a predictive tool (Yuan 2008).

2 Examples of Levee Classification Systems in the United States

The U.S. Army Engineer Research and Development Center (ERDC), in conjunction with DHS, has recognized the need to develop a uniform system of classification for levees that assigns a management identity to each levee segment while providing useful information about the condition or expected performance-impacting characteristics of the segment. The following sections describe recent and current research conducted by the U.S. Army Corps of Engineers (USACE) and the State of California to develop widely applicable levee classification systems.

Classification and condition assessment for the International Boundary and Water Commission

In recent work for the International Boundary and Water Commission (IBWC), ERDC developed a levee classification system that divided levees into segments that were then ranked to indicate the segments' condition, to indicate those most in need of attention. Early in the IBWC work, the ERDC team considered segmenting levee reaches using geographic locations and uniform lengths, such as equal thousands of feet per segment. After ERDC acquired data for levee and foundation soils via airborne electromagnetic (EM) signatures, a new classification opportunity emerged. The EM data were processed in a color-coding system showing electrical conductivity, which corresponds approximately to soil type. The first component of the classification system for IBWC levees was definition of levee segments of varying length based on uniformity of EM conductivity. Segments were numbered sequentially on U.S. Geological Survey topographic quadrangle base maps and layered into a geographic information system (GIS) (Dunbar et al. 2003). Figure 1 shows an example of the levees in one quadrangle divided into reaches according to uniformity of EM conductivity.

Over a period of days to weeks, EM conductivity is not a fixed property. The EM signature changes as the soil moisture changes in response to rainfall or a flood event during which levee soils change from a dry to a saturated condition. However, EM surveys for the IBWC were conducted

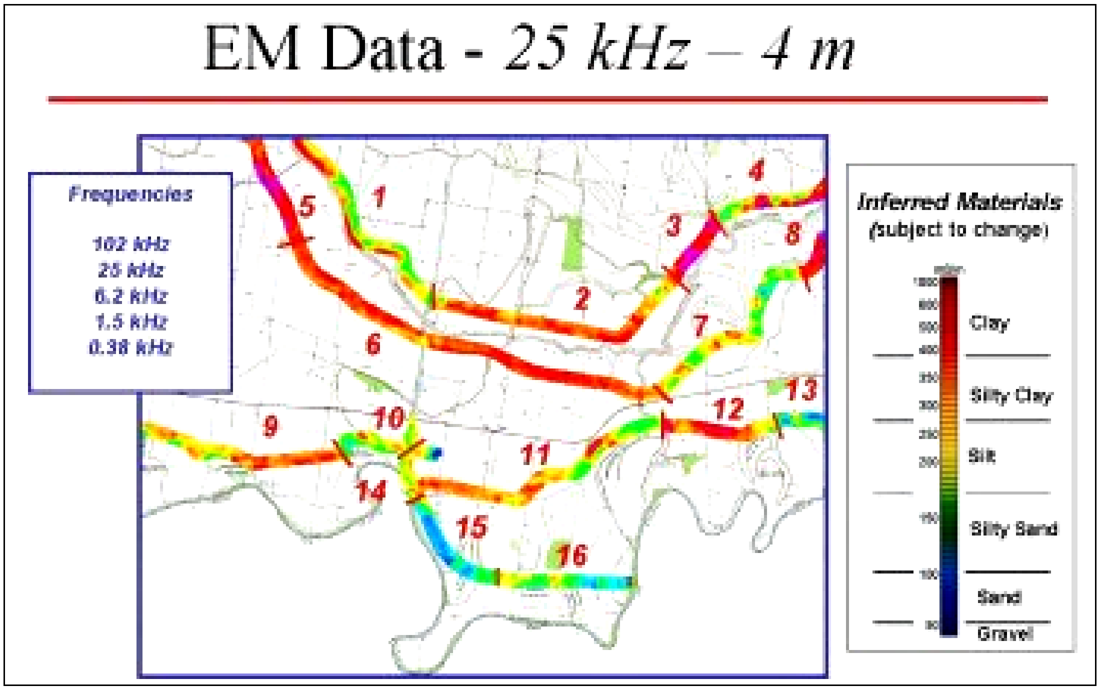

Figure 1. IBWC levees in one quadrangle divided into numbered reaches by material type at a depth of 4 m below the crest of the levee as inferred from EM conductivity at 25 kHz (Dunbar et al. 2003).

while the levees were in a dry condition (no water impounded), and the entire system was surveyed within a few days. This rapid survey of dry levees gave the closest possible indication of material types without the complexity of flood conditions. The dry-baseline data also provide a basis for change detection during a flood flight. The actual classification of the levee system into management reaches was based on empirical data, in this case, EM conductivity with ground verification of signatures.

Once levee reaches were defined and numbered, the team identified and quantified those factors that influence the stability and performance of IBWC levees. Segment condition was determined according to several classification parameters and related data sets, including levee height by a remote-sensing system using LiDAR (light detection and ranging) and geologic information taken from historical and recent imagery, plus ten quantifiable criteria. See Appendix A for a list of factors used to index levee condition and generate a numerical expression of the scores for each reach based on the ten factors identified as critical to levee performance.

The numeric condition-index score was intended to allow IBWC managers to target limited annual funding to repair and upgrade segments that were susceptible to poor performance. Dunbar et al. (2003) and Dunbar and Llopis (2005) describe the process of identifying and ranking levee reaches for two geographic regions within the IBWC jurisdiction.

National Levee Inventory Program

In 2006, the USACE initiated a project to survey all Federal levees under its responsibility and develop “a database model” that includes “all necessary attributes of levees/floodwalls relevant to design, construction, operations, maintenance, repair, inspections, and potential for failure” (Pangburn 2008). The database developed by USACE, and now being populated, has nationwide shared standards for georeferenced data collection and formatting, to ensure “commonality of levee data with other agencies.”

The national inventory effort uses pre-existing segment definitions and georeferences and collates massive amounts of fixed data into a comprehensive management system. The basis for classification is pre-existing segment names, already in use in USACE districts, based on project authorization, levee district, or geographic entity. Segment lengths range from a small fraction of a mile to 15 miles or more. In some districts, levee segments have names such as “East Bottoms Unit” and “North Kansas City Lower Unit.” Other districts have named segments according to local flood protection projects (LFPP), such as “Covington LFPP” or “Jefferson-Clarksville LFPP.” Fixed data include segment length, corresponding river mile (location), construction dates, number of acres protected, design flood frequency, and other quantifiable entities. Certain data fields for all segments are updated as new data are available, such as the date of and information from the most recent levee inspection. The model does not define segments on the basis of geotechnical properties, but instead tracks properties for segments defined on the basis of levee-construction projects.

Figure 2 shows an aerial view of typical mainline levees in the central United States, indicating some of the many categories of geospatial features included in the National Levee Database.

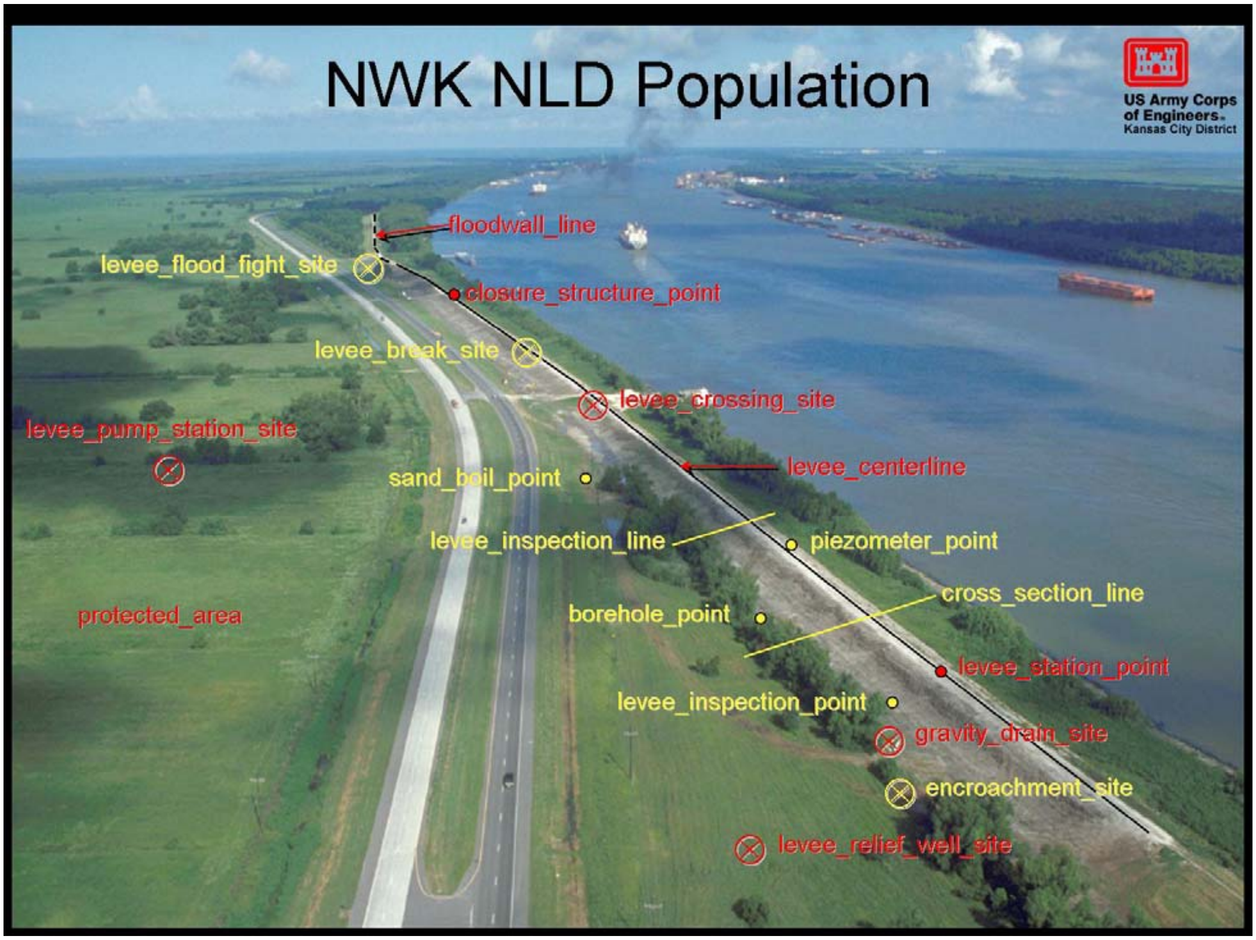

Figure 2. Example geospatial features from the National Levee Database (NLD) (Pangburn 2008). NWK is U.S. Army Engineer District, Kansas City.

Urban Levee Geotechnical Evaluations Program

The California Department of Water Resources (CA DWR) has the responsibility to develop "a comprehensive program of levee evaluation and upgrades" called the Urban Levee Geotechnical Evaluations Program. About 350 miles of levee in the densely populated urban centers in great Sacramento, Stockton/Lathrop, and Marysville/Yuba City are referred to as "Urban Project Levees." The urban levee project requires CA DWR to "evaluate the geotechnical conditions of these levees with regard to seepage, stability, seismic stability and erosion" (URS Corp. 2007). The evaluation process begins with data such as existing subsurface information, levee performance records, and site-specific geology in its geomorphologic context. The project also requires geophysical investigations, drilling, GIS development, and has many other elements in common with the ERDC IBWC effort.

The urban levee program addresses the issue of classifying levees into management segments by a process called "reach selection," the aim of which is "to divide the levee alignment into a minimum number of reaches with similar geometric and geotechnical characteristics" (URS Corp. 2007). Initial definition of reaches is based on geometry and subsurface stratigraphy. Reach definitions then are refined iteratively as the assessment team obtains more data about levee geometry, stratigraphy, historical performance, and geotechnical and geologic properties of the levee foundation. The objective is to define management segments, each of which has consistent geotechnical characteristics and geometry. Each reach then has certain shared characteristics throughout, to minimize the number of major changes in condition within a given management segment. An initially defined reach may be subdivided into multiple reaches if there is any major change in conditions, such as installation of a slurry wall or berm, or if additional study reveals inhomogeneities that are likely to require individually focused management.

The program's Guidance Document (URS Corp. 2007) describes the process of defining, refining, and finalizing levee reaches, in addition to the theory and implementation of analyses of seepage, slope-stability, and seismic hazard required for each reach within the full evaluation program.

Predictive model for the middle Mississippi

A 2004 ERDC study addressed prediction of seepage under mainline Mississippi River levees along the Missouri-Illinois border (Glynn and Kuszmaul 2004). The focus of this study was the critical hydraulic gradient that exists under a levee when uplift pressure of water in pervious layers exceeds the resisting forces of the soils above the pervious layer on the landward side (as explained by Terzaghi and Peck 1967). This critical hydraulic gradient determines where underseepage threatens levee integrity versus where underseepage is contained by the topstratum and associated geotechnical properties of the system. Because of the inhomogeneities of levee foundations and soils, a levee system will have many critical gradients at many locations.

Glynn and Kuszmaul (2004) recognized the need to compute critical gradients for shorter lengths or reaches of a levee, as a critical input to their model that assigns a value relative to the potential for underseepage and piping within a given reach. The basis of their classification system was geology and topstratum thickness for each 250-ft segment of levee, each of which was assessed for empirical evidence of piping. Thus, their classification system began by defining reaches according to arbitrary lengths, and then incorporated empirical geotechnical data for each reach.

3 Major Classification Systems in Europe

Several groups in the United Kingdom (UK) and in the European Union (EU) have undertaken major research programs focused on improving the performance of flood defenses. Some of these efforts included the development of levee classification systems. European efforts included here are the Risk Assessment of Flood and Coastal Defence Systems for Strategic Planning in the UK; the Modeling and Decision Support Framework, also in the UK; Investigation of Extreme Flood Processes and Uncertainty, known as IMPACT, which involves 10 countries in Europe; and the Integrated Flood Risk Analysis and Management Methodologies, known as FLOODsite, an EU research initiative that continues through 2009. Web sites for each of these entities can be located using any common Web browser.

Risk Assessment of Flood and Coastal Defence Systems for Strategic Planning (RASP)

The purpose of RASP was to develop and demonstrate methods for dealing holistically with systems of flood defenses in the UK, recognizing that flood risk cannot be reduced significantly if single flood-protection structures are considered as isolated entities. Because of the island geography of the UK, the system is large but its boundaries are well defined. This clarity of system definition contributes to the applicability of a holistic approach to the UK flood-defense system.

RASP uses multiple tiers to tailor the level of analysis to the importance of a decision and its sensitivity to uncertainty. That is, once system segments are defined, the effort and funds expended to gather and analyze data for any segment are based on risk, not just risk to the physical levee but also risk of resultant damage (RASP 2004). Intense analyses and modeling—the “detailed” level of RASP—are applied to the critical components of the system. Recognizing that the highest risk levee may not be the one most likely to fail, the RASP approach allows levee-system managers to focus on reducing uncertainty where it is possible and important to do so (Sayers 2007).

The first parameter used to define segments or reaches in the RASP system is construction type, for example, whether the segment is a levee or a floodwall. Next, lengths of like construction are segmented by changes in height. Segments of like construction type and consistent height then are divided into reaches with a maximum length of 300 m. This third delimiter is based on the geotechnical assumption that similarity of foundation and materials can be assumed for a distance of no more than 150 m in each direction from a borehole (Sayers 2007).

Once segments have been defined by a combination of fixed properties and arbitrary lengths, each segment or group of segments can be analyzed at the appropriate level in the three-tiered RASP system. Outputs may include estimates of flood risk associated with failure of one or a group of segments, flood-risk estimates for critical zones of the flood plain, and ranking of the contribution of each component to total risk (RASP 2004).

Modeling and Decision Support Framework (MDSF)

The MDSF is the Modelling and Decision Support Framework developed by HR Wallingford, Halcrow, CEH Wallingford and others for the Environment Agency and the Department for Environment, Food and Rural Affairs (DEFRA) of the UK. MDSF is a tool to be used by the Environment Agency and consultant staff in the development of Catchment Flood Management Plans and other flood studies.

MDSF consists of a set of procedures accessed through GIS-based software. The MDSF Web site provides a forum for distribution of information, documentation, upgrades, and user support for the MDSF software and the procedures. MDSF and RASP are closely related and were developed jointly. MDSF uses the levee classification system established via the RASP process as input to a standard GIS platform for visualization and decision support (RASP 2004).

Investigation of Extreme Flood Processes and Uncertainty (IMPACT)

IMPACT is a consortium of 11 research entities in 10 countries in Europe, working to reduce uncertainty in predicting extreme flood conditions. Specific objectives are to advance scientific knowledge and understanding and to develop predictive modeling tools in four critical areas: flood-related movement of (potentially polluted) sediments, the mechanisms and locations of embankment breaching, simulation of catastrophic inundation of urban areas, and the use of geophysical techniques for the rapid assessment of embankments. A key objective of the IMPACT project was to advance the understanding of uncertainty associated with each research focus area.

Of the four IMPACT focus areas, the focus on mechanisms and locations of breaching has the greatest need to define a method of classifying levee reaches (IMPACT Work Package 2.4, Identifying Potential Breach Locations). Much of the breaching work centers on breaching of fixed-length embankments, such as small dams, and does not address the need to classify reaches of an extensive levee system (Vaskinn et al. 2008).

One technical report from Germany (Broich 2005) describes a study that combined empirical data with a modeling effort to predict levee-breach locations. In this study, flow regimes were determined for locations of actual breaches that occurred during a flood in Germany in 1999. From these data, the researchers calculated shear stress at both the crest and the toes of the embankment, and delineated the combination of shear stress values that best fit real levee failures. They classified the levees into reaches based on the critical combination of shear stresses. Their resulting predictive method was correct for 7 of 10 levee-failure incidents.

Another technical report (IMPACT 2004) builds on the RASP multi-tier approach combined with work in the Netherlands (Buijs et al. 2003) and describes an extensive modeling effort. Essential early steps in their model include selecting cross sections, dividing the flood-protection system into "defence types," and defining "embankment stretches" comparable to the levee reaches defined in other systems. The following section is paraphrased from IMPACT (2004, pp 6–7):

> The division (into embankment reaches) is based on external physical characteristics and not on characteristics directly connected to failure modes, although implicitly the connections are there. The following characteristics are important for this selection:
>
> - Orientation to the wind directions: embankment stretches that are orientated differently will be loaded by different wave regimes and therefore must be discerned as different embankment stretches.

- High water regimes, differences in extreme water levels: lengths of the water defence system for which different high water regimes are relevant must be discerned as separate embankment stretches.
- Geometrical characteristics foreshore: Embankment stretches with significantly different sizes of the foreshore in terms of height and width.
- External geometry of the water defence: lengths of the water defence system with significant differences in height and (external) construction are discerned as different embankment stretches. Differences in geometry will lead to differences in loading conditions due to the hydraulic boundary conditions.

After the system has been divided into reaches with roughly the same type of characteristics, cross sections have to be defined such that they can be regarded as representing the total embankment stretch. If there are still significant differences between cross sections in an embankment stretch, the stretches need to be divided further into flood defence sections. The following considerations related to failure mode can form a basis for a division in embankment sections:

- Different types of outside slope revetment (types and construction). This will lead to a further division for the failure mode, namely damage of the revetment on the outside slope versus erosion of the embankment body.
- Differences in geometry on a detailed level have consequences for each of the failure modes.
- Differences in the foundation soil can have a considerable effect on the contributions to the probability of failure of geotechnical failure modes. For these failure modes a further division has to be made.
- Differences in the inside slope revetment of embankments (quality of the grass, thickness and qualification of the clay cover layer on the inside slope, the angle of the inside slope, etc.). This kind of information is especially useful for reaches expected to fail by

overtopping and consequent erosion of the inside slope.
- Information about the construction of the embankment (clay embankment, sand embankment with a clay core, etc.) and information about the soil layers underneath and directly next to the embankment (foundation soils and topstratum). This information is relevant to failure by piping and erosion of the embankment body.

The IMPACT study continues with an explanation of fragility curves in risk assessment, an issue also discussed by a Research Project Leader for HR Wallingford, Ltd. (Sayers 2007). Other than the concern about wind direction and wave regimes, which is more a coastal than a fluvial concern, this IMPACT approach for understanding contributors to levee condition is similar to the IBWC approach taken by Dunbar et al. (2003) and to the urban levee-assessment program in California (URS Corp. 2007).

Integrated flood risk analysis and management methodologies (FLOODsite)

FLOODsite is an undertaking of the European Union to provide an EU framework for holistic flood risk management, co-funded by the European Community in its Global Change and Eco-systems Sub-priority. The following statement of the purpose and scope of FLOODsite is taken from Samuels (2008):

> The FLOODsite Integrated Project has been designed to produce improved understanding of specific flood processes and mechanisms and to develop integrated methodologies for flood risk analysis and management ranging from the high level management of risk at a river-basin, estuary and coastal process cell scale down to the detailed assessment in specific areas. The project will deliver
>
> - An integrated, European, methodology for flood risk analysis and management.
> - Consistency of approach to the causes, impacts and control of flooding

- Techniques and knowledge to support integrated flood risk analysis and management in practice
- Dissemination of this knowledge including the development of training media
- Networking and integration with other EC national and international research.

As of August 2008, the FLOODsite Web site has links to 57 project reports, more than 40 journal articles, 66 tech notes, and many other products, several of which address or describe levee classification systems.

Allsop et al. (2007) describe the process of classifying the flood-protection system into reaches such that the failure mode of each reach can be analyzed. The following is paraphrased from this report (Allsop et al. 2007, pp 3–6):

> The division into stretches with very similar characteristics is the first step towards a more detailed schematization of the defence system. Similar characteristics are, e.g., its orientation to the wind directions, a particular kind of defence type or the use of a certain type of revetment. Within each category of structure types, there are many potential sub-divisions, often by principal material. The more detailed stretches can be as small as required for detailed calculations. Order of magnitude of the lengths can vary from 50 to 300 m. The characteristics of one cross section are taken to be representative for one stretch. Neighbouring cross sections often share similar characteristics and are therefore more likely to fail simultaneously.

Various studies within the FLOODsite program confirmed the need for better ways to include transitions between reaches with differing properties and to track levee condition relative to time-dependent processes. The FLOODsite program supports the need for a dynamic classification system.

4 Classification System in Japan

As is true in the UK, the network of flood-control structures in Japan lends itself to holistic classification because the system boundaries are well defined. In the early 1990s, the Government of Japan began the process of assessing levee condition nationwide. Their national levee database was built as a repository for all existing data that could contribute to a better understanding of the condition of a given levee reach. The source of the following information is an internal report of the Japanese Ministry of Construction, Flood Control Department, dated October 1996.

Data collected for the Japanese system include the location, geometry, geomorphology, and engineering of foundations and embankments; system hydrology and hydrologic history; soils in foundations and embankments; and performance or failure history. These and many other components went into a “Flood Control Topographic Classification Map” and were used to construct “cross sections” (actually complex tables) to represent a given levee reach.

The initial definition of each reach in the Japanese system came from pre-existing arbitrary divisions, such as name of the river, name of the levee section, or river mile. Using all of the complex data assembled into the data tables and “cross sections” (without benefit of GIS), they created summary tables of the present condition of each levee reach. One unique component of the Japanese system is the importance they attributed to the age of the levee. Reaches were automatically flagged with a poor-performance indicator if the levee reach was built prior to 1955. The report does not explain the reason for the 1955 delimiter; it may represent a specific change in construction practice, or it may be an arbitrary date indicating levees that were more than 40 years old when their condition was assessed.

In its 1996 report, the Ministry of Construction had recognized the importance of understanding the properties of the materials both in the foundation and in the levee embankment. Oyo Corporation conducted a study for the Ministry in 1998[1] to explore the possibility of using resistivity imaging

[1] The Oyo Corporation report is not dated. However, a date of 1998 is assumed, based on the presence in the report of photographs dated 1997.

for rapid nonintrusive characterization of levee and foundation soils. The method they used is similar to the EM conductivity floodplain mapping performed by Dunbar et al. (2003) for the IBWC, wherein the results of the geophysical survey are color coded and related to soil type.

Before conducting resistivity surveys, Oyo Corporation investigators divided levees into reaches based on material type. They used a multiple-matrix system first to assign a ranking letter *a* through *d* based on material, specifically the combination of levee material and foundation material. The second matrix assigned a ranking letter *a* through *d* based on external forces, those being high-water duration and average hydraulic gradient. The results of these two matrices then were combined into a third matrix, to rank the levee reach based on the combination of material and external forces, ranging from *A* = relatively safe to *D* = relatively unsafe. Figure 3 is a page from the Oyo Corporation report showing the classification matrix. Oyo Corporation also reported on some field observations of levee materials in excavated pits, and site-specific investigations adjacent to flood-caused levee breaches.

The combination of techniques used by Oyo Corporation (1998) demonstrated that geophysical investigations using resistivity can be used for rapid characterization of the soils in levees and their foundations, with a high correlation between soils indicated by the geophysical method and soil data from field measurements.

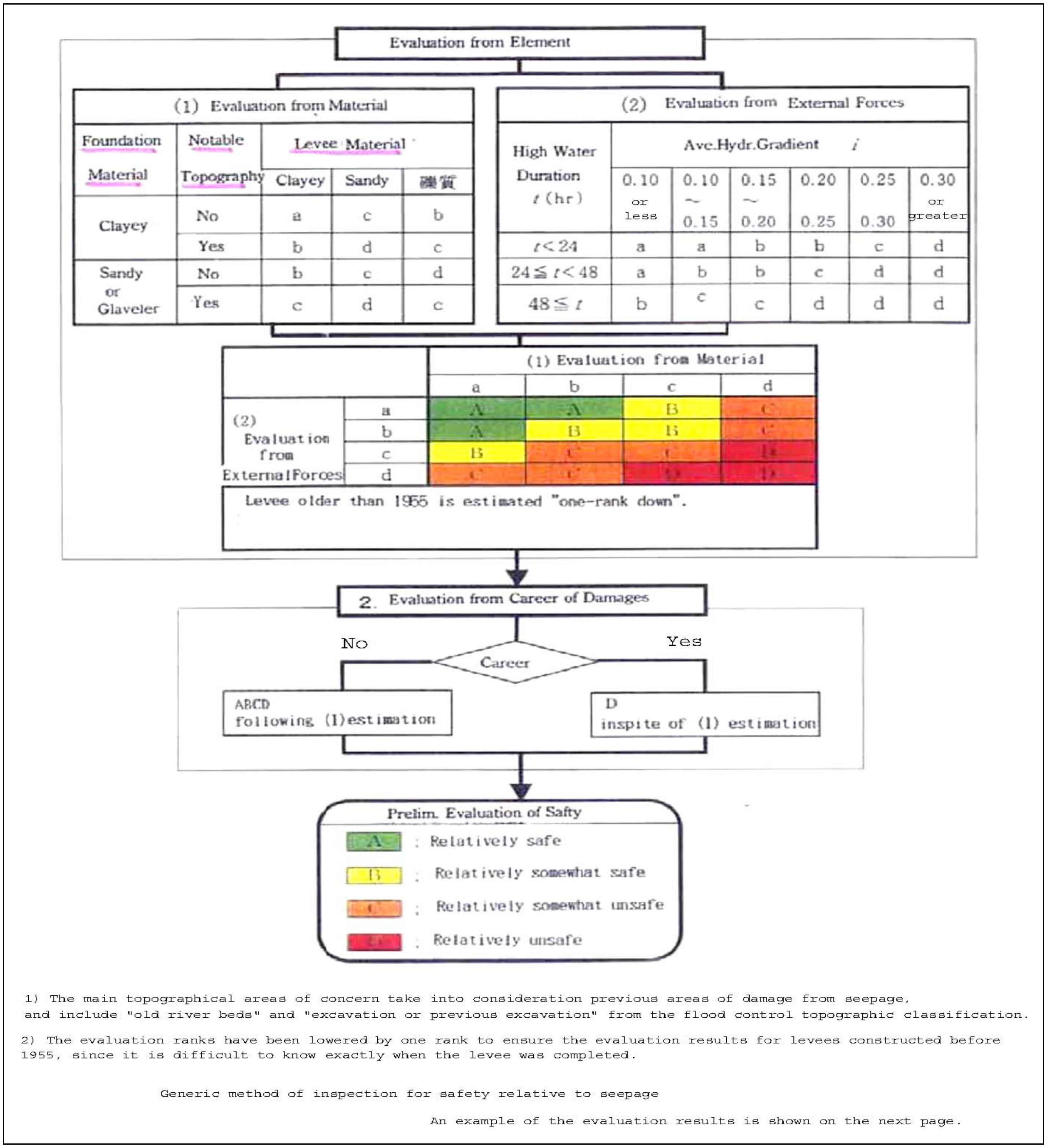

Figure 3. Levee classification matrices from Oyo Corporation (1998).

5 Summary

Classification systems and inventories of levees have received renewed focus and attention since Hurricane Katrina in the United States. Levee classification efforts are ongoing by various government-sponsored programs in recognition of increasing risks associated with changing land use and urban growth in areas protected by levees. The programs variously inventory, segment, and determine aspects of the condition of levees. The government agencies with responsibility for levees and current efforts in levee classification include the National Levee Inventory of the USACE, the International Boundary and Water Commission, and the State of California in the United States; the RASP program of the United Kingdom; IMPACT and FLOODsite in the European Union; and programs of the Ministry of Construction, Government of Japan.

Different classification systems focus on various aspects of management of levee systems or flood risk including hydrology, flood routing, levee material properties, geology of the foundation, levee geometry, levee age, and other properties. Geophysical surveys are a component of rapid levee classification performed by ERDC for the IBWC, by the Government of Japan, and as part of the European IMPACT program. The use of geophysical and remote-sensing techniques is expected to increase, to meet the need for periodic assessment to quantify changes in condition of levee segments and system-wide changes triggered by evolving land use and hydrologic loads.

6 References

Allsop, W., A. Korenhaus, and M. Morris. 2007. *Failure mechanisms for flood defence structures*. FLOODsite Project Report T04-06-01. www.floodsite.net.

Broich, K. 2005. *Breach location*. IMPACT Technical Report, Work Package 2.4, Annex II, Part A (November).

Buijs, F. A., P. H. A. J. M. van Gelder, J. K. Vrijling, A. C. W. M. Vrouwenvelder, J. W. Hall, P. B. Sayers, and M. J. Wehrung. 2003. Application of Dutch reliability-based flood defence design in the UK. In *Proceedings, Conf. ESREL 2003, 15–18, Maastricht, The Netherlands*, 1:311–19.

Dunbar, J. B., and J. L. Llopis. 2005. *Condition assessment of U.S. International Boundary and Water Commission Tijuana River Levees, San Diego, California*. ERDC/GSL Technical Report (unpublished). Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Dunbar, J. B., J. E. Stefanov, M. J. Bishop, L. Peyman-Dove, J. L. Llopis, W. L. Murphy, and R. F. Ballard. 2003. An integrated approach for assessment of levees in the Lower Rio Grande Valley. In *Proceedings, Symposium on Applications of Geophysics to Engineering and Environmental Problems (SAGEEP) 2003*.

Glynn, M. E., and J. Kuszmaul. 2004. Prediction of piping erosion along middle Mississippi River Levees—an empirical model. Technical Report ERDC/GSL TR-04-12. Vicksburg, MS: U.S. Army Engineer Research and Development Center. http://libweb.wes.army.mil/uhtbin/hyperion/GSL-TR-04-12.pdf.

IMPACT. 2004. *Identifying potential breach location*. IMPACT WP2: Deliverable D2.4.1 (December) .

Japan Ministry of Construction. 1996. *Safety inspection for river levee seepage*. Internal report, River Bureau, Flood Control Department [in Japanese; translated by Globalization Group, Orem, UT].

Oyo Corporation. 1998. *Applications of resistivity imaging to river levees* (also known as *Resistivity imaging exploration of river dike*). Internal report, Ministry of Construction of Japan [in Japanese; translated by Globalization Group, Orem, UT].

Pangburn, T. 2008. Status of the National Levee Database (conference presentation). *2008 Midwest Levee Conference, 2 June, St. Louis, MO*.

RASP. 2004. Risk assessment of Flood and coastal defence systems for strategic planning (pamphlet). http://www.rasp-project.net/RASP A4 Flyer v5.pdf.

Samuels, P. 2008. *Year 4 periodic report—publishable executive summary*. FLOODsite Project Report T35-08-07.

Sayers, P. 2007. Seminar presentation (June). U.S. Army Engineer Research and Development Center, June 2007. Oxfordshire, UK: HR Wallingford, Ltd.

Terzaghi, K., and R. Peck. 1967. *Soil mechanics in engineering practice*. New York: John Wiley and Sons.

URS Corporation. 2007. *Guidance document for geotechnical analyses; Rev. 5*. Report prepared for State of California, Department of Water Resources, Division of Flood Management. Sacramento, CA.

Vaskinn, K. A., A. Løvoll, K. Höeg, M. Morris, G. Hanson, and M. A. A. Mohamed Hassan. 2008. *Physical modeling of breach formation: Large scale field tests*. IMPACT Project Report, Annex II, Part A, WP2—Breach Formation.

Yuan, May. 2008. Dynamics GIS: Recognizing the dynamic nature of reality. *ArcNews* 30(1):1, 4–5.

Appendix A: Condition Assessment Tool for Levee Segments Developed for International Boundary and Water Commission, U.S. Sector

________________ Quadrangle
Levee Segment # __ Condition Assessment

	Weight	Value	Score
Performance history (under flood stage) *	3		
Construction history (original or upgraded) *	3		
Visual inspection apparent condition (on-site observation) *	3		
Material type (sand [worst] transitioning to clay [best]; (from EM, borings, soil maps)	3		
Topographic irregularity (swags, erosion) (from LIDAR)	3		
Potential slope stability (material type, relation to flow)	3		
Man-made intrusions (utilities, bridges, pump stations, etc.)	3		
Geology (old stream beds, river deposits)	3		
Proximity of borrow area (size, depth, distance, side of levee)	2		
Anomalies (unexplained radical conductivity “spots”)	2		

** Input must be provided by IBWC*	Total Score
	Average Score
	Condition Poor (0 – 3) Marginal (4 – 6) Acceptable (7 – 9) Good (10 – 12)

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* February 2009	**2. REPORT TYPE** Final report	**3. DATES COVERED** *(From - To)*
4. TITLE AND SUBTITLE Classification Systems for Earthen Levees: A Worldwide Review		**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Lillian D. Wakeley and Joseph B. Dunbar		**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Engineer Research and Development Center Geotechnical and Structures Laboratory 3909 Halls Ferry Road Vicksburg, MS 39180-6199		**8. PERFORMING ORGANIZATION REPORT NUMBER** ERDC/GSL SR-09-2
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Homeland Security Washington, DC 20528		**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Most nations of the world rely on levees in complex flood-control systems to protect hundreds of billions of dollars' worth of homes and businesses, and the lives of uncounted millions of people. With continuing urban growth and economic development, flood-control systems have been expanded and modified repeatedly to protect changing assets. The safety and reliability of a flood-control system depends on the condition of each individually built component. Yet there is no shared or standard system in the United States, and certainly not worldwide, for defining levee-management reaches, assessing levee condition, or predicting performance.

A unified system of levee classification should be based on best current practices. This report summarizes levee classification systems in use in the United States, in the European Union, and in Japan. A review of these systems revealed three approaches to levee classification. Approach 1 defines levee-management segments based on geographic location. This type of classification system allows easy identification of each entity of the system under discussion, but provides minimal additional information. Approach 2 defines segments or reaches based on some aspect of condition or materials. This type of classification system identifies the geographic location for each reach and also provides useful information about fixed properties, which either do not change or change slowly relative to a human timescale. In Approach 3, segments are defined dynamically for a particular time frame by some parameter of vulnerability that incorporates risk. The geographic identifier of a reach remains constant while its condition-related or risk classification changes as physical conditions change with time. A dynamic classification system is a powerful levee management tool, with space and time integrated into a predictive system.

15. SUBJECT TERMS

Condition assessment	Flood protection	Levee foundation
Flood control	Geotechnical engineering	Levee inventory
	Levee classification	Levees

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT UNCLASSIFIED	**b. ABSTRACT** UNCLASSIFIED	**c. THIS PAGE** UNCLASSIFIED		30	**19b. TELEPHONE NUMBER** *(include area code)*