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Renovation and reinforcement Techniques of Levees: An International Report by the ISSMGE TC201

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ABSTRACT: An international report on renovation and reinforcement of levees is being prepared by members of the ISSMGE TC201 'Dykes and levees'. This report aims to facilitate researchers and professionals to select, design, and implement techniques for retrofitting and reinforcement of levees. The report is made of two parts, i) a critical review of retrofitting and reinforcement techniques and ii) case examples of such techniques. Part I is drafted by the core team authoring this paper. Techniques are classified against three main failure modes, i.e., internal erosion, external erosion, and slope stability. This classification followed the feedback of TC201-members retrieved via an international survey about the knowledge needed by levee specialists to retrofit and reinforce levees. Part II includes contributions submitted by TC201 members and their networks. The format of the contribution can be a case study of a traditional reinforcement or retrofitting project and/or a case study of a pilot or demonstration project focusing on innovative techniques and/or a technical factsheet for a given technique. Contributions including case studies and factsheets were received from a significant number of TC201-members. This paper gives an overview and a summary of the main milestones achieved so far.

KEYWORDS: levees, dikes, reinforcement techniques, TC201.

1 INTRODUCTION

Levees play an important role in protecting society from flooding and have done so for centuries. Knowledge about how to design and build levees has developed over time. Guidelines such as The International Levee Handbook (2013) allow designers to compute failure probabilities and design levees to withstand prescribed water levels. Mechanisms and failure paths that can lead to damage of the levee and ultimately flooding have been reviewed by a TC201 as mentioned in Van et al. (2022). Processes such as degradation of levee performance, an increase in hydraulic loading, an increase in population, economic value of the hinterland, and new insights into failure mechanisms, can prompt the need for reinforcement or retrofitting of levees. The methods used for this purpose depend on the failure mechanisms and failure paths that affect the performance of the levees. Besides this, other considerations may influence the selection of reinforcement techniques. These may be related to uncertainties on the long-term evolution of the loading on the levee, including sea level rise, land subsidence, and changes in the frequency or intensity of extreme weather events. Environmental concerns can also play a role, including carbon dioxide emissions during construction, biodiversity, and ecological restoration. Societal considerations surrounding levees, such as a change in attitude towards accepted risk and means of organizing flood prevention can also play a role. To meet the reinforcement needs, a variety of retrofitting solutions exist, and novel techniques are being developed.

2 AIM OF THE INTERNATIONAL REPORT

An international report on retrofitting and reinforcements of levees is being prepared by members of ISSMGE TC201 'Dykes and levees'. This report will be launched during the ICSMGE Vienna conference in 2026. The report aims to aid practitioners in selecting appropriate methods for their specific problem and facilitate knowledge sharing among international experts on traditional and innovative methods. The report provides an overview of reinforcement and renovation techniques for key geotechnical failure mechanisms associated with high-water events (e.g. not due to earthquake loading or other types of loading). The techniques described in the report relate to reinforcement and retrofitting, but not repair (short-term interventions after major damage) or daily maintenance.

3 TERMINOLOGY DEFINITIONS IN THE REPORT

Terminology may differ among countries or even among practitioners with different backgrounds. Therefore, an overview of key terminology and concepts is first presented.
Definitions from the ISSMGE TC201 report on *Failure paths for levees* by Van et al. (2022) are used. A failure mechanism is a physical process that can lead to degradation, damage, or collapse of a structure or one of its parts. A failure path is considered a sequence of events whereby an initial event, the high-water loading, leads to flooding of the protected area. Although the term failure path suggests a linear sequence of events, different mechanisms may occur simultaneously in time and influence each other. The term failure tree, which indicates the presence of branches, describes such situations.

Maintenance, repairs, renovation, and reinforcement are defined in the report as shown in Figure 1. Maintenance includes all activities aimed to maintain or restore a system in a state or in given safety or working condition, to perform a required function. It includes preventative maintenance, repairs

(exclusive options), and activities such as servicing mechanical parts and mowing the grass revetment. It may consist of repairing or replacing the components of a structure (whose life span is less than that of the overall structure), or a localised area that has failed or may fail as defined in The International Levee Handbook (2013).
Major repairs consists of restoring the levee to operating condition after damage has occurred and structure functionality has been reduced. Major repairs include rehabilitation (or renovation or refurbishment). Minor repairs are aimed at restoring a structure based on observations during inspections. Regular/planned maintenance like mowing the grass is usually performed by the levee manager staff or local contractor.
Renovation (also Rehabilitation) is the process of restoring an asset for the purpose of returning that asset to its original as-designed performance. Reinforcement (also Refurbishment or Retrofitting) is the process of improving the safety/and or performance of an asset above the original design performance. This includes improving (historical) levees without a known design level. Reinforcement of a structure entails either the improvement of it above the original design performance, restoration after some deterioration, or damage caused by ageing or by an event. Reinforcement of a function entails adding or improving one or more components acting on this function (i.e. sealing, drainage, filtration, water spilling, etc.).

In this report, the focus lies on techniques of renovation and reinforcement of levees. Three types of maintenance are shown in Figure 1: minor repairs (also regular/planned maintenance), major repairs (also renovation or rehabilitation), and reinforcement (also refurbishment or retrofitting). Minor repairs, containing regular/planned maintenance, are outside the scope of this report.

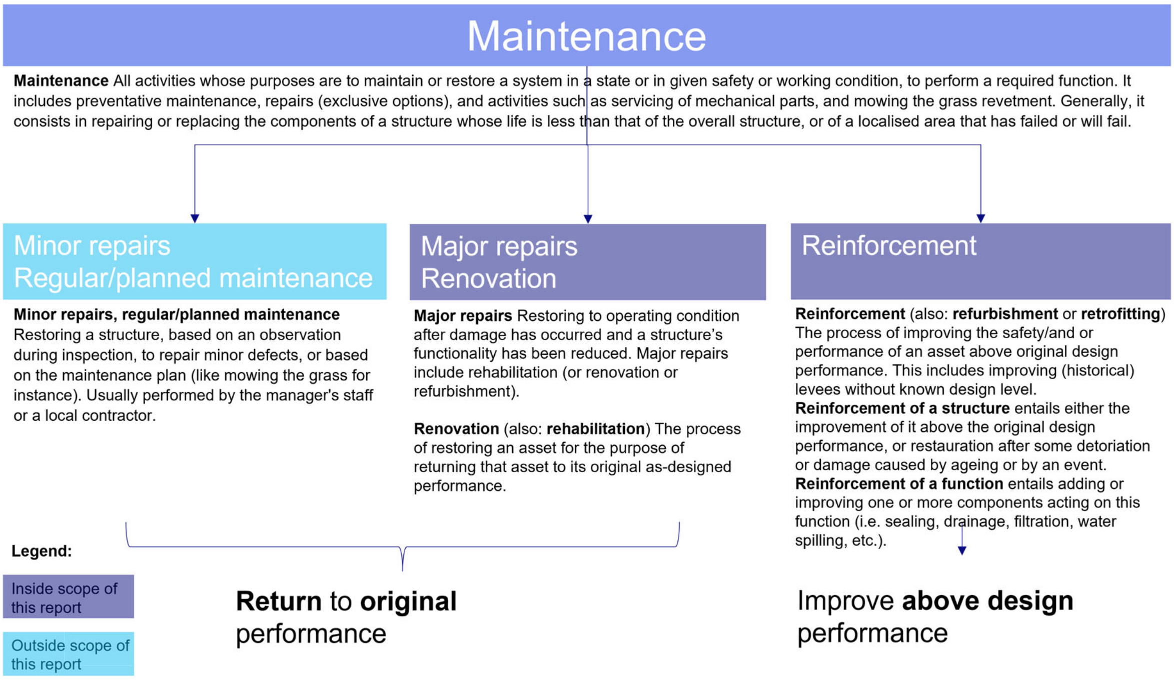

Figure 1. Diagram of categories of maintenance and their definitions.

In the glossary of the international levee handbook (2013), there is also a distinction between returning to the design performance and improving it. These definitions are slightly different. Renovation is defined as the process of returning an asset to its original as-designed performance; Rehabilitation is the process of restoring an asset for the purpose of returning that asset to design performance and reinforcement is the process of improving the performance of a structure (or one of its components) against an event or a degradation mechanism.

4 INTERNATIONAL SURVEY ON REPORT NEEDS

To focus on the needs of the international community, a survey was circulated in the winter of 2023-2024 amongst the members of the TC201, who in turn shared it with their network. Participants provided input on their needs about knowledge of design and implementation of techniques or information for retrofitting and reinforcement, as well as their requirements with regard to other considerations and uncertainties in design. The results are briefly presented here.

4.1. Participants background

A total of 67 participants responded. The participants were involved with renovation and reinforcement in different roles, as shown in Figure 2. The majority of the respondents were active as consultants or engineers, many also had experience in different roles throughout their career.

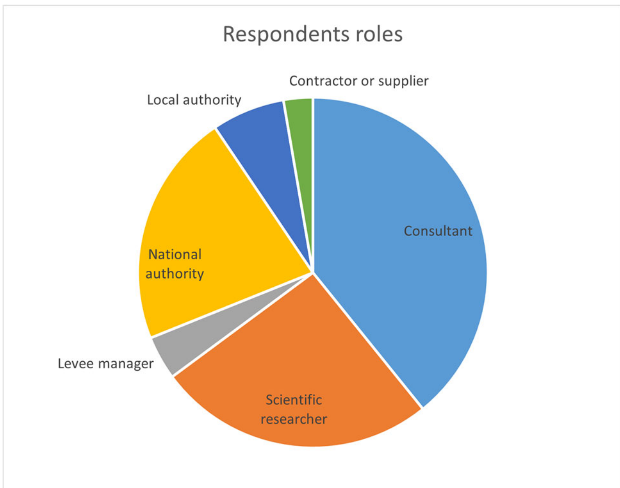

Figure 2. Overview of respondent roles

4.2. Failure mechanisms and environments

The majority of respondents have experience in river or coastal environments. Additionally, some respondents are also concerned with works on estuarine levees and levees for mountain streams as shown in Figure 3.

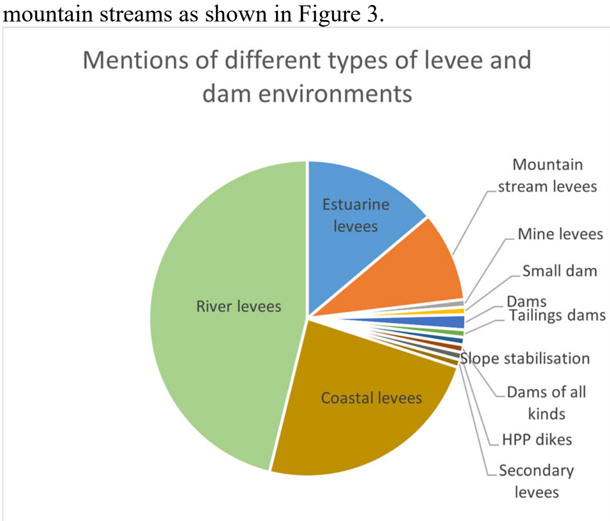

Figure 3. Overview of working experience in types of environments

As shown in Figure 4, the survey prompted three main families of mechanisms:

- internal erosion;
- slope sliding (instability);
- external erosion (on the water side).

Several respondents indicated that the mechanism of main concern strongly varies depending on the situation and geometry of the levee. Also, they remarked that there can often be a combination of different mechanisms which are of concern for a specific levee.

Seepage and increase of pore-water pressure were not explicitly asked in the survey. These are hydraulic conditions which have influence on the mechanisms and they are implicitly included through the failure paths for failure mechanisms such as internal erosion and slope stability; techniques targeting seepage or pore water pressure are also included in this report.

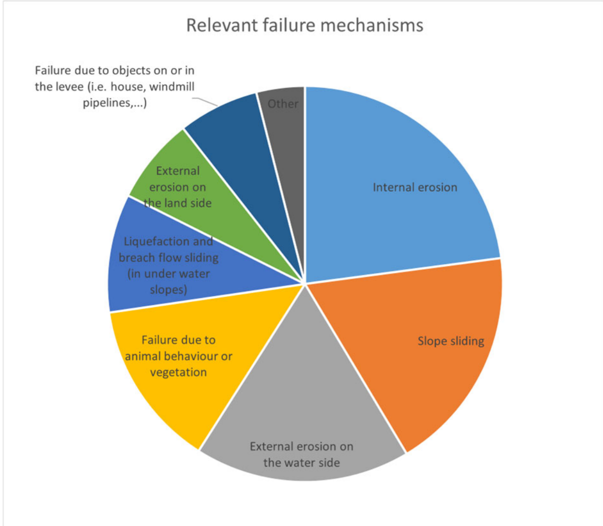

Figure 4. Overview of survey result on relevant failure mechanisms

4.3. Importance of long-term developments and uncertainties in short- and long-term design

Respondents were asked to score how much uncertainties in the long term affect their design for reinforcement and renovation. This question showed that increasing flood frequency, intensity, or duration due to climate change and environmental considerations are the most important concerns when defining design criteria and assessing long-term uncertainty (see Figure 5).

4.4. Survey conclusions

Most respondents find that existing techniques and guidelines can only partially meet their needs and there is a demand for guidelines concerning relatively new techniques. This includes the use of geosynthetics and soil mixing. Another demand is a 'ductile' behaviour of the levee during breaching, resulting in less severe flooding. It would be interesting to conduct these types of surveys periodically since some of these aspects may not be deemed of importance right now, but could become more of importance in the future

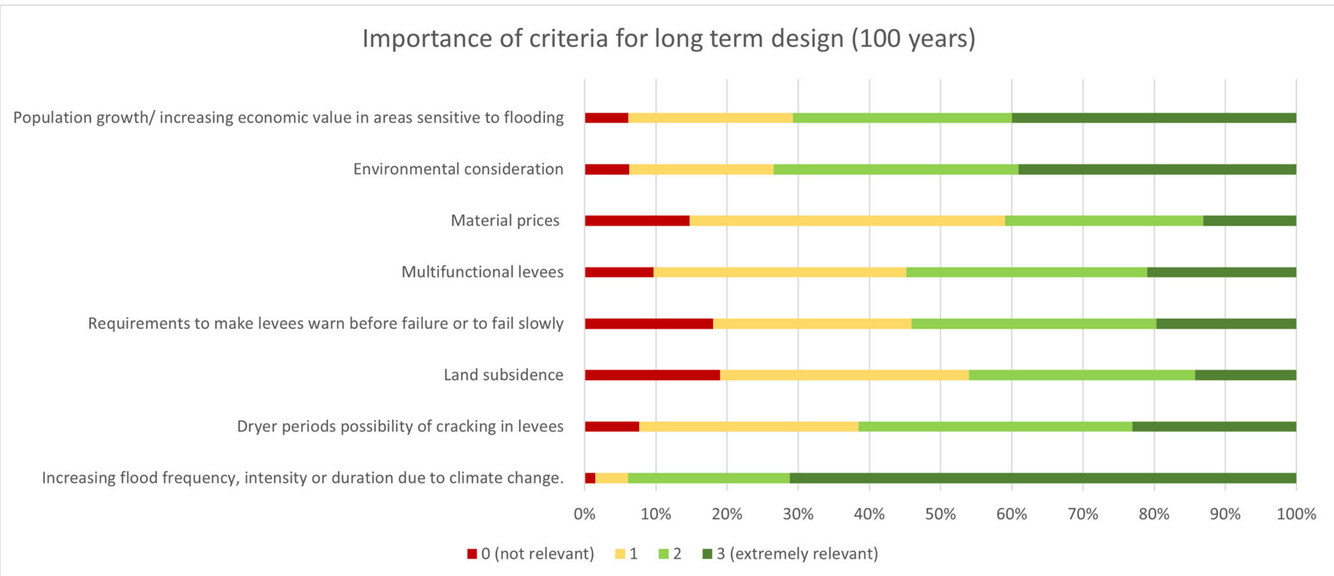

Figure 5. Overview of criteria and their importance for long term design (100 years)

5 INTERNATIONAL CASES AND FACTSHEETS

The members of the ISSMGE TC 201 contributed with information, case examples, and information on renovation and reinforcement techniques. These contributions will be presented in Part II of the report to provide an inventory of case examples or factsheets of techniques. Each contribution consists of the description of a case and/or a technique factsheet, showing details of the relevant failure mechanisms, and of the application of the relevant technique.

6 FRAMEWORK OF REINFORCEMENT AND RETROFITTING TECHNIQUES

Based on the case studies and factsheets originated from different countries, recommendations will be formulated about the selection of renovation and retrofitting techniques, and potentially promising innovations. Part I of the TC201 report will provide a structured overview of reinforcement techniques including the main failure mechanisms addresses by such a technique and references to practical examples. A comparison amongst countries will also be made. A brief overview of possible additional considerations and their influence on a selection of commonly used techniques will provided and conclusions and recommendations will be drawn.

Based on the indicated demands from practitioners in the survey, the report will provide an overview of techniques that can be used for renovation and reinforcement, with a focus on the three key families of mechanisms of concern, i.e., (internal erosion, slope stability, and external erosion (see Figure 6).

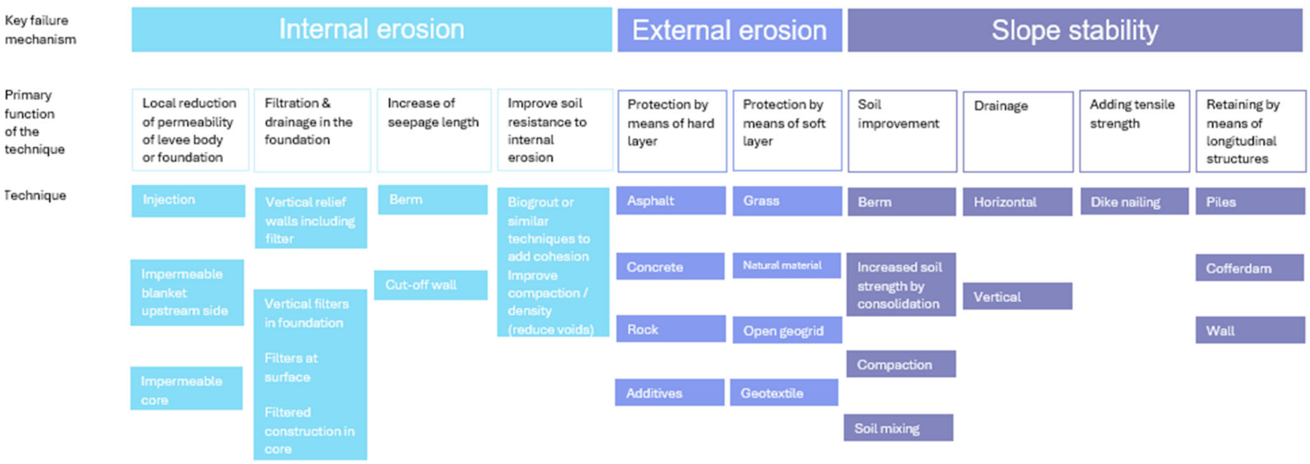

Figure 6. Overview of principles for techniques that can be used for retrofitting and reinforcement.

Damages caused by animal burrowing or vegetation are also aspects of concern and techniques targeting these damages are also included. This overview intends to be as complete as possible; however, specific situations or new innovative approaches might give rise to additional techniques that may not be included in the report.

In order to support practitioners in the selection of methods, these are first grouped per family of mechanisms addressed and then per physical principle and functionality.

In the report, the content of Figure 6 provides references to all the contributions in Part II where case examples and technique factsheets will be submitted by the members of the TC201 and their networks. These chapters will also include references to design guidelines and manuals or other relevant literature.

7 CONCLUSIONS AND RECOMMENDATIONS

The respondents of the survey amongst the network of the TC201 members indicated that key failure mechanisms of concern are internal erosion, slope stability, and external erosion. Furthermore, the effect of animal burrowing or vegetation is of concern. Many respondents find that existing national and international guidelines and manuals (e.g. the International Levee Handbook [CIRIA 2013] or the Eurocode EC7) meet their demands only partially, especially for innovative methods where less information available. The report will therefore include also applications of innovative techniques.

There are different reasons for developing and applying innovative techniques, for example, growing demand for space, increasing material cost, and consideration of biodiversity and carbon emissions. In the long term, the effects of climate change making the loading on levees less predictable may lead to an increased demand for methods that are easier to extend or adapt in front of these uncertainties.

Considering the increasing demand for space, multifunctional levees that provide social space or ecological benefits are receiving increased interest, for example levees providing room for recreation, or that promote biodiversity using more diverse grass covers. Other examples of innovative techniques in this report include for example mix-in-place walls and vacuum consolidation for improving stability against slope sliding.

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