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Chapter 25. Conclusions and outlook

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ABSTRACT: This chapter brings all information from the previous chapters together and restates the main topics that have been covered in this book. The topics to which more research energy has been devoted and the remaining open questions are discussed. Based on the current knowledge and state-of-the-art, as well as the practical experiences presented by the authors in this book, practical recommendations are presented.

1 CURRENT BODY OF KNOWLEDGE ON LOAD TESTING

The current body of knowledge on load testing is reflected by the available codes and guidelines, and the experience gathered with these codes and guidelines reported in project reports and articles. The current codes and guidelines reflect past practice, while the available project reports and articles show new insights that have been successfully applied.

In this book, the current body of knowledge and best practices are gathered in the first five parts. The first part shows the historical development of load testing, which arose from the need to assure the traveling public that a new bridge is safe for use. The first part also summarizes the main features of the available codes and guidelines from Germany, the United States, the United Kingdom, Ireland, Poland, Hungary, Spain, the Czech Republic and Slovakia, Italy, Switzerland, and France. The second part gives best practices for load testing, regardless of the type of load test and the structure type and construction material. These best practices are subdivided in the general considerations that are important prior to each load testing project, and the preparation, execution, and post-processing of a load test. The third and fourth part then address diagnostic load tests and proof load tests respectively, two types of load tests that serve different purposes. For both parts, a number of case studies are included that can give the reader guidance for the preparation of a load test. The fifth part addresses the current body of knowledge regarding load testing of buildings, based on the experience developed from using the German guideline for load testing over the last two decades.

Currently, structures are designed by designing the structural members, and structures are assessed by evaluating the strength (and sometimes stability) of the individual structural member. While load testing aims at confirming the adequate design of a new structure by measuring responses of the critical structural member, or at assessing the critical structural member through measuring its response, load testing gives us information about the global behavior of a structure. By measuring the structural responses of several members, information about the load distribution can be gathered. By measuring the deflections, the overall stiffness of the structure can be evaluated. By measuring deformation profiles in the longitudinal direction, the effect of (unintended) continuity (for example, caused by frozen bearings or caused by continuous decks over simply supported girders) can be evaluated.

At the moment, a load test is typically carried out as an isolated project to evaluate a given structure. After a load test, a report of the test may be developed, but these reports are typically not publicly available. As such, it becomes difficult to learn from the experience of past projects and improve the practice of load tests. With the increased attention paid to improving assessment practices, including load testing, the output from conference sessions and volumes with articles that have been gathered has become available. This book aimed at bringing information, practical recommendations, open questions, and different national/local practices together and becoming a reference work for engineers planning to carry out load tests. This book also shows, in particular in Part V, that unsafe practices for load testing are still used, and warns the reader against the use of unsafe load application and measurement methods.

2 CURRENT RESEARCH AND OPEN RESEARCH QUESTIONS

This book identifies two main research topics: applying new measurement techniques in load tests, and using concepts of structural reliability and life-cycle assessment and cost-optimization together with proof load tests.

At the moment, instrumenting a structure that will be load tested, can be a time-consuming activity. Contact sensors need to be applied to measure the structural responses, and each sensors has to be calibrated, applied, wired, and its output interpreted. At the moment, the only non-contact equipment that is typically used during a load test is a total station, which measures the deflections. To speed up load testing, there is a need to develop sensor plans that rely on non-contact measurements, and to combine long-term monitoring measurements with field testing based on embedded sensors. This book has shown the application of non-contact measurements such as methods based on photography and video as well as radar techniques. An interesting measurement technique, especially for load tests that involve large load levels when micro-cracking needs to be recorded, is the use of acoustic emission measurements. Such measurements could be combined and/or expanded in the future with embedded smart aggregates. Finally, optic fiber sensors show to be a promising method to capture strains over a larger distance or surface than what can be covered with traditional strain measurements, which can only capture the structural response at a given position.

In the past, when load tests were used to show the traveling public that a new bridge is safe for use, safety was demonstrated by showing that a bridge can carry a given number of heavily loaded vehicles. Nowadays, our codes and guidelines express safety in terms of a probability of failure. The practice of load testing, and in particular proof load testing, still needs to make the step to move from showing that a bridge can carry a heavy load to quantifying the safety in terms of a probability of failure. For that purpose, concepts of structural reliability should be combined with the practice of load testing. Whenever an assessment of "safety" is required, this assessment should be quantified in terms of a probability of failure. By the same token, a transition from member safety to systems safety (considering the entire structure and the overall structure behavior) is needed and requires research.

In particular for proof load testing, research is needed to determine the target proof load so that it can be concluded that a certain bridge fulfils the code requirements in terms of safety, expressed as a probability of failure. This research should also address which uncertainties are removed with a proof load test and which uncertainties still need to be considered. Moreover, the effect of testing only one span but possibly extending these results to the entire bridge, needs to be addressed.

Since load tests at the moment are usually isolated projects that arise from the need for an improved assessment of a given bridge, they do not form an integral part of a bridge management plan yet. Research to identify the optimal time during the life-cycle of a structure to load test is necessary. The optimal time could, for example, be based on cost-optimization, take forecasted traffic loadings into account, and consider deterioration mechanisms. Moreover, each bridge should be considered to be part of a road network. The optimal time could be analyzed based on the cost of temporary bridge closure on the road network and the resulting driver delays. This topic requires further research.

At the moment, the current codes and guidelines only allow load testing (especially proof load testing) of structures that are expected to fail in a ductile manner, so that the structure will show signs of distress prior to collapse. However, often structures that may fail in a brittle mode are more difficult to assess, so that proof load testing becomes an interesting option. More research on concrete structures that are critical in shear, punching shear, tension, or torsion is needed, as well as more research on fatigue- and fracture-critical steel and composite structures. Safe stop criteria for these structures need to be developed. More research on the application of load testing to timber, masonry, and plastic composites structures is needed as well to identify the critical structural responses and stop criteria.

3 CONCLUSIONS AND PRACTICAL RECOMMENDATIONS

An engineer preparing a load test in a territory where no codes or guidelines for load testing are available could ask: “Which code or guideline should I follow?” As shown in Part I, different codes and guidelines address load testing from a different perspective. Some codes, such as the Manual for Bridge Evaluation cover diagnostic and proof load tests for all bridge types, except for bridges that may fail in a brittle manner and long span bridges, in a general and qualitative manner, whereas other guidelines, such as the German guideline, focus on proof load tests of flexure-critical building structures only, providing detailed methods to determine the target proof load and detailed stop criteria. However, when preparing a proof load test, it is important to realize that each project is different. Depending on the goals for the load test, a different type of load test may be selected, a different load application system, a different sensor plan, and a different overall planning of the project will result. As such, it is often interesting for the engineer preparing such a load test to gather information from the different codes and guidelines that are available, and to learn from previously published load testing projects, such as the case studies presented in this book.

A general recommendation that holds true for all load tests, regardless of the type of test and structure type, is that a good preparation is important. First and foremost, a feasibility study is necessary to gather the required information to prepare the test. Where possible, missing information and material properties should be gathered and/or measured to have a better understanding of the structure and the expected structural behavior. Then, the goals of the load test should be clearly stated, and it should be studied if load testing is the recommended method to meet these goals. From a practical point of view, a good preparation is important to avoid confusion on the bridge site when time is scarce. A technical inspection prior to the load tests should identify possible site restrictions and limitations. A detailed planning of the on-site activities is necessary to help with finishing the load test within the available time. Prior to the load test, the test engineers should think through possible failures of equipment and personnel. A plan B for each scenario should be developed, and the necessary backup equipment and sensors should be available on site.

A second practical recommendation is that communication and safety on site are of the utmost importance. Good communication helps all parties involved to know what needs to happen when, and when possibly dangerous situations arise. Safety on site is important to protect the structure, personnel involved with the load test, and the traveling public. For the structural safety, an adequate sensor plan is important, as well as thorough preparatory calculations exploring the expected structural behavior. For the safety of the personnel involved with the load test, the local safety regulations should be closely followed and a safety engineer should be dedicated to the safety of personnel and the execution. Finally, the safety of the traveling public should be considered and when necessary, a full closure of the tested bridge may be necessary. When road closures are necessary, good communication to the affected communities and traveling public is important. During the preparation stage of the load test, the way in which such hindrances for the traveling public will be communicated, and who will be in charge of the communication, should be determined.