On the under-exploitation of reuse principles

Sobre la subexplotación de los principios de reutilización

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ABSTRACT

Current construction practices are far from sustainable. Given the threats posed by climate change, the sector is required more than any other to reduce energy and material consumption quickly and massively, as well as greenhouse gas emissions. Against this backdrop, extending the service life and reusing existing structures or components is more important than ever to achieve sustainability goals. Surprisingly, there are still many reservations about reusing existing systems and stakeholders involved often lack knowledge on how to make rational decisions concerning their reliability. Some barriers to a wider implementation of reuse principles in practice are identified in the paper and illustrated by a case study.

RESUMEN

Las prácticas de construcción actuales distan mucho de ser sostenibles. Dadas las amenazas asociadas al cambio climático, el sector está más obligado que ningún otro a reducir de forma rápida y masiva el consumo de energía y materiales, así como las emisiones de gases de efecto invernadero. En este contexto, prolongar la vida útil y reutilizar las estructuras existentes es más importante que nunca. Sorprendentemente, todavía existen muchas reservas respecto a la reutilización de los sistemas existentes y muchos agentes carecen de conocimientos sobre cómo tomar decisiones racionales en relación con su fiabilidad. En el artículo se identifican e ilustran barreras para el empleo de los principios de reutilización.

KEYWORDS: material consumption, greenhouse gas emissions, existing structures, reuse, reliability, updating.

PALABRAS CLAVE: consumo, emisiones, estructuras existentes, reutilización, fiabilidad, actualización.

1. Introduction

Already in the 90s of the last century, a scientific consensus crystallised on the possibility of global warming. Now, after a series of years with record global average temperatures, "the era of global boiling has begun", says the Secretary-General of the United Nations [1], and actions against global warming are presented as an epochal challenge. Indeed, at least since the youthful Fridays for Future movement aroused the bad conscience of older generations, the media has been filled with contributions on the subject and political promises of profound and imminent transformations abound. But is anything serious really being done to fight climate change? The construction sector illustrates in an exemplary way the gap that exists between promises and reality.

Globally, construction-related activities cause more than 20% of greenhouse gas emissions [2]. Between a quarter and a half of these emissions are due to cement production, while the remainder is a result of the manufacture of other materials, transportation and construction processes. The operation and maintenance of the built environment accounts for an additional 30% of CO_2 emissions.

Current construction practices are far from sustainable. Given global population growth and increasing urbanisation trends in many regions and countries, construction emissions alone could jeopardize the achievement of the goals of the Paris agreement [2]. Given the threats posed by climate change, the sector is required more than any other to quickly and massively reduce energy and material consumptions, as well as greenhouse gas emissions.

To achieve the required changes in best construction practices, the scientific and technical communities must collaborate with industry, administrations and standardisation bodies, to develop and promote methods, tools, regulations and financial incentives that lead to solutions compatible with protection of the planet, to improve the lives and future prospects of everyone [2]. In this transition, measures such as the development of new materials, products and technologies that generate minimal emissions, or the establishment of performance requirements based on environmental effectiveness are of particular importance. This reorientation of the sector, however, is very slow, among other reasons because it requires a change in mentality, both among construction agents and the public, as well as a change in training, with the aim of transmitting to the future engineers, but also active professionals, the knowledge that allows them to address sustainability issues from a holistic perspective.

In contrast, the most efficient of all possible measures to reduce the construction industry's carbon footprint and achieve sustainability goals, namely extending the service life and reusing existing structures or components, is readily available. Surprisingly, however, there are still many reservations about reusing existing systems and the stakeholders involved often lack knowledge about how to make rational decisions regarding their reliability. Possible reasons for this situation are identified in the article and illustrated using a case study, as part of an overview of the essential differences between the assessment of existing structures compared to the design of new structures and their treatment in regulations and standards.

2. Assessment versus design

In general, an existing structure may be subjected to the assessment of its actual reliability in case of [3]:

- a change in the purpose of the structure compared to that for which it was originally designed or previously assessed;
- deviations in the properties of the structure or the environment from those adopted in the original design or in the previous assessment.

As in the design of new structures, when assessing existing structures, the effects of the relevant actions and influences on the load-bearing system and its response are determined based on recognized engineering theory and practice, taking into account all relevant parameters. The general principles of structural reliability regarding the treatment of the uncertainties associated with these parameters also apply to both, design and assessment, when using different methods to verify the specified requirements. Taking further into account that new or existing civil engineering works are usually unique, either because they are prototypes or because nominally identical structures are subject to different, site-specific conditions, from an engineering point of view, structural analysis and verification must be carried out, both in the design and in the assessment, on a case-by-case basis according to the same principles. The question might therefore arise to what extent an assessment, from a technical perspective, differs from structural design?

The approach to assessment of an existing structure is indeed in many aspects different from that taken in design of a new structure. The key differences are listed below, along with some references for further information:

- state of information and its updating through distinct types of data [3 - 6];
- structural condition, in particular concerning possible deterioration [7];
- reliability requirements [6 - 10];
- verification methods and formats [3, 4, 5, 7, 9 - 12];
- multiple outcomes and decision options [5, 7].

3. Assessment codes

In many cases, existing structures do not meet the requirements of present regulations, either because they were designed and built based on outdated knowledge compared to the currently valid provisions or because they are subject to continued deterioration [10]. Therefore, over the last twenty years, specific standards for assessing existing structures have been developed at both national and international levels. National standards are available for assessing existing structures in general and bridges in particular. Examples of the former are the Dutch standard NEN 8700 [13], the Swiss standard SIA 269 [14] and the Czech standard CSN 730038 [15], while CAN/CSA-S6-06 [16], AASHTO [17] and AS 5100.7 [18] are dedicated to bridge assessment. The assessment principles for seismic situations are provided, for example, by FEMA [19].
The international standards for assessment include ISO 13822 [20] and parts of the ICC [21]. Recently, the fib Model Code [22] has been systematically revised to provide state-of-the-art prenormative guidance and synthesis of international research with concrete industrial and engineering expertise. The main objective of the new edition is to bring together coherent knowledge and experience for both design and assessment and to provide a single code for new and existing concrete structures.
The above standards for assessing the reliability of existing structures and most of the available literature on this topic are based on approaches with multiple assessment levels and degrees of complexity [10]. The choices and preferences adopted in such documents for dealing with assessment-specific issues compared to traditional methods for designing new structures depend on national decisions, the type of engineering work being assessed or its constitutive material. Harmonisation of such different rules is therefore urgently needed.
In this context, the first generation of EN Eurocodes, published between 2002 and 2007, contains rules mainly intended for the design of new structures, and only seismic assessment and retrofitting of buildings were part of the seismic structural design code [23]. Therefore, within the framework of the second-generation Eurocodes, new technical rules for the assessment and retrofitting are planned for all types of existing structures and construction works, including geotechnical aspects, exposed to all sorts of actions. In the sense of the mentioned harmonization, those supplementary or amended provisions were first developed which make it possible to apply the material-independent general principles and rules set out in the Eurocode for structural design [11, 24] to the assessment of existing structures. The Technical Specification dedicated to this topic [4] and its further development into a new part of the Eurocode [5] are therefore not independent and only address the differences – regarding reliability aspects and actions on structures– between, on the one hand, the design of new structures and, on the other hand, the assessment and retrofitting of existing structures.
With regard to material-specific provisions, it should be noted that calculation models for quantifying structural resistance when designing new structures can be implicitly or explicitly

based on compliance with specific requirements for material properties, detailing arrangements and execution tolerances. Structures that were designed and built to withdrawn standards may not meet these requirements. In such cases, design strength models cannot be used for assessment purposes, even if the existing structure being assessed is not affected by any deterioration mechanism. To allow the assessment of the strength of structures that do not comply with the design standards, the material-specific Eurocodes need to be supplemented with additional provisions that must be consistent with the basis of assessment and retrofitting [5] and harmonized across materials. Of the material-specific Eurocodes of the second generation, only the one for concrete structures [25] initially contains an annex with specific provisions for existing structures.

4. Implementation in practice

Relevant differences between the assessment of existing and the design of new structures [7, 9, 10], along with their treatment in codes (see 3), can often lead to a high degree of conservatism when design-oriented methods are used for assessment. Unnecessary strengthening or replacement of existing structures can be the result. To avoid such unsatisfactory outcomes and related decisions, for example when using fixed partial factors for verification (see worked example in [10]), both from an economic and a sustainability point of view, reliability-based and risk-informed methods can be applied to demonstrate the sufficient reliability of existing structures. Such methods, which have been developed over the past decades, are well documented in the literature and a growing number of codes, including the Eurocodes [4, 5], allow their use in addition to the partial factor method. However, although they represent the state of the art and despite their advantages compared to standard verifications and their recognition by current regulations, these more advanced methods of demonstrating structural reliability are rarely applied in practice. Possible reasons for this situation have been identified and discussed in previous work [9, 10] and are listed below due to their importance in the context of this paper. Possible explanations include:

- reliability- and risk-based methods are time-consuming, e.g., to collect valid and sufficient input data;
- they also require specific knowledge of the responsible engineer for an assessment;
- insufficient training at early stage of engineering education;
- lack of basic knowledge of the principles of reliability and risk-based methods amid stakeholders, i.e., communication problems outside their circles among the specialists who advocate the use of these methods;
- engineers' preference for hard-and-fast rules over decision-making processes, e.g., as a result of actual or perceived liability reasons;
- lack of time and financial resources for advanced analysis, possibly because engineering services in the construction sector are viewed by owners, promoters and contractors as an expense rather than an investment;
- in connection with the previous aspect, the inefficient business model in the construction sector, which links budgets and fees to material consumption;
- low relative costs for structural interventions compared to the other costs for conversions of existing buildings or infrastructure, in cases of change of purpose or needs, where an assessment is required;
- availability of other efficient approaches and tools to assess the full capacity of structural systems, e.g., nonlinear finite element analysis, etc.

Of course, there may be other reasons, or a combination of reasons, for the sparse practical application of reliability-based and risk-informed methods. Critical analysis of practical cases can help in identification (see 5).

5. True story

5.1 Background

The bridge over the Reuss near Mühlau (Figure 1), Switzerland, is integrated into the surrounding area dominated by the river and is part of the federal inventory of landscapes and natural monuments of national importance. The trough-like superstructure consists of two steel-plated I-girders spaced 4.25 m apart and a concrete slab supported by transverse beams every 4 m. The 3 m wide single lane runs between the main girders and leaves space for 0.45 m wide shoulders on each side. The two main girders of the 80 m long bridge, which is straight in plan, are continuous over 3 spans, with the inner main span measuring 32 m and the outer spans 24 m. The upper parts of the piers consist of reinforced concrete walls, which are supported by sheet pile casings filled with concrete.

The existing bridge from 1940 was built in the first years of the Second World War. Probably due to the difficult economic situation at the time, the construction system was extremely efficient and economical. Some of the structural members show signs of deterioration, as can be expected on an 80-year-old bridge. This is the case of the pier walls and sheet piles, where ongoing corrosion has been observed, or of the main beams, which are generally in good condition and only show patches of surface corrosion. In contrast, the slab of the bridge superstructure is in a very poor state of conservation due to the lack of sealing of the road surface. Refurbishment and urgent strengthening work on the slab was carried out in 2018 and 2021, respectively. Despite these interventions, the reinforcement shows severe corrosion damage and is exposed in several places due to spalling. As a consequence of the poor condition of the deck, the bridge is currently closed to vehicles weighing over 8 t. Due to the damaged condition and insufficient width of the bridge deck, a complete refurbishment of the structure is no longer an option for the relevant authorities. It was therefore decided to replace the bridge.

In this context, a bridge design competition was organised. More precisely, it was a selective two-stage process. In a prequalification phase, those applicants were selected who were best suited to solving the task based on their proven experience and skills. The five selected teams received then a mandate of developing possible solutions.

Figure 1. Reuss bridge near Mühlau, Switzerland (Source www.schweizmobil.ch, January 2022).

According to the competition specifications, such solutions should be compatible with the goal of replacing the existing bridge with a particularly environmentally friendly structure [26]. At the same time, it should be durable, require little maintenance and repair, and minimize life cycle costs. Finally, the new bridge should be carefully integrated into the park-like cultural landscape.

5.2 Boundary conditions

Since no significant changes to the layout of the roads on either side of the bridge are planned, entries were allowed only minor adjustments to the alignment. However, improvements to the various traffic flows were not ruled out, especially with regard to an adequate connection of the new bridge, whose width was defined by the commissioning authorities as 7.6 m [26], to the existing roads and paths for pedestrians and cyclists. An additional geometric condition arises from flood protection. In practice, the corresponding requirements are met if the lower edge of the new superstructure is not lower than that of the existing bridge.

The functionality conditions included a definition of the carriageway cross-section on the bridge with a 5.0 m wide area for two lanes of traffic, a 2.0 m wide strip for pedestrians and two 0.3 m wide shoulders. If a solution that is structurally separated from road traffic should be chosen for the pedestrian path, it should have a minimum width of 2.50 m. The bridge would also need to be equipped with a drainage system that aligns with the longitudinal and transverse slopes of the carriageway and flows into a treatment basin from where rainwater is conducted to the river. Different supply lines and cable trays must be accommodated in the bridge superstructure and, last but not least, noise reduction is also a priority in terms of functionality requirements.

The ground conditions were relatively well known, as the drilling profiles from the subsoil investigation for the bridge construction were available. These profiles showed a sequence of gravel and sand layers in the upper 20 m and thus a fairly high soil load-bearing capacity.

The location of the bridge is partially within or surrounded by nature conservation and water protection areas. Furthermore, in addition to the other river fauna, in this area the Reuss is also an important natural habitat for water birds. All of these conditions should be taken into account when designing environmentally friendly solutions, not only from the perspective of the final phase of the bridge. In fact, such solutions should also enable protection of flora and fauna during construction. For the construction method to be chosen it was also relevant that a high-voltage cable runs over the bridge, to which a safety distance of 5 m must be maintained. Finally, construction methods and solutions were required that make it possible to shorten the execution time as much as possible and quickly replace the existing bridge due to its limitations in use.

5.3 Competition entry

5.3.1. Basic ideas

The basic ideas underpinning the conceptual design of the competition entry for the replacement of the Reuss bridge follow directly from the above conditions. The proposal submitted is therefore based on the principle of reusing those parts of the existing bridge that can be integrated into the new structure. This is particularly true for the main beams, which, as mentioned, are in good condition and can easily be converted or strengthened if necessary. Reusing the lower part of the piers is also straightforward, as they transfer the loads of the existing bridge to the ground and can be readily connected to a new foundation.

The reuse of these members not only significantly improves the ecological and energy balance compared to a completely new structure and thus contributes to achieving the sustainability goals, but also makes the construction of the new bridge easier because the main girders are available as a working platform throughout the entire process. This also means that construction time and costs can be significantly reduced and, more importantly, the ancillaries required for construction can be simplified, helping to protect the river environment. Aesthetically, the existing beams are particularly simple, which is typical of the first welded steel structures, and express order, equilibrium and regularity. Preserving this original appearance ensures a harmonious integration of the bridge into the sensitive natural environment.

To conceive a structure that is both reliable and robust, the design should provide for a ductile, statically indeterminate structure, given the advantages of such systems over other approaches [27]. The general design should aim to make allowance for measures to protect against specific accidental actions such as vehicle impact. A second intention is to minimise dynamic effects by eschewing expansion joints and bearings, a measure that in addition to lowering noise levels would also reduce fatigue problems and enhance durability, thereby contributing to low life cycle cost. In the same vein, the load-bearing structure must also be designed to ensure ready accessibility for inspection and maintenance.

The micromobility lane should run downstream and spatially separated from road traffic to encourage pedestrians to spend time by the river and enjoy the beautiful natural landscape. Such an arrangement of lanes allows improving the different traffic flows and their connection to the existing roads in general, not just for micromobility.

Figure 2. Competition entry based on reuse principles (Lüchinger Meyer Partner AG; CESMA Ingenieros SL; Waeber Dickenmann Steinegger Partner AG Architekten).

5.3.2. Structural system

In line with these ideas, the existing steel plated girders are used to create a new and wider trough-like steel-concrete composite superstructure (Figure 2). The 80 m long bridge is designed with a continuous three-span deck with the same span lengths as the original structure: 24 m - 32 m - 24 m. The reinforced concrete piers, like the abutments, are monolithically connected to the deck. Overall, then, the system acts like a jointless frame system. Such integral systems, provided they are designed for ductile behaviour, are not only more reliable and robust compared to other systems [27] but feature the added advantages of favourable service behaviour and low maintenance. The micromobility lane is arranged outside the trough cross-section on a lightweight construction.

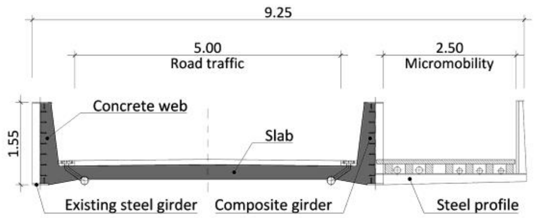

Figure 3. Superstructure cross-section.

5.3.3. Members

In keeping with the requirements for the carriageway, the total clear width and the shoulders are set between the steel-concrete composite girders (Figure 3). These are built up by connecting concrete webs to the inside of the existing steel profiles. The shape of these webs is determined by their additional function as a parapet and results in a total width of the new trough of 6.6 m. With a cross-section height of 1.55 m, given by the height of the existing steel profiles, and a maximum main span of 32 m, the slenderness ratio is 21, a conservative value for continuous steel-concrete composite girder bridges. However, the need to install parapets would not allow to further reduce the visual slenderness of the superstructure. The webs are likewise integrated into the concrete slab, which transfers the loads to the longitudinal members without transverse beams. Finally, the lightweight construction for the micromobility lane consists of steel profiles that cantilever from the downstream main beam and wooden elements.

The lower part of each pier, i.e. the existing foundation, is supplemented by a pile foundation to which it is connected (Figure 4). The upper part is replaced by a new, X-shaped reinforced concrete wall with a thickness of 0.45 m and chamfered edges to increase their visual slenderness. Its connection to the new superstructure spans the entire width of the trough. A formally and structurally equivalent solution is chosen for the abutments, with the difference that they are completely new.

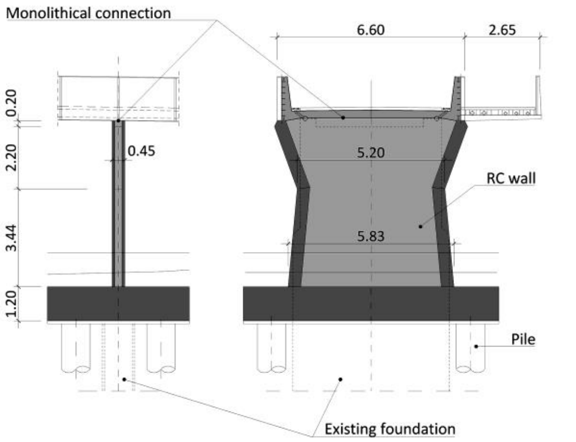

Figure 4. Bridge pier.

5.3.4. *Detailing*

Detailing, which is essential to ensure correct load transfer mechanisms and durability, requires in-depth analysis. Good detailing may also facilitate bridge construction and significantly affect its final visual impact. This bridge requires the development of special solutions for two non-standard types of connections, namely girder-pier and girder-abutment, with equivalent underlying principles. The former is shown in Figure 5. Its design is governed by the need to transfer bending moments, in addition to shear forces, from the composite girder to the reinforced concrete pier wall. A short column welded to the bottom flange of the existing steel profile ensures clear load transfer from the superstructure to the pier wall. The connection to the concrete is made using prestressed anchors to avoid long-term problems caused by repeated variable action effects. The pier reinforcement is designed to protrude into the web of the composite girder. This detailing provides for moment transfer from the girder to the pier. Transverse reinforcement is inserted on top of the concrete wall to absorb deviation forces and for confinement.

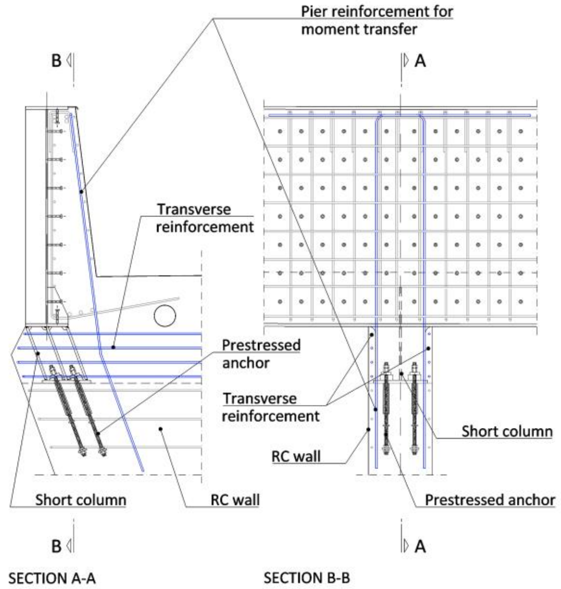

Figure 5. Monolithic connection between composite girder and reinforced concrete pier wall.

5.3.5. *Ecological and economic efficiency*

Compared to a traditional solution for replacing the Reuss bridge, which involves the complete demolition of the existing structure and the construction of a new bridge, the proposed solution, based on the principles of reuse, is extremely efficient. This applies to both ecological and economic efficiency. In terms of greenhouse gas emissions, the reuse solution is estimated to achieve a reduction of around 30%. The savings in the use of embodied energy are around 20%. And due to the reuse of existing members and the cost effectiveness of the proposed solution, a reduction in construction costs of around 80% is expected compared to a traditional solution. These savings only relate to the initial costs. Further economies can be expected from reduced maintenance and repair costs over the entire life cycle, for example due to the complete elimination of joints and bearings.

5.4 Jury's verdict

According to the conclusions of the jury responsible for evaluating the proposals of the five selected teams [26], the previously described solution is based on an original approach and is the only one that shows how the main members of the existing structure can be reused. The jury is further of the opinion that the goals of upgrading the built infrastructure and of minimizing interventions, including those in the natural environment, are consistently pursued. And that the proposal exemplifies the intensive engagement with construction culture, also in material terms.

Despite this seemingly positive assessment by the jury, the reuse solution ranks last among the solutions delivered by the five selected teams. This is of course due to the high quality of all proposals, as explicitly emphasized by the jury [26]. But the fact that the reuse solution appears at the bottom of the ranking must also be interpreted in a way that the jury does not give the high priority to achieving sustainability goals and minimizing life cycle costs as required in the design competition specifications (see 5.1). In contrast, the verdict appears to be biased towards artistic considerations. This can be inferred, for example, from the jury's comment in the sense that a reuse solution implies an artistic challenge which, in their opinion, is not given a completely convincing solution in this case.

Even more insight into jury's priorities can be gleaned from the hearings prior to the verdict. On this occasion, one of the questions asked by a jury member was whether the authors had anything to offer other than the same bridge that already exists. Behind such a question there seems to be a lack of awareness that the application of reuse principles does not hinder the design of a completely new and modern bridge. And not just through improvements to the carriageway cross-section and traffic flow organization. In the present case, the integral load bearing system is also completely different from the original one. But the jury member's question can also be an expression of the fact that authorities and promoters, in general, prefer the new. If this were the case, it could be considered the epitome of throwaway culture and should be added to the list of obstacles to the wider implementation of advanced methods for evaluating existing structures (see 4).

6. Conclusions

It is expected that, to demonstrate adequate performance of existing structures, the interest of engineers in the use of reliability-based and risk-informed methods will increase once the new European assessment standard and the new fib MC 2020, which forms the basis for design and assessment, are published and implemented in practice [10]. However, given that all these tools have been available for a long time, it seems that the engineering profession is not ready to undertake a paradigm shift towards reusing existing structural systems and elements, which would be the right way to help protect the planet, unless society puts even more pressure on the sector.

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References

[1] United Nations. Secretary-General's opening remarks at press conference on climate. July 27, 2023; https://www.un.org/sg.

[2] GLOBE - Global Consensus on Sustainability in the Built Environment, https://www.rilem.net/article/globe.

[3] ISO 2394. General principles on reliability for structures, International Organization for Standardization, ISO, Geneva, 2015.

[4] CEN/TS 17440. Technical Specification – Assessment and retrofitting of existing structures, European Committee for Standardization, CEN,

Brussels, 2020.

[5] FprEN 1990-2. Eurocode - Basis of structural and geotechnical design - Part 2: Assessment of existing structures, CEN, Brussels, 2024.

[6] Joint Committee on Structural Safety (JCSS). Probabilistic assessment of existing structures, RILEM publications S.A.R.L., edited by D. Diamantidis, 2001, ISBN: 2-912143-24-1.

[7] European Commission, Joint Research Centre. Reliability background of the Eurocodes, Publications Office of the EU, Luxembourg, JRC139110, 2024.

[8] Rackwitz R. Optimization — The basis of code-making and reliability verification. Structural Safety, 2000, 22(1): 27–60. doi:10.1016/s0167-4730(99)00037-5.

[9] Tanner P., Hingorani R., & Lara C. New or existing, does it matter? Acta Polytechnica CTU Proceedings, 36, 286–295, 2022. https://doi.org/10.14311/APP.2022.36.0286.

[10] Diamantidis D., Tanner P., Holicky M., Madsen H.O., Sykora M. On reliability assessment of existing structures, Structural Safety, 2024, 102452, ISSN 0167-4730, https://doi.org/10.1016/j.strusafe.2024.102452.

[11] prEN 1990-1. Eurocode - Basis of structural and geotechnical design, CEN, Brussels, 2023.

[12] Ellingwood B. Reliability-based condition assessment and LRFD for existing structures. Structural Safety, 1996, 18(2+3): 67-80.

[13] Nederlands Normalisatie-instituut, Dutch Standard NEN 8700. Assessment of existing structures in case of reconstruction and disapproval, The Hague, Netherlands, 2011.

[14] SIA 269. Grundlagen der Erhaltung von Tragwerken, Schweizerischer Ingenieur- und Architekten Verein, Zurich, Switzerland, 2011.

[15] CSN 73 0038. Hodnocení a ověřování existujících konstrukcí - doplňující ustanovení, Urad pro technickou normalizaci, metrologii a statni zkusebnictvi, Prague, 2019.

[16] Canadian Standard CAN/CSA-S6-06. Canadian Highway Bridges Design Code, Canadian Standards Association, Chapter 14, 15, Mississauga, Canada, 2006.

[17] AASHTO. Manual for Bridge Evaluation, 2nd Edition, American Association of State Highway and Transportation Officials, Washington DC, 2011.

[18] Australian Standard AS 5100.7. Rating of existing bridges, Sydney, Australia, 2004.

[19] Federal Emergency Management Agency (FEMA), FEMA 310 – Handbook for the Seismic Evaluation of Buildings, Pre-standard, Washington DC, USA, 1998.

[20] ISO 13822. Basis for design of structures - Assessment of existing structures, ISO, Geneva, 2010.

[21] ICC International Code Council. Existing Buildings Code, 2021.

[22] fib MC2020. Model code for concrete structures, Fédération internationale du béton, 2023, ISBN: 978-2-88394-175-5.

[23] EN 1998-3. Eurocode 8 - Design of structures for earthquake resistance - Part 3: Assessment and retrofitting of buildings, European Committee for Standardization, CEN, Brussels, 2005.

[24] prEN 1991. Eurocode 1 - Actions on structures, Drafts, CEN, Brussels, 2021.

[25] 1992-1-1. Eurocode 2 - Design of concrete structures - Part 1-1: General rules - Rules for buildings, bridges and civil engineering structures, CEN, Brussels, 2023.

[26] Kanton Aargau (Departement BVU). Studienauftrag mit Präqualifikation - Ersatzneubau Reussbrücke Mühlau, Bericht des Preisgerichts, Aarau, 2023.

[27] Tanner P., Hingorani R. Approach to robust and elegant bridge design, Structural Engineering International. 2021; 31(4): 638-648.