Acta Polytechnica CTU Proceedings **36**(0):286–295, 2022
https://doi.org/10.14311/APP.2022.36.0286

NEW OR EXISTING, DOES IT MATTER?

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Abstract. Both when designing new and when evaluating existing structures, methods of analysis must be based on established engineering theory and practice. Also, the general principles of structural reliability regarding the treatment of uncertainties when verifying the established requirements apply to both, design and assessment. Taking further into account that new or existing civil engineering works are usually unique, either because they are prototypes or because they are exposed to specific conditions, from an engineering point of view, structural analysis and verification must be carried out, both in the design and in the assessment, under case-specific conditions according to the same principles. However, important differences exist between assessment and design, for example regarding the state of information and its updating through different types of information, the structural condition, reliability requirements, verification methods or decision options. Such differences, which are briefly summarized in the contribution, can often lead to a high level of conservatism when using design-oriented methods for assessment purposes. There is therefore a need to develop a generally recognized, coherent and harmonized set of rules for the assessment of existing structures. The CEN Technical Specification for assessment and retrofitting partially closes this gap, but only establishes principles on assessment-specific reliability aspects. The consistent application of these generic assessment rules in practice requires further assumptions, or even case-specific developments. Practical applications are therefore of paramount importance in identifying relevant issues to consider in the future development of assessment methods and codes.

Keywords: Existing structures, deterioration, risk, reliability, robustness, acceptance criteria, assessment, uncertainty, updating, probabilistic methods, partial factors, codes.

1. Introduction

Current and future activities related to the development of cities, industrial areas and infrastructures should be determined by sustainability goals [1]. Changing needs are therefore not simply answered by adding new buildings and infrastructures to the existing built environment or by replacing existing with new engineering works. Rather, ways are being explored to modify existing systems to meet new demands, or simply to extend their service life. For this purpose, the performance of existing structures must be evaluated, activity that is usually denominated as assessment [2, 3]. In general, an assessment of an existing structure may be required in the case of [4]:

- 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.

Society expects the failure of any engineering structure, whether new or existing, to be an extremely rare event. As with the design of new structures, the assessment of existing structures must therefore demonstrate their ability to meet specified requirements throughout their remaining service life, with the aim of achieving an acceptably low probability of failure. It is this ability that is understood as reliability, a notion covering structural performance related to safety, serviceability, durability and other requirements that could be affected by uncertainties. Reliability analysis is therefore a fundamental part of any structural engineering activity.

Both in the design of new and in the assessment of 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 for the system under consideration [5, 6]. 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. Inasmuch as all engineering structures, new or existing, are fundamentally different as they are mostly prototypes that are exposed to specific conditions, the question could arise as to whether an assessment is basically equivalent to structural design, since in both cases structural analysis and verification must be carried out on a case-by-case basis according to the same principles. Nonetheless, there are important differences between assessing existing and designing new structures. The use of design-oriented methods to assess existing structures therefore often leads to a high degree of conservatism with serious economic, ecological and socio-political consequences if resources are invested in the unnecessary strengthening or replacement of existing structures with the associated disruptions [1].

Against this background and focusing on reliability issues, relevant differences between assessment and design are briefly reviewed in Section 2 of this article. Widely divergent approaches exist to deal with these differences. Such approaches differ according to their historical stage of development and are characterized not only by national choices and preferences, but also by differences depending on the type of structure being assessed [7]. There is therefore a need to merge the various options into a harmonized set of rules for the assessment of existing structures that complement those for the design of new structures. This was the main impetus for including the working item of assessment and retrofitting of existing structures as a high priority in the mandate for the evolution and extension of the Eurocodes to develop their second generation [1], assigned to the European Committee for Standardization, CEN, by the European Commission and the European Free Trade Association. The status of Eurocode developments on these topics is summarized in Section 3. It should be emphasized that the codes currently available mainly set out general principles of assessment-specific reliability aspects. The consistent application of such rules in practice therefore requires further, often case-specific assumptions and developments, as the contribution shows using a practical example (Section 4). In this vein, there is a need for further research and evolution in the area of assessment methods and codes. Before choosing the direction of such developments, the reasons for the sparse practical application of reliability- and risk-based methods should be identified, as suggested in the concluding Section 5.

2. Assessment versus design

2.1. Information

2.1.1. State of information

The main difference between assessing the performance in existing and design phase structures is that many characteristics whose values are merely anticipated in the latter can be measured in the former. In the assessment of an existing structure, the effects of the construction process and subsequent service life, during which it may have undergone alteration, deterioration, misuse and other changes to its, respectively, as-designed and as-built states, should also be taken into account. The accuracy of the assessment results obtained by applying load and strength models can usually be improved by collecting more data about the structure under analysis and about the actions and influences to which it is exposed (see 2.1.2). This does not mean, however, that the uncertainties can be completely resolved: in-service inspection and testing are also associated with uncertainties [4]. Therefore, assessment is conducted by stages [3], raising the quality of the information available from stage to stage.

2.1.2. Updating

The acquisition of new data about an existing structure by means of inspections, measurements or tests is intended to supplement the available prior information, which may often be vague, with respect to parameters such as geometrical properties, actions and influences, construction material and geotechnical properties, as well as the actual condition of the structure, its behaviour or deformation capacity [3]. When new information becomes available, all relevant data need to be evaluated, taking into account the existing prior information. This process is known as updating of information, which is one of the main tasks of any assessment.

Two complementary approaches can be considered to update information about the properties of a structure and its performance under the actions and influences to which it is exposed [4]:

- the updating of the probability of structural failure by using information from load testing or about the performance of the structure in the past;
- the collection of data on individual basic variables by performing on-site inspections to update previously available uncertain information.

2.2. Deterioration

Deterioration due to environmental influences, repeated actions, or use-induced wear, is typically a cumulative process that can adversely affect the reliability of existing structures. When designing new structures according to the rules of most codes, the possible combination of cumulative deterioration and extreme action effects is often neglected: durability design is usually considered separately from the design for ultimate and serviceability limit states. In some material-oriented codes, the design to prevent deterioration is based on verifications of well-defined and controllable limit states without direct negative consequences. These are often approximations to real limit states, with direct consequences, that are difficult to quantify and are therefore referred to as condition or proxy limit states [4]. Such simplifications are not appropriate for the assessment of existing structures that are already affected by deterioration mechanisms:

- reliability requirements should be verified for the combined effects of cumulative deterioration and the relevant actions and influences likely to occur during the remaining service life;

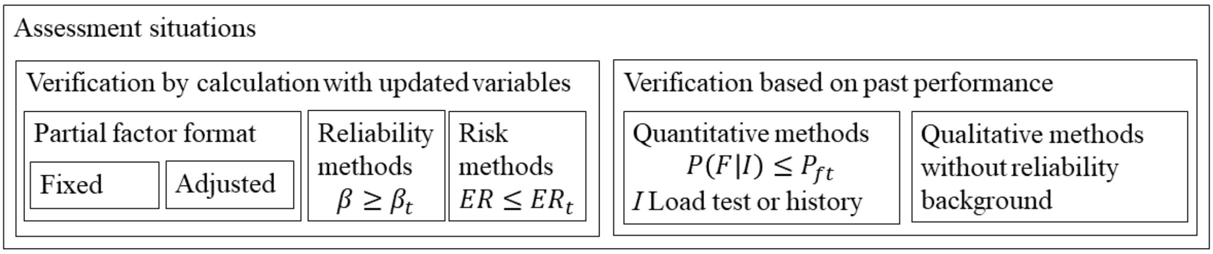


Figure 1. Quantitative and qualitative methods to verify the reliability of existing structures.

- condition limit states intended to prevent deterioration from affecting the performance of a new structure may not apply to existing structures that are affected by ongoing deterioration;
- indicators that are not based on measurable quantities cannot be used for inspection and maintenance planning.

Any verification of the reliability requirements for the combined effects of deterioration and the relevant extreme actions assumes that models are available that adequately describe the propagation of deterioration as a function of time, as well as resistance models for deteriorated structures. In this context it is also important to acknowledge that in deteriorating structures the reliability requirements should be based on a shorter reference period than the design of new structures, e.g., one year, and that verifications should be carried out for the final year of the intended remaining service life.

2.3. Reliability requirements

Although the principles and parameters to consider are the same, another relevant difference between the design of new and the assessment of existing structures manifests itself in the required level of reliability. The requirements for existing structures can often be lower than for new structures. Economic, social and sustainability considerations can justify such a choice [8]:

- the relative cost of safety measures to increase the reliability of an existing structure can be very high, while the additional cost of increasing the reliability in the design phase of new structures is generally low;
- the strengthening or replacement of existing structures can lead to the resettlement of residents, the interruption of activities or may influence the values of cultural heritage, circumstances that normally do not play a role in the design of new structures;
- extending the life of existing buildings and infrastructures or adapting such systems to new needs implies a reduction in resource consumption compared to replacing them with new structures.

Because of these circumstances, the required reliability levels for new structures can be considered conservative in most cases when used for the assessment of existing structures. In more detailed investigations, requirements, expressed in terms of acceptable failure probabilities, P_{ft}, or required reliability indices, β_t, can be derived based on an explicit risk analysis or economic optimization, meeting acceptable human safety levels, e.g. with regard to current best practice [8]. When selecting required reliability levels, it should be taken into account that the intended remaining service life of an existing structure often may be shorter than the design service life of new structures. This is particularly relevant for cases in which the consequences of failure are dominated by economic losses: lower reliability requirements make sense for shorter periods of time, as investments in structural reliability are more cost-effective when the benefits can be realized over a longer period of time [8]. It should be noted that the reference period to which the target reliability is related can be selected regardless the anticipated remaining service life. If annual reliabilities are used, the corresponding structural performance should be achieved in each year of the remaining service life (see 2.2 for deteriorating structures).

2.4. Verifications

Similar to the design of new structures, when assessing existing structures, it should be verified that with an appropriate reliability level no limit state is exceeded for all relevant assessment situations [6]. Verifications can be performed using different methods (Figure 1):

- quantitative assessment based on calculations;
- qualitative assessment based on past performance;
- combination of both types of methods.

If qualitative methods are used to assess a structure at the relevant limit states based on satisfactory past performance over a sufficiently long period of time, a detailed structural investigation should be carried out to show that several specific conditions (e.g., no damage nor deterioration, no changes to the structure or the environment, etc.) are met [6]. Note that there is no reliability background for qualitative assessment methods. On the other hand, the available information about the past performance of a structure can also be used in a quantitative assessment, for example, for direct updating of failure probabilities or for resistance updating based on action effect histories (see 2.1.2). When elaborating the results of proof load tests or track records, it is important to distinguish between conclusions related to the structure (or structural member) that was actually proof loaded and other (similar) structures or members [8]. For verification purposes (Figure 1), the probability, P, of a structural failure event represented by a limit state, F, updated by new data, I, for example in case of load survival, $P(F|I)$, is compared with the acceptable probability of failure, P_{ft}.

The most accurate way of assessment would be to explicitly consider updated load and strength variables through the use of reliability methods or risk-based decision procedures. In the case of the former, the requirements are met if the reliability index, β, determined by using updated basic variables, reaches or exceeds the corresponding required value, β_t, for all relevant assessment situations. Alternatively, reliability can also be demonstrated in terms of failure probabilities [6]. When applying risk-informed methods [6, 8], the reliability of an existing structure with significant human, economic and environmental consequences of failure is demonstrated when the expected risk, ER, also determined using updated basic variables and considering relevant assessment situations, does not exceed the corresponding acceptance criteria, ER_t.

Reliability- and risk-based methods and procedures are time-consuming, however, calling for a specific operational knowledge of probabilistic methods, and are only used in special cases. To verify whether an existing structure meets the relevant reliability requirements for all assessment situations, the partial factor format is normally used, equivalent to the format specified for structural design [5]. The difference is that the relevant parameters can be modified based on updated information [6]. This applies in particular to the characteristic values of the basic variables, while partial factors can be fixed, valid across a range of cases, or adjusted in individual cases.

2.5. Conclusions from the assessment

Although the detailed design of any engineering structure requires multiple iterative steps, the ultimate result is a clear definition of the type, layout and dimensions of the load bearing system and its individual members and details, as well as an appropriate selection of construction materials. This can be fundamentally different in an existing structure in which, after completing the assessment, different approaches may be advisable.

The staged assessment process (see 2.1.1) of an existing structure is usually completed if clear conclusions can be drawn from the findings regarding the assessment objectives, or if an additional assessment step is unlikely to provide relevant new knowledge. Depending on the assessment findings, the structure or a structural member may, within the scope of the assessment [6, 8]:

- achieve the reliability required, assuming adequate inspection and maintenance during the remaining service life;
- achieve the reliability required at the time of the assessment, but not for the complete period of time during which the existing structure is intended to remain operational, taking into account the anticipated development of its condition and the planned level of maintenance;
- fail to achieve the reliability required;
- need immediate correction of the existing condition by means of urgent risk mitigation measures.

An intervention is required for each but the first of the possible assessment outcomes, i.e., if the required degree of reliability is not achieved with regard to structural safety, serviceability or durability, or if damage propagation after local failure is possible due to lack of robustness. Interventions can include constructional or operational measures that belong to different categories [6]. Appropriate interventions should be defined case-specifically, taking account of [6, 8]:

- the type and importance of the structure;
- the type of basic requirement (i.e., robustness, structural safety, serviceability, durability) that is not met;
- possible cause and mode of attaining a limit state;
- expected consequences of failure;
- options of interventions that are available.

3. Existing structures and the Eurocodes

3.1. General

The first generation of EN Eurocodes, published between 2002 and 2007, includes rules primarily intended for the design of new structures. Additional provisions are needed to allow assessment of existing structures considering the differences between both tasks as described in Section 2. New European 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. As a first working item, the material independent general rules, on the basis of assessment and actions on structures, should be developed [1]. However, there are two exceptions to this seemingly logical priority:

- Since the first generation of Eurocodes, rules for seismic assessment and retrofitting of buildings have been part of the seismic structural design code [9]. A revised assessment part of this Eurocode is also being developed for the second generation of Eurocodes [10], including rules on the basis of seismic assessment.
- Among the second-generation material-specific Eurocodes, that for concrete structures [11] includes

an annex with specific provisions for existing structures. This document was prepared prior to the general rules on the basis of assessment [6].

CEN's standardization work programme envisages that work for all new parts of the Eurocodes, including the new rules relating to existing structures, should follow a step-by-step approach. New prenormative documents are first published as Science and Policy Reports (e.g., [1], related to assessment and retrofitting). Subject to the relevant approval, these documents are transformed and published as Technical Specifications (e.g., [3], see 3.2). After a period of trial use and comments, CEN decides whether such specifications should be converted into new Eurocodes or new parts of existing Eurocodes (e.g., [6], see 3.3). This process allows progressive development to consider observations not only from CEN members but also from national experts and users.

3.2. Technical Specification

The Technical Specification [3] is intended to provide, based on the recommendation of the pre-normative document [1], those additional or modified provisions which can allow the general principles of structural reliability, specified in the Eurocode for structural design [5, 12], to be applied to the structural assessment of existing structures. The document thus addresses the reliability-related differences between assessment and design specifications (Section 2). It also provides general principles regarding actions for assessment, complementing those for actions on structures used for design [13]. On the other hand, the document does not contain:

- specific rules for the initiation of an assessment;
- supplementary provisions for assessment and retrofitting in case of seismic actions;
- resistance models that depend on the structural system and constituent materials;
- rules on how to undertake interventions that can be carried out as a result of an assessment;
- design of new members to be integrated into an existing structure.

According to CEN's internal regulations, the Technical Specification [3] is a normative document made available at national level. However, it is important to realize that this type of document does not have the status of a Eurocode and conflicting national standards may still exist.

3.3. Eurocode on basis of assessment and retrofitting

3.3.1. General rules and actions

The starting point for converting the Technical Specification [3] into a Eurocode is that, as in the former, the rules for existing structures are not self-standing. Consequently, they only address the differences between the design of new structures and the assessment and retrofitting of existing structures and are being developed as a new part [6] of the Eurocode on basis of design [5]. Its scope includes principles related to:

- using updated data for basic action effects and strength variables, as well as for updated structural analysis and resistance models;
- structural assessment in case of retrofitting, including the assessment of retained parts from existing structures.

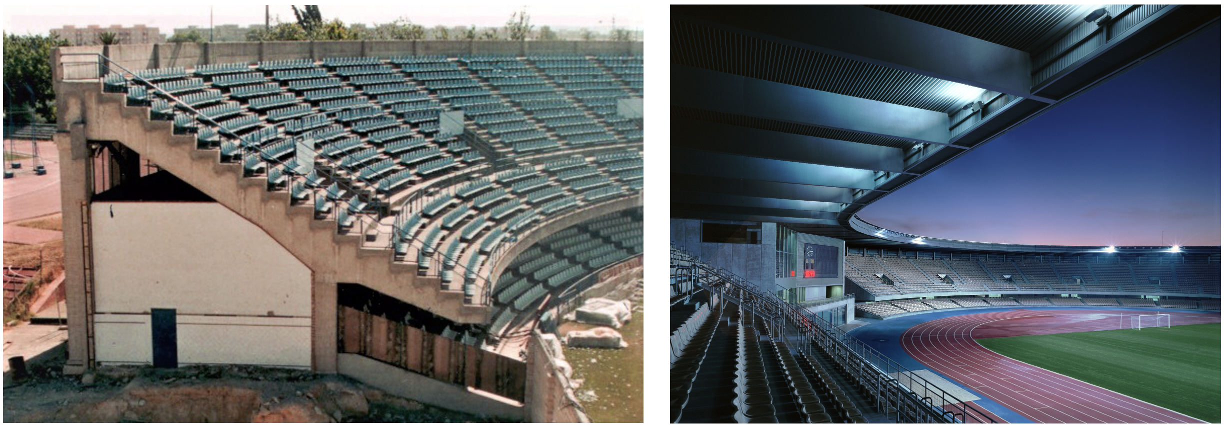
3.3.2. Material-specific provisions

Calculation models used for quantifying structural resistance in the design of new structures can implicitly or explicitly rely on specific requirements for material properties, detailing arrangements and execution tolerances being satisfied. 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 [6] and harmonized across materials. The background document [14] establishes recommendations and guidance for consideration by the code committees for the development of material-specific assessment and retrofitting provisions in the relevant future generation Eurocodes, after the end of the current mandate. The document does not contain any requirements or instructions, but it seeks to achieve a consistent approach throughout the Eurocode suite.

4. Stadium refurbishment and extension

4.1. Context

Structures should not only meet specified safety, serviceability and durability requirements with the aim of achieving an acceptably low probability of failure over a specified period of time (Section 1). Load-bearing systems are also expected to be robust [5, 6]. To reach an adequate level of robustness, many modern codes, such as the Eurocode on basis of design [5], require that the consequences of damage to structures due to an unforeseen adverse event must not be disproportionate to the original cause. Although the relevance of this feature of structures is well recognised, the clauses in structural codes and standards that seek to achieve this design goal are usually vague [15] and are mainly limited to general statements and deem to satisfy rules. To improve structural performance in terms of robustness, most known strategies require the adoption of measures in the conceptual design phase. A major problem in this regard is the lack of a general design philosophy for robustness. Therefore, any conceptual solution used may improve the



a) b)

Figure 2. Grandstand of the Chapín stadium: a) as originally built; b) after refurbishment and expansion (courtesy of Cesma Ingenieros and Cruz y Ortiz Arquitectos, © Duccio Malagamba).

structural performance for some hazard scenarios and worsen it for others [16].

Given this situation, even for apparently robust solutions, it is of the utmost importance to unequivocally identify all relevant hazards and hazard scenarios and to take them into account appropriately in the analysis. This is particularly relevant in the context of existing structures, where the adoption of measures related with the conceptual layout is normally not possible without constructional interventions. In addition, operational rules are needed to check structural robustness, beyond a list of general strategies such as those included in current codes [5, 6, 17]. These rules should comprise quantitative criteria for decision-making. A case study serves to illustrate a possible way to overcome the lack of practical rules to demonstrate sufficient robustness of an existing construction.

4.2. Structure and intervention

The existing Chapín Stadium in Jerez, Spain, a purely functional construction with no particular architectural or structural significance, was completed in 1988. The grandstands consist of in-situ concrete frames spaced 6 m apart and prefabricated concrete platforms for the spectator seats, with only the main grandstand being covered. A typical frame is constituted by an inclined beam, reaching a maximum height of about 11 m above the ground and having a standard cross-section of 0.85 m × 0.5 m, and two supporting columns about 9.25 m apart, which transfer the loads to the foundations (Figure **??**). The effective cross-sections of the outer and inner columns are 1.1 m × 0.5 m and 0.8 m × 0.5 m, respectively.

The stadium's refurbishment and expansion included the addition of a new roof (Figure **??**) and gallery to the existing grandstands. Access for the public has also been reorganized. In addition, a sports centre and a hotel were integrated into the stadium. Working areas for sports officials have been set up on two levels under the access to the main grandstand.

A section through one of the standard frames after the stadium's expansion shows the new cantilevered roof with integrated catwalk for maintenance purposes, as well as the new gallery with a 2.25 m wide slab for the circulation of the spectators (Figure **??**). The cross-section also shows the new concrete wall surrounding the entire stadium, with integrated doors giving access to the new stairs, which in turn lead to a new slab and new walkways for spectator access to the stands. In the case of the main grandstand (Figure **??**), the solution is essentially the same. The main differences are the presence of a basement and that the access to the grandstand is formed by a solid slab instead of walkways.

Steel frames are connected to the existing concrete frames to form the new roof, implying an important change of the structural system and leading to completely different internal forces and moments in the existing members than those for which they were originally designed and built. Gravity loads and positive wind pressure result in the flow of forces in the steel structure as shown in Figure **??**, and in important action effects, in particular bending moments, in the existing concrete frames. Wind tunnel tests have shown that negative wind pressure can reverse the action effects, leading to inverted bending moments in the existing concrete structure (Figure **??**).

The assessment of the existing frames for situations at sports and other events, when persons are present on and below the grandstand, is not discussed here as setting reliability requirements for structures under temporary use conditions implies specific considerations due to reduced risk exposure times [18].

Irrespective of the above situations, the office space under the main grandstand (Figure **??**) is subject to normal use conditions. The question arises whether the risks associated with the existing frames are still at an acceptable level after the change in the static system. Indeed, in particular, extreme wind loads acting on the new roof could lead to frame failure with important consequences including fatalities when

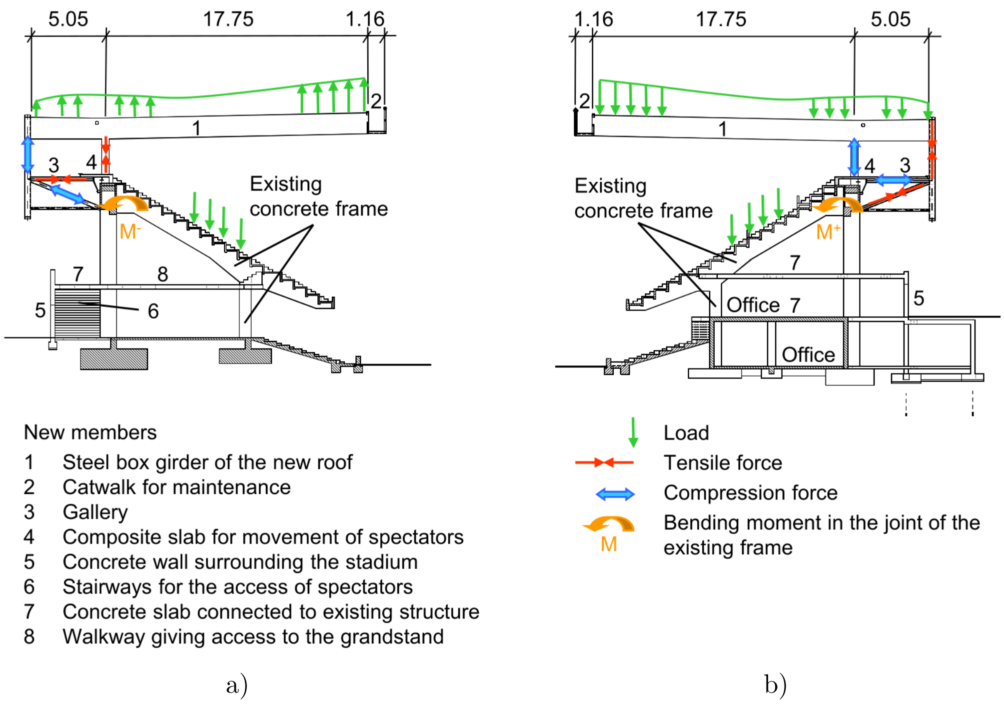


Figure 3. Cross-sections after refurbishment and expansion (courtesy of Cesma Ingenieros): a) standard frame; b) frame of main grandstand.

persons are present in the office areas. It must therefore be investigated whether the stadium conversion might lead to insufficient robustness (see 4.1).

4.3. Operational procedure

4.3.1. Reliability requirements

The target reliabilities, which may be associated with indicative consequence classes according to some codes, $\beta_{t,code}$, often pursue economic optimisation [4, 19]. When failure is assumed to entail possible human death or injury, life safety risk should also be embraced by an additional reliability requirement, $\beta_{t,LR}$. This typically occurs when considering robustness problems. In such cases, the target reliability index should therefore be taken as the greater of $\beta_{t,LR}$ and $\beta_{t,code}$. Under an operational criterion suggested [16], reliability requirements for human safety, $\beta_{t,LR}$, are inferred from current best practices and represented in Figure 4 for a reference period of one year, varying with the area affected by the collapse, A_{col}, and the respective Consequence Class, CC1 to CC3, as defined in the Eurocode [5].

4.3.2. Assessment of robustness

Inasmuch as the expected consequences of failure and the relative cost of safety measures may differ depending on the failure mode envisaged, a distinction should be drawn among reliability requirements for:

- member failure due to identified design situations: $\beta_{t,code}$;
- key member failure due to identified design situations: $\max(\beta_{t,LR}; \beta_{t,code})$;
- collapse of the remaining system still standing during and after key member failure due to an unidentified accidental situation: $\beta_{t,rs}$.

In this context, key members are those on which the strength and stability of the structural system or subsystem depend. They may be identified, then, as members in whose absence an anticipated load-bearing mechanism will develop only if suitable measures are adopted, i.e., if the corresponding structural behaviour can be verified with sufficient reliability. In terms of the remaining structural system left standing after key member failure, both the relevant design situations and the performance requirements depend on the design goal, e.g., rescuing any endangered people [16]. Given that in robustness verifications the possible failure of a key member is assumed to be due to an unidentified accidental situation, the required reliability for the remaining system, $\beta_{t,rs}$, may be lower than calculated for persistent and identified accidental situations, since conditional reliability is envisaged [5]. The required reliability, $\beta_{t,rs}$, can therefore be found by factoring in the likelihood of scenarios that might induce key member failure, a parameter for which exact values cannot be determined and discussion of which lies outside the scope of this paper. Approximate values can be drawn from empirical estimates of the likelihood of specific natural and man-made hazards, which are available in the literature [20–22].

4.4. Robustness of existing frames

In the event of a frame failure, induced for instance by unexpected extreme wind loads acting on the new roof

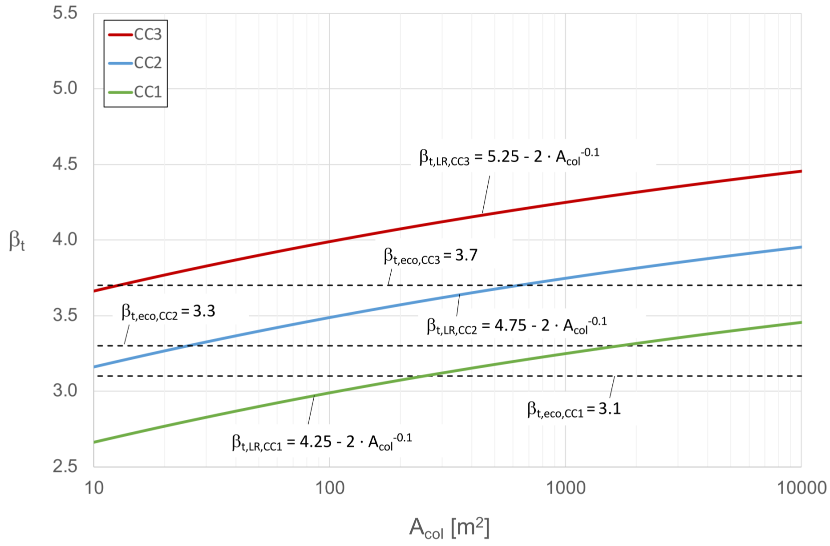


Figure 4. Annual reliability requirements for human safety, $\beta_{t,LR}$, depending on the collapse area, A_{col}, and the consequence class, CC [5], recommended for the assessment of existing structures; $\beta_{t,eco}$ [19]: tentative target reliabilities based on economic optimization for large relative cost of safety measures and different consequence classes, CC.

connected to the existing frames, collapse propagation would be prevented as the existing prefabricated transverse platforms are statically determinate without being anchored to the adjacent frames, while the transverse steelwork needed for the new gallery and for the out of plane stability of the steel frames of the new roof allow for large deformations without pulling down adjacent frames. Regardless of this collapse stop mechanism, the frames over the office areas (see 4.2) should be considered key members (see 4.3) as persons may be at risk.

A potential beam, column, joint or foundation failure of any of these existing frames, for which reliability requirements need to be established, could affect an office area of approximately $A_{col} \approx 24 \cdot 6 \cdot 2 \cdot 2 \approx 580\,\mathrm{m}^2$. With such an area possibly affected by a failure mechanism of a frame, for whatsoever assessment situation, more stringent reliability requirements may need to be imposed on frame members than on other grandstand members, in persistent and also in identified accidental situations. If the grandstand with office space is classified under standard Eurocode [5] consequence class CC2 (buildings where people normally enter, e.g., residential and office buildings), the requirement to reliably ensure human safety, $\beta_{t,LR,CC2}$ (Figure 4), that must be used in frame assessment in persistent situations is higher than the relevant requirement based on economic optimization, $\beta_{t,eco,CC2}$ [19]. The reference period used for comparison is $T_{ref} = 1$ year. On the other hand, the human safety requirement, $\beta_{t,LR,CC2}$, is considerably lower than the target value specified in the Eurocode, $\beta_{EC,1}$ [5]. Reasons for this difference are that in the Eurocode [5]:

- target values are intended for new structures where the relative cost of increasing safety is rather low, making them conservative for existing structures (see 2.3);
- no distinction is made between target and minimum requirements [23];
- annual requirements do not take into account correlation in failure events in each year of the lifetime:

$$
\begin{aligned}
&\beta_{EC,1}(CC2)\\
&\quad = 4.7 > \beta_{t,LR,CC2}(A_{col} = 580\,\mathrm{m}^2; 1\text{ year})\\
&\quad = 3.7 > \beta_{t,eco,CC2}(1\text{ year}) = 3.3
\end{aligned}
\tag{1}
$$

This result calls for partial factors for verifying frame structural safety in persistent situations that are higher than the values that would result from purely economic optimization, but lower than the values recommended in the Eurocode for design [5]. Analogously, the assessment action effects and respective strengths may have to be adjusted to verify structural safety in identified accidental situations.

5. Conclusions

Individuals and society expect civil engineering structures to be safe for users and people in their sphere of influence, and to protect the relevant tangible and intangible assets. The failure of a load bearing system should therefore be an extremely rare event. Accordingly, the ability of structures must be ensured to meet specified safety, serviceability and durability requirements with the goal of achieving an acceptably low probability of failure over a specified period of time. In this context, the methods of analysis based on established engineering theory and practice and the general principles of structural reliability with regard to the treatment of uncertainties when verifying the specified requirements are the same, both for the design of new structures and for the assessment of existing ones. That notwithstanding, there are important differences between assessing existing and designing new structures. Such differences, which are summarized in the paper along with their treatment in the Eurocodes, 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 an unsatisfactory outcome, both from an economic and a sustainability point of view, reliability- and risk-based methods and procedures 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, allow their use. 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. The question arises why? Beyond aspects like the fact that reliability- and risk-based methods are time-consuming, e.g., to collect valid and sufficient input data, and require specific knowledge and software (see also 2.4), is it because of:

- insufficient training at engineering schools, i.e., educational problems?
- insufficient knowledge of these methods among stakeholders, i.e., communication problems, outside of their circle, of the specialists who advocate the use of probabilistic and risk-based 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 perverse 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, more efficient methods and tools to assess the full capacity of structural systems, e.g., nonlinear finite element analysis?

There may be other reasons, or a combination of reasons, for the sparse practical application of reliability- and risk-based methods. That notwithstanding, or perhaps because of it, operational procedures and tools are essential for the efficient assessment of existing structures, against the background of dwindling resources and increasing awareness of sustainability issues. There is therefore a need for further research and development in the area of assessment methods and codes. In this sense, answers to the questions raised should be sought and considered when choosing the most promising way forward.

In addition, it should also be considered that recent work on the reliability background of the Eurocodes [8] has shown that on certain issues there are discrepancies between current codes and the state of the art, or that on other aspects there is a lack of sufficient scientific knowledge. Most of these issues are relevant to both the design of new and the assessment of existing structures. They are not listed here, but also represent topics for future research.

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