HERITAGE VALUE ASSESSMENT METHOD – APPLICATION TO HISTORIC STEEL BRIDGE IN PRAGUE

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ABSTRACT

Survey of heritage structures, reliability assessment and subsequent design of appropriate interventions are disciplines where intensive multidisciplinary cooperation between architects, civil engineers and heritage preservation specialists is necessary. Surveys including visual inspections, measurements and tests provide vital information for reliability assessment. Non-destructive or minor-destructive tests are generally preferred in surveys of heritage structures. However, reliability assessments providing key information for decisions on structural interventions may require more detailed insights that may only be obtained by destructive tests. This is why incomplete information from a survey overly restricted to protect heritage values may lead to imprecise reliability assessment and to suboptimal decisions on structural interventions. As a consequence, such interventions may then lead to a loss of heritage value that might have been avoided. To provide guidance for practical applications, the submitted contribution presents an analysis of segments of heritage value that may be associated with buildings or bridges. Basis of the method was recently included into the Czech standard on assessment of existing structures. Sensitivity of each segment to the invasiveness of various methods of structural surveys is then discussed, considering also the potential need for input of reliability assessment. The presented framework is applied in the case study of a historic steel bridge located in the UNESCO site – historic centre of Prague. The contribution demonstrates that the segmentation of a heritage value by heritage preservation specialists and architects often helps to identify an optimal strategy for structural survey that provides sufficient information for detailed reliability assessment of the heritage structure. The case study presents a benchmark to be further developed and refined for its effective operational use in practice in the future.

Keywords: analysis of heritage value, heritage structure, invasiveness, ISO 13822, reliability assessment, structural intervention.

1 INTRODUCTION

Survey of heritage structures, reliability assessment and subsequent design of appropriate interventions are disciplines where intensive multidisciplinary cooperation between architects, civil engineers and heritage preservation specialists is necessary. Surveys including visual inspections, measurements and tests provide vital information for reliability assessment. Non-destructive or minor-destructive tests are generally preferred in surveys of heritage structures. However, reliability assessments providing key information for decisions

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on structural interventions may require more detailed insights that may only be obtained by destructive tests. This is why incomplete information from a survey overly restricted to protect heritage values may lead to imprecise reliability assessment and to suboptimal decisions on structural interventions. As a consequence, such interventions may then lead to a loss of heritage value that might have been avoided.

To provide guidance for practical applications, the submitted contribution presents an analysis of segments of heritage value that may be associated with buildings or bridges. Basis of the method was recently included into the Czech standard on assessment of existing structures, CSN 73 0038:2019. Sensitivity of each segment to the invasiveness of various methods of structural surveys is then discussed, considering also the potential need for input of reliability assessment. The presented framework is applied in the case study of a selected historic steel bridge located in the UNESCO site – historic centre of Prague.

2 PRINCIPLES PROVIDED BY CSN 73 0038 ON ASSESSMENT OF EXISTING STRUCTURES

2.1 General

CSN 73 0038 is fully consistent with and gives supplementary guidance to ISO 13822:2010 on the assessment of existing structures. The Czech standard mainly provides principles for reliability assessment of existing structures – buildings and bridges, including guidance for:

- Surveys
- Evaluation of the obtained data
- Reliability analysis and assessment
- Interventions and upgrades

One normative chapter of the standard and an informative annex are specifically focused on load-bearing structures with a recognised heritage value and on structures that support objects with heritage value such as statues, mobile equipment and plasters (hereafter 'heritage structures'). The principles of the standard should be adequately applied also to structures that are not protected by relevant authorities and legislation, but the values of which are recognised.

Assessment of heritage structures shall cover both the following aspects:

1. Technical and reliability aspects such as mechanical resistance and stability; fire safety; requirements concerning hygiene, health and environment; safety in use; noise protection; energy, economy and heat retention, etc.
2. Principles of preserving the heritage value

These values shall be both taken into account in any decision-making about the heritage structure. An exception is made for structures of strategic importance (such as bridges included in critical transport infrastructure) where the preservation principles may be applied in a limited extent. However, the cooperation with a heritage protection authority is required.

2.1.1 Structural surveys

Reliability assessment and decisions about repair or upgrade of heritage structures shall be based on adequate knowledge about the present structural conditions and information on original construction processes and used materials, past modifications of the structural system and past exposures. Required information shall be provided by historical and heritage reports, adequate (technical) structural surveys and possibly also by monitoring.

Focusing hereafter on structural surveys, adequate methods should be selected considering:

- Invasiveness of the survey and related potential loss of heritage value (Section 4)
- Technical needs for acquiring data, e.g. by making distinction between decisions about significant interventions with severe impact on the heritage value and a small intervention with no long-term effects on the heritage value (Section 5)

Further aspects to be considered in decision-making include the type of the structure and accessibility of locations where specimens could be taken or tests made.

3 SEGMENTS OF HERITAGE VALUES

Before analysing the invasiveness of the methods and deciding on the approach to structural survey, the heritage value associated with the structure shall be defined by a relevant authority. To assist the interactions between heritage specialists and engineers, Eberhardt and Pospisil proposed methodology for assessing the heritage values of buildings and bridges through appropriate segmentation [1]. Besides providing a formal process of quantification of the heritage value, the methodology allows selecting survey methods that have no or limited impact on segments of the heritage value for which the structure is recognised. Note that the procedure can be applied to both listed and non-listed structures. CSN 730038 adopts this method and includes its main principles in the informative annex focused on heritage structures.

The methodology allows evaluating buildings and structures according to segments of their cultural significance. Sensitivity of each heritage value segment to the invasiveness of survey methods may be ranked from none (the heritage value segment is not sensitive, in the case study in Section 6 this is expressed as $S = 0$), to low ($S = 1$), high ($S = 2$), up to very high ($S = 3$).

The distinction is made between *Analytical values* and *State-of-conservation values*. Analytical values may be classified as follows:

- Age value: characterised by dated appearance of monuments, related to their incomplete form, aged materials and signs of common degradation due to standard long-term use – considering the case study presented in Section 6, sensitivity ranking is provided in this list of bullet points in brackets (sensitivity of the age value <u>very high</u>)
- Historical value: distinct coincidence of the structure to a historical epoch, event, outstanding person etc. (<u>very high</u> sensitivity)
- Use value: utility value, significant when the structure has retained its original purpose throughout time or when its use has been adapted to current needs (<u>low</u>)
- Creative (artistic and/or technical) value: artistic value of the load-bearing structure (<u>low</u>), value of the technically innovative structure (<u>low</u>)
- Surrounding value (urbanistic/landscape): linked with the qualitative context and environment of the structure including historical surroundings, specific perspectives and views, qualitative natural environment, etc. (<u>no</u> sensitivity)
- Craftsmanship value: high standard of handmade work as a sign of both abilities of the craftsman and the technological level of the society at the time of construction presents a very special part of the creative value (<u>high</u>)
- Symbolical value: recognised when the structure has become an exceptional symbol of a historical epoch, stage, event, movement, cultural, social or economic activity, etc. (<u>low</u>)

- Scientific value: relevant for monuments designed or used for scientific purposes, particularly in natural sciences or technology (high)
- Social value: associated with monuments that enable or support social connections, networks and other relations in a broad sense – social gatherings such as celebrations, markets, picnics or sport activities (low)
- Spiritual value: related to spirituality, recognised for sites of organised religious events, experiences of wonder (low)
- Uniqueness/singularity: recognition when a building or group of buildings is uncommon and/or has been built according to an isolated and outstanding plan (very high)
- Typicality/representativeness: representativeness regarding a specific movement and/or period of time, representativeness of a typology; the structure represents a typical example of its kind (very high)

Further to Analytical values, the State-of-conservation values, representing the materiality of buildings and structures, may be classified as follows:

- Integrity value: related to the comprehensiveness and completeness of what remains in the structure (very high sensitivity)
- Authenticity value (material): the structure is composed of original elements in original material and in original positions (very high)
- Authenticity value (non-material): the structure is manufactured as an exact copy according to the original structure (or documentation), using original production technology and material of the same kind as was the original one (no sensitivity)
- Transformation value: the purpose of the structure has a potential to be changed, so that it can retain its authenticity (very high)

The heritage value of a particular structure typically consists of several segments of various levels of importance.

The case study of a historic steel bridge presented in Section 6 illustrates assessment of the segments of the heritage value and their sensitivity with respect to various survey methods. Detailed discussion on the relationship between the segments of the heritage value and survey methods is provided in [1].

4 INVASIVENESS OF STRUCTURAL SURVEYS

Survey methods shall be selected to avoid significant impacts on segments of the heritage value relevant for the structure and simultaneously to provide sufficient information for reliability assessment and subsequent decision-making. When dominating segments are less sensitive to invasiveness (e.g. use, surrounding or social value), more invasive methods of the survey should be selected. When dominating, equally important segments include both less and more sensitive types of values, and survey methods should be selected regarding the impact on more sensitive segments. In all cases, it should be kept in mind that the results of less invasive methods are associated with larger uncertainty and may lead to wrong decisions about upgrades (see Section 5 for further discussion).

Focusing on historic metallic structures, inspections are mostly focused on the verification of the effects of corrosion including functionality of protective coatings, level of the corrosion (corrosion weakening and pits), fatigue (including the development of cracks, their depth, width, and length and stress concentration zones), occurrence of eccentricities in members and checks of system behaviour (functionality of joints and bearings, stress transfer). Regarding these goals, the following methods of surveys are considered [2–5]:

1. *No or negligible intervention* into the coatings and into the structure:
   a. Global tests and surveys with no or negligible invasiveness:
      ii. Static load tests, local or global dynamic tests
      iii. Monitoring of deformations – geodetic, photogrammetry, laser scanning, etc.
   b. Local surveys with no or negligible invasiveness:
      iii. Non-destructive (NDT) detection of cracking by time-of-flight diffraction, phased arrays, ultrasonic testing, magnetoscopic examination and eddy current testing
      iv. Metal magnetic memory detection for stress concentration zones and cracks detection related particularly to fatigue
      v. Radiography testing (associated with health risks)
2. *Local damage to coatings and surface* of the material:
   a. Non-destructive (NDT) hardness tests related to the strength of materials
   b. Surveys of coatings: thickness, chemical composition, layers analysis, adhesion tests and colour
3. *Small intervention into the structure*: chemical composition, metallography, endoscope inspection through small holes – minor intervention, small specimens with a size of one or a few centimetres to be taken and small openings to be cut out
4. *Destructive (DT) tests*: tensile coupon tests, tests of fracture toughness – specimens of dimensions exceeding 10 × 3 cm to be taken; their number is commonly specified in relation to relative fraction of the cross section (say, 1% to be covered) and with the aim of reducing statistical uncertainty (typically at least three tests are required for a homogeneous material)

5 IMPLICATIONS OF UNCERTAINTIES OF SURVEY METHODS

CSN 730038 clearly indicates that NDT methods should be preferred in surveys of heritage structures. When the use of DT methods is necessary, DT tests should be carried out at locations where structural resistance and heritage value are not affected. This may be broadly possible. In specific cases, however, it might be difficult to follow this principle. For instance, when local defects are observed or expected to occur due to possibly insufficient material properties, it may be difficult to judge on material properties in the location considering the results of material tests from other locations with a likely higher-quality material.

The standard recognises that the results of less invasive methods are mostly associated with higher test or measurement uncertainties. This is why it should be carefully assessed whether or not the use of a less invasive method is likely to yield a wrong decision about structural reliability, implying unnecessary interventions or accepting a ‘no upgrade’ strategy when structural reliability is too low and the safety of users and the heritage value may be endangered by structural failure.

These principles are in agreement with the Guide for the Structural Rehabilitation of Heritage Buildings by CIB [6]. The Guide indicates for structures with any level of protection that NDT methods are preferable. If they are insufficient, destructive tests will be considered, but they will be carried out only after a cost–benefit analysis considering test costs, loss of heritage value due to testing, and the benefit due to the use of a DT method is completed. The illustration of the full cost–benefit analysis and decision-making about surveys of a historic masonry structure is provided in [7].

Keeping the focus on the assessment of historic metallic structures, an important decision between the use of NDT hardness-based and DT (tensile tests) methods is to be made. Recent studies [8, 9] thoroughly investigated the uncertainties in the most common NDT methods. Figure 1, adapted from [8], displays the variability of the error in estimating the characteristic steel yield strength with a number of NDT or DT results. Error is defined as the ratio of true strength and strength statistically inferred from tests. The values above unity indicate conservative estimates. Important is to note that mechanical properties of plates and profiles often significantly vary even within a structure as they may come from different mills. This is why Fig. 1 refers to the situation where the structure is made from one type of steel elements.

Figure 1 clearly shows that the error approaches unity effectively for a very small number of DTs, say up to five. In contrast, the measurement uncertainty results in a scatter of NDTs and the error remains far from unity (converging to about 1.15, retaining its large scatter). This suggests that, on average, the true characteristic strength is ~15% larger than that based on a very large number of NDTs, while the five DTs make the estimate reasonably unbiased. The main reason for this difference is that the variability in NDTs is commonly larger than that of steel yield strength and increased variability inevitably results in lower estimates of the characteristic values. Fifteen per cent is thus the expected gain when the characteristic value of steel yield strength is estimated based on five DTs instead of a large number of NDTs. While similar observations are expected to apply for wrought irons [10], the use of tensile and compressive tests (DTs) is recommended for cast iron structures due to the inherent variability of their strength, the weaker relationship between the hardness of surface layers and tensile or compressive strength, and the overly conservative estimates of cast iron properties provided in normative documents [11, 12].

Further to measurement or test uncertainty, survey methods should be further selected considering the level of accuracy required for information. This depends on the difference between the actual structural reliability (normally unknown prior survey) and the target reliability level. In more practical terms, the difference can be quantified through the ratio ϕ – the ratio of:

- The strength based on preliminary investigations such as NDT surveys or historical reports

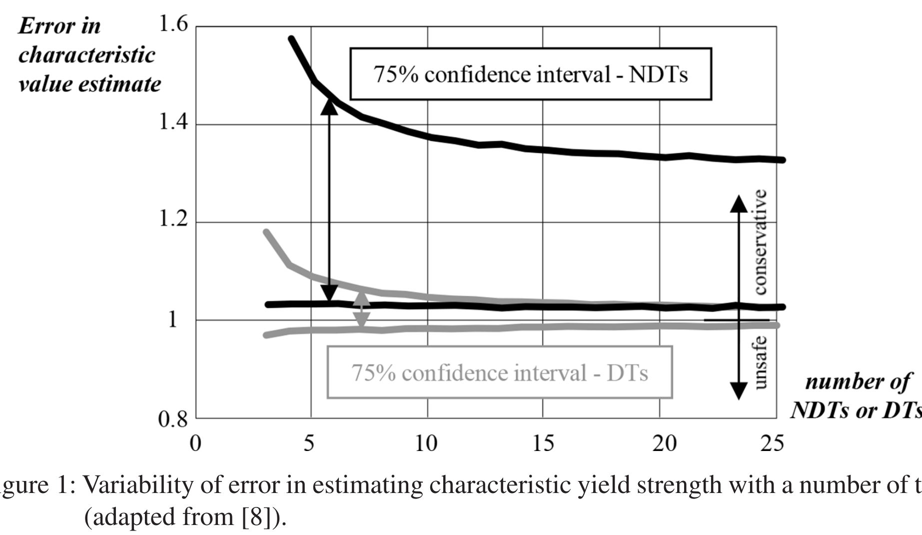

Figure 1: Variability of error in estimating characteristic yield strength with a number of tests (adapted from [8]).

and information by a producer of the material to

- The strength required to meet reliability requirements (mostly according to the assessment based on valid codes of practice)

The importance of this aspect typically leads to an adaptive strategy – first apply non-invasive techniques (particularly when heritage value can be affected) and then, if needed, proceed with a detailed assessment based on more invasive techniques. The second phase should be carefully planned as follows:

- Poor information based on non-invasive techniques may lead to erroneous decisions about upgrades or incorrectly accepted low reliability of the monument.
- The effect of an invasive survey on the heritage value may be small or negligible when the dominating segments are insensitive or when specimens for DTs can be obtained from parts of structure, that is, for instance hidden from view of the public or from parts of the structure to be replaced for some other reason.

Application of the adaptive strategy is illustrated in Fig. 2, where the optimum number of DTs, n_{DT}, is indicated as a function of the ratio ϕ and failure consequences. It is assumed that a preliminary survey is based on non-invasive techniques (NDT), the ratio ϕ is computed, and then DTs are taken in the second phase to supplement the NDT survey and calibrate the NDT results. Failure consequences should cover all expected economic, societal and environmental consequences (ISO 2394:2015 for the general principles of structural reliability), as well as the damage to the heritage value [1].

Figure 2 demonstrates several important principles:

1. The results show that the optimal number n_{DT} generally increases with increasing failure cost.
2. When the NDT survey indicates that the reliability requirement is exactly fulfilled, $\phi = 1$, it is beneficial to calibrate the NDTs by at least one DT even for low failure cost. Due to

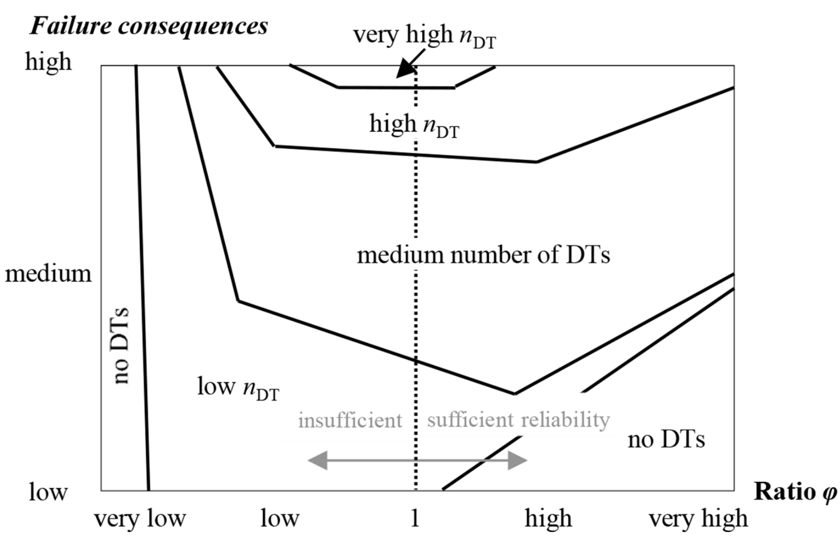

Figure 2: Optimum number of DTs as a function of ratio ϕ and of failure consequences.

uncertainty in the NDT method, ϕ must well exceed unity to have sufficient confidence in the decision *keep as it is* without calibration by any DT.

3. Similarly, in the case of a very unfavourable outcome of the NDT survey, only very low ϕ-values are so negative that it is beyond doubt that an *upgrade* is needed and no DT is needed. In cases 2 and 3, additional DTs would be a waste of effort as the likelihood of changing the decision (2 – *keep as it is*, 3 – *upgrade*) based on NDTs is negligibly small.

In cost–benefit analyses that lead to strategies similar to that in Fig. 2, essentially two cost components are being balanced:

- Incremental cost due to an additional DT including possible loss of the heritage value
- Failure cost reduced by the improved assessment based on an additional DT as there is always little chance of taking a wrong decision based on DTs performed

In general, for very low ϕ the upgrade cost dominates the total costs, the true strength is unlikely to exceed the required level, and thus an optimum decision on upgrade can be based on NDTs only. With increasing ϕ (yet below unity), the upgrade cost is still dominating, but a suboptimal decision can be made if considering NDTs only.

For medium and high failure costs which exceed the upgrade cost by far, any higher ϕ-value and DTs become necessary. For these structures, the failure cost is important and the test costs are outweighed by the information gained.

A detailed numerical study demonstrating the cost–benefit analysis of a historic masonry wall is provided in [7].

6 CASE STUDY OF HERITAGE BRIDGE – CECHUV MOST IN THE CITY CENTRE OF PRAGUE

The case study is focused on the bridge of Svatopluk Cech (Cechuv most in Czech, hereafter ‘the bridge’); see Fig. 3. The bridge spans over the Vltava River in the city centre of Prague, Czech Republic (UNESCO heritage site).

A three-span steel-arch structure was completed in 1908, and since then, the bridge has been serving for road, tram and pedestrian traffic. The bridge is equipped with rich fine-arts decorations. Since 1958, it is a part of the Prague Heritage Site; in 1975, it was listed in the Czech cultural monuments register, and since 1992, it has been a part of the Historic centre of Prague listed in the UNESCO World Heritage List.

During its service life, several repairs have been carried out and some parts of the structure (particularly the bridge deck) have been strengthened or replaced due to degradation, local

Figure 3: View of the bridge of Svatopluk Cech.

damage due to traffic accidents or due to the need of adapting the structure to meet demands of modern traffic. The main load-bearing structure retains its original values, unaffected by major interventions; the original coating has been replaced by new painting.

The case study is specifically focused on steel arches – the main load-bearing structure of the bridge. Table 1 indicates the effect of survey methods (Section 4) on the segments of the heritage value (Section 3) considering the bridge under investigation (main load-bearing steel structures only). In the table, level of each heritage value segment is ranked from L = 0 (none – the bridge entirely lacks this value), 1 – poor, 2 – below average, 3 – average, 4 – above average, to 5 – excellent. The L-values are specific to this bridge (L denotes the actual level; Lr is the level possibly reduced by application of a survey method).

Two factors are then included to indicate the sensitivity of a segment to a survey method:

- S-values give general indications, representative for a number of heritage buildings and bridges and a range of survey methods. It ranges from 0 – none (no effect of application of survey methods on a heritage value segment) – to 3 (very high impact). An S-value just provides the first insight into possible sensitivity of the segment.
- In contrast, the r-coefficient is specific to the bridge, its segments of the heritage value and to a particular group of methods (1–4 as defined in Section 4). The indicator ranges from 0% to 100% and gives a fraction of the heritage value segment that is damaged (lost) by applying the survey method.

It is important to emphasise that particularly r-values reflect not only the quality of measurements (typically proportional to invasiveness) but also related quantity expressed, e.g. through a number of locations, damage at the location and number of specimens to be taken. Commonly, surveys of heritage structures follow minimum requirements of technical standards. It is considered that the application of the methods in Table 1 would require the following (all indications per one arch; they should be considered to present minimum requirements to provide sufficient information for reliability assessment):

- Local damage to coatings and structure (2) – 20 locations where coating would be removed and the surface grinded
- Small intervention into structure (3) – fifteen small fragments
- DT tests (4) – five specimens for each type of a structural member (e.g. plates and L-profiles)

The Lr-level is related to a segment and survey method, and it is obtained as the product of an initial level, L, and effect of the method, r: $Lr = (1 - r) \times L$.

Note that all the L, S and r-values are based on judgement of experts on heritage preservation and structural surveys and analysis.

The analysis of the Lr-values in Table 1 indicates that the use of:

- No intervention methods – group of survey methods (1) in Section 4 – has no effect on the heritage value
- NDT methods causing local damage to coatings and structural surface (2) has already some effect on the heritage value (its loss might be around 1%)
- Small intervention methods (3) and destructive testing (4) has significant effect (associated losses around 2% and 5% respectively)

Table 1: Effect of survey methods on the heritage value segments (Cechuv most in Prague, steel arches – main load-bearing structure).

Heritage value segment	Level of heritage value segment	L	S	No intervention methods (1)*	Local damage to coatings (2)	Small intervention into structure (3)	DT methods (4)
Age	Average – main load-bearing trussed arches remain preserved with the exception of few cross members; original paint has been entirely replaced	3	3	$r = 0$ $Lr = 3$	$r = 0.05$ (Damage to coatings yields the loss of the age value. Usually some historical layers are lost. Nevertheless, a new age value begins to form.) $Lr = 2.85$	$r = 0.08$ (These tests cause local material loss with a more unfavourable impact than methods (2), but lower damage than DT methods. The specimens can be cut out in hidden places where the effect on the age value is reduced.) $Lr = 2.76$	$r = 0.1$ (DT tests require removing parts of original elements. The age value related to a long-term use is then lost at the location. Usually, removing a part of an element cannot be fully hidden.) $Lr = 2.7$
Historical	Above average – the era of construction related to important industrial, economic and political growth of Prague	4	3	$r = 0$ $Lr = 4$	$r = 0.03$ (Loss of historical coatings is the loss of information about the way how the structures were originally protected.) $Lr = 3.88$	$r = 0.05$ (Loss of a historic material is the loss of information about the way how the material was composed and produced.) $Lr = 3.8$	$r = 0.1$ (Loss of a historic element or of its part is the loss of information about the way how the structure was originally designed and manufactured.) $Lr = 3.6$

Use	High – the bridge serves as an urban bridge with high intensity of road and tram traffic	5	1	$r = 0$ $Lr = 5$	$r = 0$ $Lr = 5$	$r = 0.01$ $Lr = 4.95$	$r = 0.03$ $Lr = 4.85$
Creative (artistic)	Excellent – the load-bearing structure is visible; it was intended as a complementary part to the fine-arts decoration	5	1	$r = 0$ $Lr = 5$	$r = 0$ $Lr = 5$	$r = 0.01$ $Lr = 4.95$	$r = 0.02$ $Lr = 4.9$
Creative (technical)	Above average – the quality of engineering works is above average, designed by most respected Czech engineers of that era. Uncommon use of low arches (criticised as being overly progressive). The only metal arch bridge in Prague at the time of construction innovative in Europe (a similar concept as Pont Alexandre III in Paris). Technologically advanced solution	4	1	$r = 0$ $Lr = 4$	$r = 0$ $Lr = 4$	$r = 0.02$ $Lr = 3.92$	$r = 0.05$ $Lr = 3.8$
Craftsmanship	Above average – the quality production, precisely assembled elements, excellent craftsmanship of cast and wrought elements	4	2	$r = 0$ $Lr = 4$	$r = 0.03$ $Lr = 3.88$	$r = 0.05$ $Lr = 3.8$	$r = 0.08$ $Lr = 3.68$

Symbolical	Above average (related to the bridge as a whole) – intended and became a symbol of the Czech national political and economic growth (as evidenced by tender conditions issued specifically for Czech authors and companies, the name of the bridge after a prominent Czech poet)	4	1	$r = 0$ $Lr = 4$	$r = 0$ $Lr = 4$	$r = 0$ $Lr = 4$	$r = 0.02$ $Lr = 3.92$
Scientific	Below average – never intended and never used for scientific experiments. Only standard historical, heritage and technical research carried out	2	2	$r = 0$ $Lr = 2$	$r = 0$ $Lr = 2$	$r = 0.02$ $Lr = 1.96$	$r = 0.05$ $Lr = 1.9$
Social	Above average (whole bridge) – at the end of the 19th century, there was a strong social pressure from citizens to build a bridge from the Old Town to the other riverbank. The bridge became the most important in its area. In 1950s, a gigantic sculpture of Stalin built on Letna Hill above the bridge. In 1989, during the Velvet Revolution, this hill was a meeting place for young people	4	1	$r = 0$ $Lr = 4$	$r = 0$ $Lr = 4$	$r = 0$ $Lr = 4$	$r = 0.02$ $Lr = 3.92$

Spiritual	0 – No spiritual value	0	1	$r = 0$ $Lr = 0$	$r = 0$ $Lr = 0$	$r = 0$ $Lr = 0$	$r = 0$ $Lr = 0$
Urbanistic	Average (whole bridge) – intended as important part of the urban development of Prague. Extends Pařížská street connecting the bridge with the Old Town. Planned extension of the bridge by a street or a tunnel in the direction to Letna (not implemented)	3	0	$r = 0$ $Lr = 3$	$r = 0$ $Lr = 3$	$r = 0$ $Lr = 3$	$r = 0$ $Lr = 3$
Landscape	Average (whole bridge) – important part of the picturesque city landscape along the Vltava River	4	0	$r = 0$ $Lr = 4$	$r = 0$ $Lr = 4$	$r = 0$ $Lr = 4$	$r = 0$ $Lr = 4$
Uniqueness (singularity)	Between average and above average – the bridge is structurally unique. However, load-bearing structures of this type (trussed arches) are common	4	3	$r = 0$ $Lr = 4$	$r = 0.01$ $Lr = 3.96$	$r = 0.03$ $Lr = 3.88$	$r = 0.08$ $Lr = 3.68$
Typicality	Low (whole bridge) – the bridge and its load-bearing structure were never intended for a series production	1	3	$r = 0$ $Lr = 1$	$r = 0.01$ $Lr = 0.99$	$r = 0.02$ $Lr = 0.98$	$r = 0.05$ $Lr = 0.95$

Integrity	Between above average and excellent – due to the bridge, its surroundings underwent significant changes in 1950s. However, the load-bearing structure has always been completed during the repairs (some original deteriorated members replaced by identical new profiles)	5	3	$r = 0$ $Lr = 5$	$r = 0.01$ $Lr = 4.95$	$r = 0.02$ $Lr = 4.9$	$r = 0.07$ $Lr = 4.65$
Authenticity (material)	Above average – about 20% of original elements in the load-bearing structure have been replaced due to deterioration	4	3	$r = 0$ $Lr = 4$	$r = 0.03$ $Lr = 3.88$	$r = 0.07$ $Lr = 3.72$	$r = 0.1$ $Lr = 3.6$
Authenticity (non-material)	Above average – the load-bearing structure has been renewed using elements and profiles very close to the original ones. However, in some cases, profiles identical to those from the 19th century have been unavailable; a few originally riveted joints have been screwed during the repairs	4	0	$r = 0$ $Lr = 4$	$r = 0$ $Lr = 4$	$r = 0$ $Lr = 4$	$r = 0$ $Lr = 4$

Transformation	Below average – the structure as a whole can only be used as a bridge or a footbridge. If the bridge is demolished, some load-bearing elements (e.g. trusses) can be used separately (as an extreme example)	2	3	$r = 0$ $Lr = 2$	$r = 0.01$ $Lr = 1.98$	$r = 0.03$ $Lr = 1.94$	$r = 0.05$ $Lr = 1.9$
Total value, ΣL		62	Total value, ΣLr (% of ΣL)	62 (100%)	61.37 (99%)	60.56 (98%)	59.05 (95%)

*See Section 4 for groups of survey methods.

It is emphasised that these estimates provide an overall picture of possible effect of applying survey methods. When identified that significant losses of the heritage value might be caused, structural surveys must be carefully planned (methods, locations and quantity), considering heritage value segments that are endangered. In the case of DT methods (4), the main losses are expected to be associated with age, historical, integrity and authenticity (material) values.

The case study demonstrates that the segmentation of the heritage value makes it possible to better analyse the effect of survey methods on segments that are main source of the heritage value of the structure. Further, the break-down of a complex task – assessment of invasiveness of survey methods on the heritage value – into smaller sub-tasks (assessment of effect on a segment) facilitates discussions between individual experts on particular segments. The numerical evaluation of invasiveness effect provides merely estimates, yet it may help to better interpret the knowledge about heritage value segments and potential effects of the survey methods.

7 SUMMARY AND CONCLUSIONS

ISO 13822:2010 and the supplementary Czech standard CSN 73 0038:2019 provide the principles of reliability assessment of existing structures including structures with the heritage value. Assessment of heritage structures shall cover both technical and reliability aspects (including safety of users) and the principles of preserving the heritage value.

Structural surveys provide key information about actual conditions of the heritage structure. Adequate methods should be selected considering:

- Technical needs for acquiring data
- Invasiveness of the survey and related potential loss of heritage value

The contribution shows that non-destructive test methods (typically non-invasive) are associated with large measurement uncertainties that may lead to underestimation of structural capacity and thus to unnecessary or inadequate upgrades. Next, survey methods should be further selected considering the level of accuracy required for assessment. This depends on the difference between the actual structural reliability (normally unknown prior survey) and the target reliability level. An adaptive strategy commonly needs to be adopted – first non-invasive techniques are applied and then, if needed, a detailed assessment is based on more invasive techniques.

Evaluation of invasiveness of survey methods can be assisted by using the method of segmentation of the heritage value for which the structure is recognised. The distinction between Analytical values and State-of-conservation values can be made. Survey methods shall be selected to avoid significant impacts on segments of the heritage value relevant for the structure and simultaneously to provide sufficient information for reliability assessment.

Application of the general principles is demonstrated by the case study of steel arches – the main load-bearing structure of the bridge of Svatopluk Cech (part of a UNESCO heritage site). Surveys of historic metallic structures are mostly focused on verifying the effects of corrosion, fatigue, occurrence of eccentricities and checks of system behaviour. Regarding these goals, survey methods may be grouped into (1) no intervention, (2) surface damage, (3) small intervention and (4) destructive test methods.

The case study illustrates how heritage value segments, relevant for the bridge and unaffected by survey, can be ranked (level L). Invasiveness of a survey method with respect to a particular segment is evaluated by the *r*-value that reflects both quality and quantity of measurements.

For each heritage value segment, the associated level is updated to reflect the expected effect of the survey method, $Lr = r \times L$. The analysis of updated *Lr*-levels indicates that for the steel arches under consideration, the use of methods (1) and (2) has no or small effect on the heritage value, while the application of methods (3) and (4) may have significant impact. This screening provides an overall picture of possible effect of applying survey methods. As significant losses of the heritage value might be caused, structural surveys must be carefully planned (methods, locations and quantity), considering heritage value segments that are endangered. The case study also indicates that the break-down of a complex task – assessment of invasiveness of survey methods on the heritage value – into smaller sub-tasks (assessment of effect on a segment) could facilitate discussions between individual experts on particular segments. The case study presents a benchmark to be further developed and refined to support effective operational use of the method of heritage value segmentation in practice.

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