ADVANCED ASSESSMENT OF INDUSTRIAL HERITAGE BUILDINGS FOR SUSTAINABLE CITIES' DEVELOPMENT

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Summary

The industrial heritage structures are mostly of significant architectural, historic, technological or social value, often form a part of the urban landscape and provide the cityscape with visual historical landmarks. However, insufficient attention to recognizing and protecting the industrial heritage may lead to their extinction.

Protection including adaptations and re-use of the industrial heritage structures may positively contribute to the sustainable development by preservation of the cultural values, avoiding wasting energy and facilitating the economic regeneration of regions in decline. It follows that the protection has considerable ecological and social contexts and may directly represent policy of the sustainable development.

When dealing with the preservation of heritage buildings, it is mostly difficult to propose construction interventions that respect all requirements for preservation of the heritage value. Modern principles of interventions seem to include aspects of removability, minimum repair, respect of the original conception and durability and compatibility of materials.

In many cases significant uncertainties related to actual structural conditions can hardly be realistically described by simplified procedures used for design of new structures without overly conservative assumptions. Therefore, application of probabilistic methods is proposed to better describe the uncertainties and take into account results of inspections and tests and the satisfactory past performance.

Desired protection of the industrial heritage structures requires a public recognition of the industrial heritage to be equally important as other cultural heritage. Introduction of educational programs and relevant legislation is needed.

Keywords: industrial heritage, structural assessment, sustainable development

1 Introduction

A number of factories, warehouses, power plants and other industrial buildings, built since the beginning of the Industrial Revolution in the second half of the eighteenth century, has

been registered as industrial cultural heritage in the Czech Republic and abroad. Such structures are mostly of significant architectural, historic, technological or social value [1]. They often form part of the urban landscape and provide the cityscape with visual historical landmarks. However, insufficient attention seems to be paid to systematic recognizing, declaring and protecting the industrial heritage in many countries including the Czech Republic. This is an alarming situation as the lack of attention and awareness of the industrial structures may gradually lead to their extinction [2].

When out of use, the industrial heritage buildings are degrading and often turning into ruins. Re-use and adaptation of such buildings allow for integration of the industrial heritage buildings into a modern urban lifestyle and help protect cities' cultural heritage [2]. These buildings are often adapted to become hotels, museums, residential parks, commercial centres etc.

This paper attempts to increase awareness of the high architectural and cultural significance of the industrial buildings and indicate positive influence of their preservation on the sustainable development of cities. In addition the paper is aimed to promote discussion among experts on sustainable use of the industrial heritage structures. Framework for complex reliability assessment of such structures is provided.

2 Importance of protection of the industrial heritage for the sustainable development

Protection (including adaptations and re-use) of the industrial heritage structures is an important issue of the sustainable development of cities. More specifically, it has been recognised in [1,3] that the protection and re-use may positively contribute to the sustainable development by:

- preservation of the cultural values,
- recycling of all potential resources and avoiding wasting energy,
- facilitating the economic regeneration of regions in decline that may provide psychological stability for communities facing a sudden high rate of unemployment.

It follows that the protection has considerable ecological and social contexts that are becoming even more important due to the global shortage of energy, economic crisis and environmental protection. The re-use of the industrial heritage is thus no longer an isolated issue, but is of general significance and may directly represent policy of the sustainable development. The protection of historical sites and the full use of limited resources deserve considerable public attention and participation.

3 Initiatives concerning the industrial heritage

The protection of the industrial heritage is a multidisciplinary topic including historical, architectonic, civil engineering and ecological aspects. First initiatives aimed at research and conservation of industrial buildings started in 1950s on an amateur basis [3]. In 1973 the Society for Industrial Archeology was established and the First International Congress on the Conservation of Industrial Monuments took place. When the third congress was held in 1978, the International Committee on the Conservation of the Industrial Heritage (TICCIH) was founded to study, protect, conserve and explain the remains of industrialisation.

The recent cooperation of TICCIH and the International Council on Monuments and Sites (ICOMOS) has resulted in registration of more than 40 industrial sites in the World Heritage List, such as Völklingen Ironworks in Germany (**Fig. 1**).

Fig. 1 Völklingen Ironworks in Germany

In the Czech Republic numerous industrial heritage structures including structures of railways infrastructures, breweries, sugar factories, and other industrial structures were built in the period from 1870 to 1930. Due to historical reasons, views of Czech architects and civil engineers on protection of the industrial heritage are often considerably different [4] and an important issue may then be to achieve consensus on significance of the heritage value to be preserved. To provide a desired coordinating platform for experts in the fields of historical-structural research, monument conservation, and the reconstruction of the industrial heritage buildings and sites, the Research Centre for Industrial Heritage has been established as an independent research institution of the Czech Technical University in Prague. The Centre - the Czech local representative in TICCIH - synthesises findings from various research fields, maintains a database of the Czech industrial monuments (containing more then 10 000 monuments) and seeks for new uses of the industrial heritage buildings.

To promote discussions among experts from various fields, the international conference Vestiges of Industry (www.industrialnistopy.cz) is organised every two years. On the occasion of the 3rd biennial conference held in 2005 international cooperation

relating to the conservation, documentation, promotion and interpretation of a common European industrial heritage was declared. The activities that deserve special attention include:

- the promotion of education, knowledge and a deeper understanding of the industrial heritage by conferences, seminars and educational programmes,
- the evaluation and conservation of industrial heritage,
- the conversion of industrial heritage to new uses as a positive form of cultural potential with the objective of revitalising industrial regions, towns and brownfields in decline.

The declaration is available on the conference web sites.

In 2009 the Czech Technical University in Prague and the University of Applied Sciences in Ås (Norway) have launched the research project Assessment of historical immovables, mainly focused on assessment of the industrial heritage structures. The project is aimed at developing the general methodology for the complex assessment of the industrial heritage structures that is an inevitable part of their preservation. The innovative methods based on probabilistic approaches and optimisation techniques are being developed to provide operational tools and background information for decision making concerning the protection, conservation, renewal and extended use of the industrial heritage structures. The target group of the project includes researchers, designers, practicing engineers, cultural heritage management and local authorities involved in preservation of cultural heritage.

4 Principles of design of construction interventions

As a rule re-use and adaptation of the industrial buildings require assessment of structural reliability. It has been recognised that many heritage structures do not fulfil requirements of present codes of practice. Minimisation of construction interventions is required in rehabilitation and upgrades, but sufficient reliability should also be guaranteed. When dealing with the preservation of heritage buildings, it may be difficult to propose construction interventions that respect all requirements for preservation of the heritage value. According to [5] modern principles of interventions seem to include the following aspects:

- removability,
- unobtrusiveness and respect of the original conception,
- safety of the construction,
- durability and compatibility of materials,
- balance between cost and available financial resources.

5 Differences between assessment of heritage structures and design of new structures

Decisions about adequate construction interventions should be based on the complex assessment of a structure considering actual material properties, use and environmental conditions. However, it appears that insufficient attention has been paid by experts to specific issues of reliability assessment of such structures so far. Only few scientific

publications seem to be available [2,3,6]. The following differences between assessment of heritage structures and design of new structures should be carefully considered:

- Social and cultural aspects - loss of cultural and heritage values, in some cases also restrictions or relocation of users and performance (these aspects do not influence design of new structures),
- Economic aspects - additional costs of measures to increase reliability of a heritage structure in comparison with a new structure (at a design stage cost of such measures is normally minor while cost of strengthening and in some cases also costs related to unavailability of a structure are much higher),
- Principles of the sustainable development - waste reduction and recycling of materials (these aspects may be more significant in case of the assessment of heritage structures),
- Lack of information for the assessment of the heritage structures - commonly, characterization of the mechanical properties of materials is difficult, expensive, but also very important due to variability of mechanical properties and changes that may have occurred during the working life of a structure (influence of deterioration and damage).

6 Probabilistic assessment of the industrial heritage structures

Significant uncertainties related to actual material properties and structural conditions usually need to be considered in the reliability assessment of the industrial heritage structures. Application of simplified procedures used for design of new structures may lead to expensive repairs and losses of the cultural and heritage value.

In accordance with EN 1990 [7] and ISO 13822 [8], a general probabilistic procedure is thus proposed to improve the reliability assessment of the industrial heritage buildings. The procedure allows for inclusion of results of inspections, testing and consideration of successful past performance of a structure.

6.1 Specification of models for basic variables

Models for basic variables should be adjusted to the actual situation and state of the structure and verified by inspection and testing. Design documentation and original standards should be used as a guidance material only. The following principles should be taken into account:

- Material properties should be considered according to the actual state of a structure verified by destructive or non-destructive testing. It may often be appropriate to combine limited new information with prior information. Bayesian techniques, described e.g. in ISO 12491 [9], or the Joint Committee on Structural Safety (JCSS) publications [10,11], provide a consistent basis for this updating.
- When significant deterioration is observed, an appropriate deterioration model should be used to predict changes in structural parameters due to foreseen environmental conditions, structural loading, maintenance practices and past exposures, based on theoretical or experimental investigation, inspection and experience.
- Dimensions of structural members should be determined by measurements. When the original design documentation is available and no changes in dimensions exist, nominal dimensions given in the documentation may be used.

- Load characteristics should be introduced considering the values corresponding to the actual situation verified. For structures with significant permanent actions, the actual geometry should be verified by measurements and weight densities should be obtained from tests.
- Model uncertainties should be considered in the same way as at a design stage unless previous structural behaviour (especially damage) indicates otherwise. In some cases model factors, coefficients and other design assumptions may be established from measurements.

It follows that reliability verification of a heritage structure should be backed up by inspection including collection of appropriate data. Evaluation of prior information and its updating using newly obtained measurements may be one of the most important steps of the assessment.

6.2 Failure probability

The failure probability related to a working life t_D can be obtained from a general probabilistic relationship:

$$p_f(t_D) = P\{Z[\mathbf{X}(t_D)] < 0\} \quad (1)$$

where $Z(\cdot)$ = limit state function; and $\mathbf{X}(t_D)$ = vector of basic variables including resistance, permanent and variable actions and model uncertainties. Models of basic variables may be updated considering results of inspections and tests.

It may be reasonable to consider satisfactory past performance of a structure during a period to the time of assessment t_A in the reliability assessment of a heritage structure. This may be taken into account in the reliability analysis by considering the conditional failure probability that a structure will fail during a working life t_D given that it has survived the period t_A. This probability may be estimated by several ways. When the load to which the structure has been exposed during the period t_A is known, the resistance or a joint distribution of time-invariant variables may be truncated (a lower bound is set to the value of load). Using the bounded distribution, the conditional (updated) probability $p_{f,upd}(t_D|t_A)$ can be estimated. This approach, similar to the updating for proof load testing, is described in [10].

Alternatively, the updated failure probability may be determined as:

$$p_{f,upd}(t_D|t_A) = [p_f(t_D + t_A) - p_f(t_A)] / [1 - p_f(t_A)] \quad (2)$$

where $p_f(t_D + t_A)$ = failure probability related to the period $t_A + t_D$.

6.3 Reliability verification

Reliability verification may be based on the following relationship:

$$p_{f,upd}(t_D|t_A) < p_t \quad (3)$$

where p_t = target failure probability. The reliability level is commonly expressed in terms of the reliability index β_t. Equation 3 can be rewritten as:

$$\beta_{upd}(t_D|t_A) = -\Phi^{-1}[p_{f,upd}(t_D|t_A)] \geq \beta_t \quad (4)$$

where Φ^{-1} = inverse cumulative distribution function of the standardised normal variable. The target reliability level can be taken as the level of reliability implied by acceptance criteria defined in proved and accepted design codes. The target level should be stated

together with clearly defined limit state functions and specific models of basic variables. For the industrial heritage buildings, moderate consequences of failure and moderate costs of safety measures may often be assumed. In this case ISO 2394 [12] indicates $\beta_t = 3.1$.

The target reliability level can also be established taking into account the required performance level of the structure, reference period, cost of upgrades (including potential losses of the cultural and heritage value) and possible consequences of failure or malfunction. Lower target levels may be used if they are justified on the basis of social, cultural, economical, and sustainable considerations, ISO 13822 [8]. A simple model for estimation of the target reliability level was proposed by Schueremans & Van Gemert [13]:

$$p_t = S_c\, t_D\, A_c\, C_f / (n_p\, W) \times 10^{-4} \tag{5}$$

where S_c = social criterion factor (recommended value for listed historical buildings 0.05); t_D = remaining working life (considered as 50 years); A_c = activity factor (recommended value for buildings 3); C_f = economical factor (5 for a moderate consequences, recommended values: 10 - not serious, 1 - serious consequences of failure); n_p = number of endangered persons (in accordance with [14] the most favourable and unfavourable estimates $n_{p,min} = 1$ and $n_{p,max} = 10$, respectively, are considered for significant risk of injury or fatalities - a middle class of consequences); and W = warning factor (1 - sudden failure without previous warning). Considering these indicative data, lower and upper estimates of the target reliability level are obtained from Equation 5 as follows:

$$p_{t,max} = 0.05 \times 50 \times 3 \times 5 / (1 \times 0.3) \times 10^{-4} \approx 3.8 \times 10^{-3}; \quad \beta_{t,min} = 2.7$$
$$p_{t,min} = 0.05 \times 50 \times 3 \times 5 / (10 \times 0.3) \times 10^{-4} \approx 3.8 \times 10^{-4}; \quad \beta_{t,max} = 3.4 \tag{6}$$

It appears that the target reliability is within the broad range from 2.7 to 3.4. The value recommended in [12] is approximately in the middle of this range. If a structure does not satisfy the reliability requirements, construction interventions may become necessary. Decision-making concerning construction interventions may be based on a cost-benefit analysis. Application of the proposed methodology is numerically illustrated elsewhere [15].

7 Discussion and conclusions

Protection of the industrial heritage structures may positively contribute to the sustainable development by preservation of the cultural values, recycling of all potential resources, avoiding wasting energy and facilitating the economic regeneration of regions in decline. It is recognised that most heritage structures do not fulfil requirements of present codes of practice.

In many cases significant uncertainties related to actual structural conditions can hardly be realistically described by simplified procedures used for design of new structures that may lead to expensive repairs and losses of the cultural and heritage value. Application of probabilistic methods is thus proposed to better describe the uncertainties and take into account results of inspections and tests and the satisfactory past performance. For moderate consequences of failure, the target reliability index might be selected from the broad range from 2.7 to 3.4.

The industrial heritage structures often form part of the urban landscape and provide the cityscape with visual historical landmarks. Present insufficient attention to systematic recognizing, declaring and protecting the industrial heritage may, however, lead to their

extinction. Desired protection of the industrial heritage structures requires a public recognition of the industrial heritage to be equally important as other cultural heritage. Introduction of educational programs and relevant legislation is needed.

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