On the assessment of existing civil engineering structures

Tadeusz Chmielewski*

Warsaw University of Technology, Politechniki Square 1 , Poland

Abstract. The paper deals with the reasons for technical and moral deterioration of civil engineering structures, which constitute the enormous economic and political assets in every country. Extending their working life is an important social issue with always limited financial resources. In the next part, the following is presented: provisions of the building law, the procedure of the preliminary and detailed assessment with a structural analysis and proposals for possible interventions (e.g. rehabilitation, performance monitoring). The paper ends with a proposal of how to prepare the final report which should be issued upon the completion of the assessment, and the example of the structure after rehabilitation.

1 Introduction

The continued use of existing civil engineering structures is very important in every country because the built environment is an enormous economic and political asset. The structural engineer is called upon to devise ways for extending the working life of structures while costs are always limited. The principles for the assessment of existing structures are substantially different from the design of new structures. The ultimate aim of the assessment is to limit construction intervention to a minimum.

This paper provides general requirements and procedures for the assessment of existing structures, such as buildings, bridges and industrial structures based on the standard ISO 13822 [1] and on the author's experiences. The author of this paper is the co-author of the ISO standard.

2 Reasons for deterioration of structures

During the use of civil engineering structures their deterioration with time is observed. The reasons for that may be divided into:
Technical deterioration:

- aggressive environment: moisture, subsidence, ground frost, vibrations, corrosion of materials, shrinkage of concrete, wind, variable ambient temperature, fatigue, biological factors, (e.g. Fig. 1),

* Corresponding author: t.chmielewski@po.opole.pl

- natural disasters: floods, fires, hurricanes, landslides, earthquakes, tsunamis, (e.g. Fig. 2),
- man - made disasters: warfare, terrorist attacks,
- natural wear as a result of long-term use, e.g. losses caused by abrasion on stairs and floors,
- mining activities (shaking and subsidence of land).
- human errors, improper use of structures.

Moral deterioration: as a result of technical development because some structures may lose their societal functionality, e.g. stadiums for EURO 2012 - the existing stadiums were not accepted, four new stadiums had to be constructed, railway station in Katowice (the 60 years old existing building has been replaced by the new one – some years ago).

Fig. 1. The example of deteriorated facade of the building by aggressive environment

Fig. 2. The damaged building after a strong wind

3 Initiation of the assessment and specification of objectives

The assessment of existing structures can be initiated under the following circumstances:

- as it is required by the Building Law in every country,
- structural deterioration due to the time-dependent action (e.g. corrosion, fatigue)
- an anticipated change in use or extension of working life,
- structural damage caused by accidental actions,
- a reliability check for a special kind of loads, e.g. increased traffic loads, earthquakes.

The owner, or the authorities when relevant, should always meet with the assessing engineer in order to formulate objectives of the assessment of the structure. The owner and the assessing engineer during consultations should specify the reasons for the assessment and the scope of the work. The utilization plan and the safety plan for the future performance of the structure should be specified as follows:

- to provide appropriate safety for users of the structure,
- to provide a continued function for special structures such as hospitals, key bridges in the event of an impact, or other hazards, etc.,
- to provide safety performance requirements of the owner related to property protection (economic loss) or serviceability.

4 Procedure of the assessment

4.1 Objectives and procedure

The assessment procedure is composed in general of some steps which are presented on the flowchart in Fig. 3.

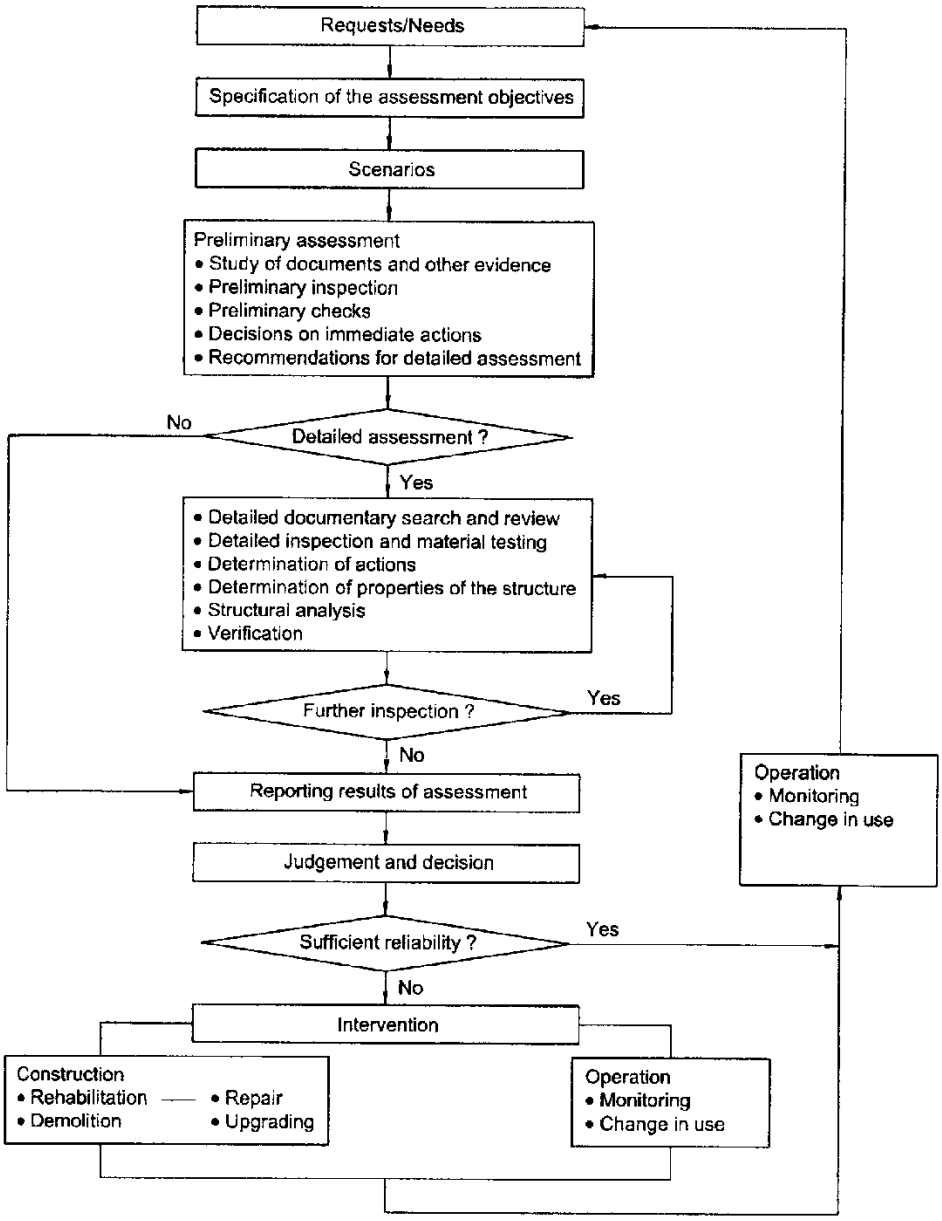

Fig. 3. General flow of an assessment of existing structures, [1]

The procedure depends on the assessment objectives and on the specific circumstances, e.g. the availability of the design documents, the observation of damage, the use of the structure. The objective of the assessment shall be specified in consultation with the owner based on the following performance levels:

a) safety performance level, which provides safety for the users of the structure,
b) the continued function performance level, which provides a continued function for special structures such as hospitals, important bridges or communication buildings in the event of a flood, an earthquake, or other predicted hazard,

c) safety performance requirements of the owner related to property protection (economic loss) or serviceability.

It is important to remember that prior initiation of the consultation with owner and the assessment procedure a site visit is strongly recommended. During the assessment procedure the following steps are carried out: a) specification of the assessment objectives, b) scenarios, c) preliminary assessment, d) detailed assessment, e) results of assessment, and f) repeat the sequence if necessary.

4.2 Scenarios

Scenarios are related to a change in structural conditions or actions which should be specified in the safety plan in order to identify possible critical situation for the structure. Each scenario is characterized by a predominant process or action and by one or more accompanying processes or actions. The identification of scenarios is the basis for the assessment and design of interventions to be taken in order to ensure structural safety and serviceability.

4.3 Preliminary assessment

Preliminary assessment consists of the following steps:

1) Study of documents and additional evidence. The design and inspection documents contain information that is necessary for good assessment of an existing structure. It will be verified that the documents are correct, and it is important to check whether they include information of any previous intervention to the structure. Additional evidence, such as the occurrence of significant environmental actions, e.g. strong winds, earthquakes, floods, changes in soil conditions, and misuse of the structure.
2) Preliminary inspection and observation of damage. The aim of a preliminary inspection is to identify the structural system and possible damage of the structure by visual observation, i.e. visible deformations, cracks, spalling, corrosion, etc. These results are expressed in terms of the qualitative grading of structural conditions for possible damage. They are as follows: none, minor , moderate ,severe destructive, and unknown.
3) Preliminary checks. The purpose of this step is to identify the critical deficiencies related to the future safety and serviceability of the structure. Based on these results, it is then judged whether a further investigation is necessary or not.
4) Decisions on immediate actions. When the preliminary inspections indicate that the structure is in danger, it is necessary to report to the client that the interventions should be taken immediately to reduce the danger with respect to public safety.
5) Recommendations for detailed assessment. The preliminary checks should clearly show the detail deficiencies of the structure, or that the structure is reliable for its intended use over the remaining working life. In the last case a detailed assessment is not required. Where there is uncertainty in the actions effects or properties of the structure, a detailed assessment should be recommended.

4.4 Detailed assessment

Detailed assessment is composed of the following steps.

1) Detailed documentary search and review. If it is available, the following documents should be reviewed:

- drawings, specifications, structural calculations, construction records, inspection and repair records, strengthening,
- regulations and by-laws, codes of practice on which the structure has been constructed,
- topography, groundwater level at the site, and subsoil conditions.

2) Detailed inspection and damage documentation. The aim of a detailed inspection is to up – to – date data on the structure. All possible damage should be identified by available tools, prescribed and documentary evidence should collected (e.g. by photographs). In this step the causes of a degradation, defects or damage during construction, or damage by accidental event or overload should be understood.
3) Data for the assessment. These data are related to the material properties, structural properties, dimensions and actions.
    - Actual material properties shall be estimated of the existing structures. They may be determined from drawings and design specifications when there is no uncertainty about their validity. In case of uncertainty, material properties should be determined by non-destructive or destructive material testing. Sampling and testing method should be in accordance with the relevant standards. Repair and/or reinforcement shall be carried out immediately after sampling. When samples are tested, the material properties shall be determined, statistically from the test results. An example of a concrete sample is presented in Fig.4 and its physical and chemical properties in Table 1are given [2].
    - Dimensions may be determined from drawings and design specifications when there is no uncertainty about their validity. In cases of uncertainty, dimensions should be determined by measurement during inspection.
    - Actions shall be determined in accordance with current codes. Changes of actions caused by the change in use or modification of an existing structure shall be taken into consideration. It is important to adjust long term and extreme effects that cannot be measured directly when collecting information on actions and environment influences.
4) Determination of properties of the structure. Field testing are useful for assessment of static and dynamical properties of existing structures, e.g. a horizontal loading test or a forced vibration test of a complete structure, a vertical loading test. Load testing of a complete structure is costly and time-consuming. But, there may be some structures that are not amenable for calculation. Field testing of existing structures should have clear objectives.
5) Structural analysis. Structural performance shall be analysed using models that reliability represent the action on the structure, the behaviour of the structure and strength of its components. The calculation model should reflect the actual condition of the existing structure, i.e. the deterioration of the structure shall be taken into consideration. The structure shall be analysed for the ultimate and serviceability limit states, using basic variables, i.e. actions, materials properties and geotechnical conditions, dimensions of the structural components with subsoil geometry, and model uncertainties.
6) Verification. Verifications shall be based on the limit state concept, i.e. on the ultimate and serviceability limit states. The verification of the assessment shall be made taking into account the remaining working life of an existing structure, the reference period, and changes in the environment of a structure associated with an anticipated change in use.
7) Interventions. The assessment of existing structures may result in several interventions, which together are called rehabilitation; they are presented in Fig. 5.

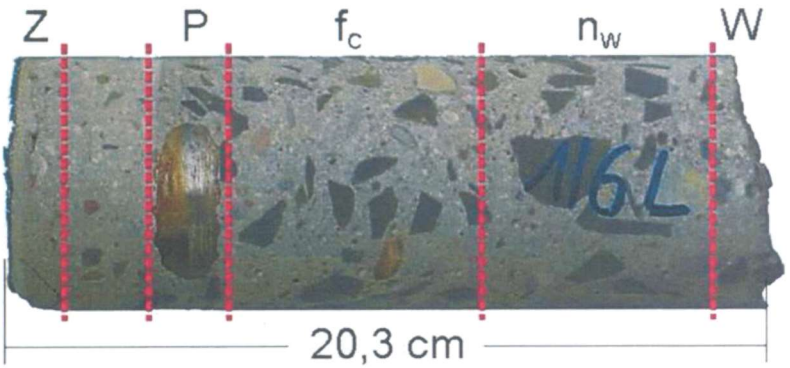

Fig. 4. A sample of concrete divided into laboratory parts

Table 1. Test results of the physical and chemical properties of a sample of hardened concrete.

Physical properties			Chemical properties			
ρ_0 [kg/dm^3]	$f_{c,cyl}$ 75 mm [MPa]	n_w %	Layer	pH	SO_4^{2-}	CL^-
2.39	42.8	5.6	E- external	11.10	2.5	0.12
			I - internal	11.80	2.5	0.08

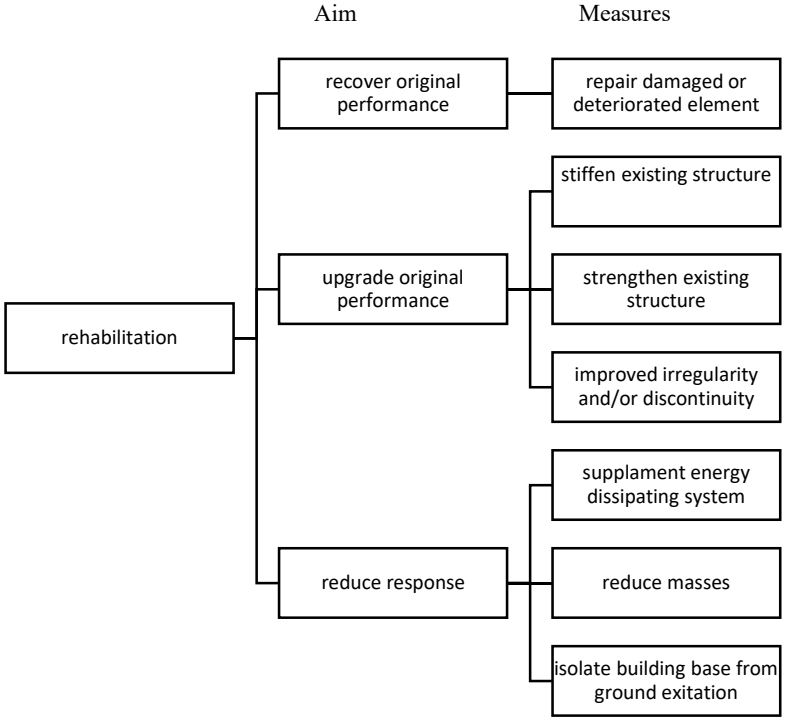

Fig. 5. Rehabilitation strategy and measures

Fig. 6. The building presented in Fig. 1 after rehabilitation

5 Report

All the information obtained during the process of the structure assessment should be documented in a report for the owner upon the completion of the assessment. In the report the following should be included:

a) scope of the assessment, in which the reasons and the scope of the work, as agreed between the owner and assessing engineer should be specified. The procedure for the assessment should be described, and all activities for the assessment should be reported.
b) description of the structure. Name, address and structural system, together with any drawings are briefly described. A history of the structure's original construction, past and present used, and subsequent alterations should be given.
c) investigation, which should consist of the examined documents, inspection items with damage description, sampling and testing procedure and test results.
d) analysis. The type of calculation carried out, and the criteria against which the results have been judged, should be given.
e) verification. The verification of structural safety and serviceability should be carried out.
f) discussion of evidence. This is the item to discuss the importance of each findings, in particular, their relevance to the objective of the assessment. Any uncertainties remaining after the investigation and any needs for further checks should be stated here.
g) review of intervention options. The possible options of interventions should be reviewed. The estimated cost associated with each of the options may be provided.
h) conclusions and recommendations. The conclusion should be concise and clear. Every conclusion should be based on matters contained in the preceding chapters of the report.
i) annexes. In this item the following should be provided: drawings, photographs, laboratory reports, calculation, etc.

6 Conclusion

In this paper reasons for deterioration of structures and all phases in the assessment of existing structures, such as buildings, bridges and industrial structures are presented.

References

1. ISO 13822, Bases for design of structures – Assessment of existing structures. (2009).
2. T. Chmielewski, M. Simon, P. Osterrieder, Assessment of existing natural draught cooling towers, Chapter in the monograph**:** *Shell Structures: Theory and Applications*, Editors: W. Pietraszkiewicz, J. Górski, Taylor & Francis Group**, 3**, pp. 495-499, (2013).