# From structural assessment to appropriate preservation strategies

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# From Structural Assessment to Appropriate Preservation Strategies

## De l'inspection structurale aux stratégies appropriées de conservation

## Von der Zustandsaufnahme zu angemessenen Erhaltungsstrategien

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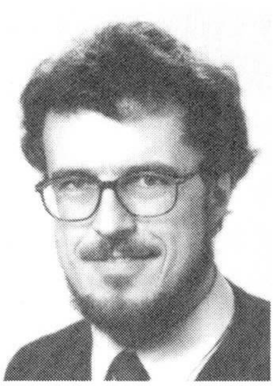

Thomas Vogel, born 1955, graduated from ETH Zurich in 1980. He gained his first five years of experience in bridge and structural design in Chur, Switzerland. For another six years he worked at first as project engineer and later as managing director of a Zurich-based consulting firm. In 1982 he joined ETH as a professor of structural engineering.

### SUMMARY
The way from structural assessment activities via the evaluation of feasible options to recommendations for preservation measures is explained by showing on which level considerations are made and decisions are taken. Although the information expected from structural assessment could lead to an extensive and expensive investigation, in a first step those assessments are justified that allow a sound evaluation of feasible options. The illustrating examples concern an exposed concrete façade of a post office building and three bridges of different types.

### RÉSUMÉ
L'article décrit le cheminement de l'inspection structurale à l'appréciation de ses résultats et à la recommandation de mesures de conservation. Il montre à quel niveau les considérations sont faites et les décisions prises. Quoique les informations attendues de l'inspection puissent conduire à une investigation étendue et coûteuse, dans une première phase seules sont justifiées les études qui permettent un jugement consciencieux des variantes de conservation possibles. Les exemples présentés concernent la façade en béton de parement d'un bâtiment postal et trois ponts de types différents.

### ZUSAMMENFASSUNG
Der Weg, der von Zustandsuntersuchungen und deren Beurteilung bis zur Empfehlung von Erhaltungsmassnahmen führt, wird erläutert, indem gezeigt wird, auf welchem Niveau die Ueberlegungen angestellt und die Entscheide getroffen werden. Obwohl die Aussagen, die von der Zustandsuntersuchung erwartet werden, zu einer umfangreichen und kostspieligen Kampagne führen könnten, sind in einem ersten Schritt nur diejenigen Untersuchungen gerechtfertigt, die eine zuverlässige Beurteilung der möglichen Erhaltungsvarianten erlauben. Die illustrierenden Beispiele streifen eine Sichtbetonfassade eines Postgebäudes und drei Brücken mit verschiedenen Tragsystemen.

# 1. INTRODUCTION

## 1.1. Sphere of experience

A working group of the Swiss structural concrete committee SIA 162 is producing a directive on the preservation of concrete structures. Simultaneously, a working group of the European Committee for Standardization (CEN TC 102/SC 8/WG 7) is elaborating general principles for the use of products and systems for the protection and repair of concrete construction works.
Both groups started their tasks with more general considerations, even valid beyond the field of concrete structures, regarding the optimal process of evaluating existing structures and of finding reasonable solutions for their preservation.
The author is member of both groups and wishes to report on some ideas that lie behind the normative rules, always keeping his individual point of view, however.

## 1.2 Nature of the task

The evaluation of existing structures consists of a **structural assessment**, the **evaluation** of its results and a **recommendation** for actions.
By the way, this is a typical task for an engineer, because
- all desirable or even necessary information is never available
- nevertheless decisions have to be taken (not to decide is the worst option of all)
- the consequences of decisions decrease while the amount of information available increases during the process

In such situations a stepwise procedure is appropriate; lack of knowledge is overcome by plausible assumptions which have to be checked later.
As formulations of questions can change during the process, a stepwise procedure is justified from the economical point of view as well.

## 1.3. The levels of considerations and decisions

To follow how considerations are made and decisions are taken effectively it is useful to define four levels:
(i) The **totality of structures** managed by an owner or belonging to a certain region (district, county, country). On this level the final decisions are made because risks, benefits and funds are related to the owner and legal or codification requirements normally are applicable following the territorial principle.
(ii) A **group of similar structures** regarding structural system (beam, arch, frame, etc. for bridges; frame-structures, wall-structures for buildings), building material (steel, reinforced concrete, prestressed concrete, masonry, wood, composites etc.) construction method and construction period. Within a group of similar structures often similar problems occur so that is the level where the exchange of knowledge and know-how has to take place.
(iii) The **individual structure**, normally subject to a structural assessment, carried out by an engineer appointed by the owner.
(iv) The **structural element**, regarded as a part of a structure with a well-defined structural purpose (e.g. a column, a diaphragm wall, a footing or a flat slab). On this level only clear and definite statements can be made about bearing capacity, deterioration processes and their future developments.

On which level the procedures described hereafter are situated, is shown by Fig. 1.

# 2. STRUCTURAL ASSESSMENT

## 2.1. Reasons for a structural assessment

The reasons for a structural assessment can have their origin on any level:
The favorite case is the owner having a preservation plan that includes a periodical assessment of all his construction works.

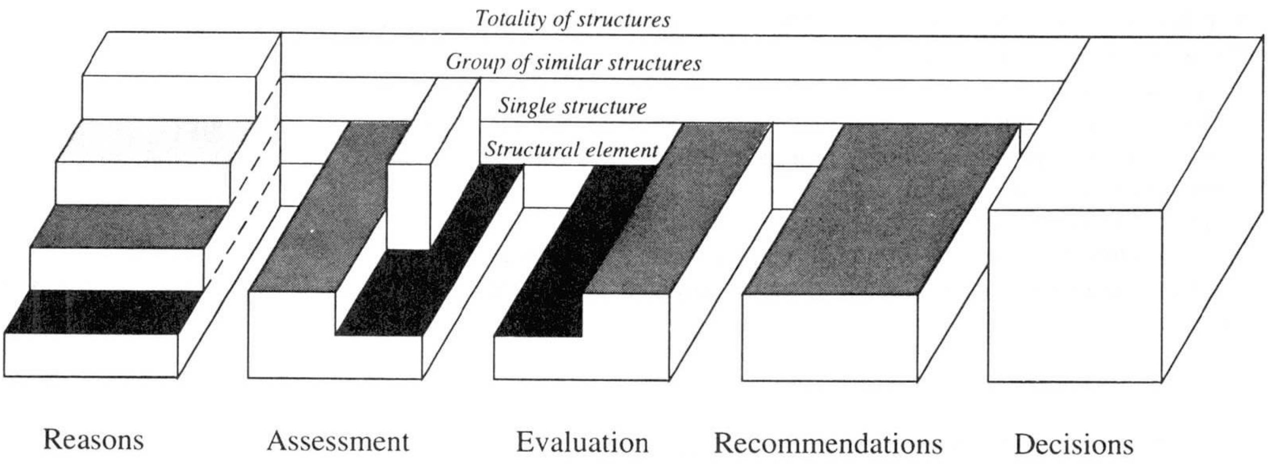


*Fig. 1* Procedure with levels of considerations and decisions

Severe damage or even failures somewhere in the world lead to questions about similar structures that have to be answered. Depending on the quality of the records, assessments are inevitable.
Individual structures having been subject to hazards (overload, fire, accidents, impact, earthquake etc.) or having to be altered for other reasons (change of use, restorations, etc.) should be assessed as well.
Finally, structures or parts of them that do not behave satisfactorily or show apparent damage, defects or deterioration will be subject to an assessment sooner or later.

## 2.2 Purpose of structural assessment

Once agreed upon a structural assessment is not complete in itself. It has to lead to a recommendation of actions to be taken without prejudicing them. Extent and methods shall be oriented on the problems faced and to be solved, the results expected and the risks to be taken or to be avoided.

## 2.3. Sequence of procedures

### 2.3.1. Preliminary assessment

Every assessment should start with general methods to judge the extent of the expected and to detect unexpected phenomena.
Normally, a carefully prepared and executed visual inspection under the best conditions available will meet these requirements. Besides, the records of the construction work should be checked regarding completeness, previous preservation actions and special notes.

### 2.3.2. Further investigations

Further investigations at this stage of a project will be undertaken only in cases, where the need of further knowledge justifies them and where their results are necessary for the evaluation.
For examinations at the structure non-destructive tests are preferrable.
The benefits of destructive tests or sampling must be compared with the damage produced by core drilling etc. The validity of these tests is normally very local and cannot be extended to a whole structure unless the basic processes are understood.

## 2.4. Objective of assessment

The above-mentioned restrictions lead to the question, what assessment should be aimed at.
Although the general view should not be neglected, the investigations will concentrate on structural elements, that have been recognized as damaged before, that are crucial for the overall behavior or that have

been found to be designed inadequately from the records. Experience of other similar structures and the problems related to them should flow in at this stage.

The process of assessment should take into account
- the present condition of the existing construction work
- the environment and its influence on the construction work
- the conditions during construction
- the history of the construction work
- the conditions of the present and the requirements for the future use

Regarding damage and deterioration the assessment will identify their nature, causes and approximate extent.

## 3. EVALUATION AND RECOMMENDATIONS

The delimitation between the assessment of a structure and the evaluation of the results thereof is flexible; let us consider it there where the reflections in the time-domain commence.

### 3.1. Objective of evaluation

The evaluation shall describe
- the present state regarding structural safety, serviceability and durability
- the likely rate of increase of deterioration and subsequently decrease of the criteria mentioned above, including the approximate time to reach a crucial state.

As mentioned above these statements refer to structural elements in a first step. The extension to the whole structure needs more structural analysis considerations.

### 3.2. Required immediate actions

In case the structural safety or other requirements concerning health and safety are not fulfilled, immediate actions have to be proposed by the engineer.

### 3.3. Recommendations for long-term actions

For the long term the engineer should consider the following options:

(i) Do nothing for a certain time, possibly supplemented by monitoring, downgrading of the function or other measures (i.e. accept the present condition).

(ii) Prevent or reduce further deterioration with or without improvement of the construction (i.e. correct the present condition).

(iii) Change the construction work by adaption, reconstruction or enlargement.

(iv) Demolish the construction work, possibly after having made use of a residual service life.

The recommendations to the owner cover the reasonable ones of the alternatives listed above. They will contain a statement concerning the achievable residual service life for every alternative. Subsequently, the decision of the owner on how to proceed is requested.

## 4. FURTHER PROCEDURES

### 4.1. Decision of the owner

The owner will decide also taking into account factors, that are not related directly to the object under discussion like priorities regarding to the function in a production or traffic system, mutual dependencies of repair sites, funds for rehabilitation existing or able to be raised and political considerations.

### 4.2. Preliminary design

In case alternative (ii) or (iii) are chosen, a preliminary design of the preservation work has to be carried out. Further investigations may be necessary to decide what principles and methods of protection or repair are suitable. These are related to the causes of damage and deterioration.

## 5. EXAMPLES

### 5.1. Sihlpost Zurich

The main post office of Zurich built in 1928/29 with a structure designed by Robert Maillart was enlarged from 1986-92. Before offices of other postal and railway services are incorporated, the building including the exposed concrete façade (Fig. 2) is being presently restored.
Assessment showed the following situation:

| Structural element | Concrete cover | Carbonation depth | Comment |
|---|---|---|---|
| Piers between window openings | 27 - 55 mm | 35 - 57 mm | increased carbonation risk |
| Lintels of recessed NW-façade | 0 - 65 mm | 28 - 56 mm | concrete spalling, first reinforcement layer corroded at any grade |

Since the building is regarded as a historical monument by the local authorities, an unchanged concrete surface with formwork texture was required. According to the different stages of deterioration and structural function, the following repair systems are used:
The piers between window openings were repaired locally concentrating on corroding areas of reinforcement by a polymer-cement-concrete-(PCC) mortar. An elastic coating on the whole surface will complete the rehabilitation work.
The recessed north-western façade was treated as follows:
- Removing of carbonated concrete following a-corrosion criteria by high-water pressure.
- Replacing with spraying concrete.
- Levelling out of the surface by a PCC-mortar.
- Coating, able to bridge future cracks.

*Fig. 2* SE-façade of the Sihlpost building

### 5.2. Dünnernbrücke Oensingen (Object Z53A)

At Oensingen (SO) an access road to the Swiss national highway N1 crosses the Dünnern creek in a skew angle on a grillage, spanning 24 m with curved girders (Fig. 3) built in 1963/64.
Structural assessment showed a deteriorated slab due to de-icing salt ingress and lack of waterproofing, an insufficient capacity for shear forces and a minimal capacity for bending moments.
As options a strengthening and a total reconstruction were studied. The will to preserve a example of elegant and material-economizing structures of the sixties overrided economical considerations. So only the slab was removed by high-water pressure and reconstructed.
The beams were strengthened by steel plates glued on the underside in mid-span and diagonal prestressed bars on either side close to the abutments.

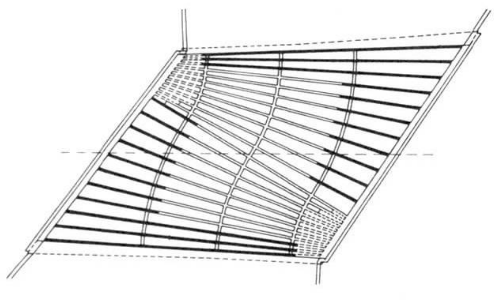

*Fig. 3* Plan view of Dünnernbrücke

### 5.3. Arch bridges Nanin and Cascella, Mesocco

The Swiss national highway N13, traversing the Alps at the San Bernardino pass, crosses at its southern ramp the Moesa creek twice on elegant arch bridges designed by Christian Menn and built in 1966-68. In 1986/87 first preservation activities like removal of the interior formwork of the box girders , improving the drainage system and replacing the bearings took place.
Since 1985 occasional heavy-load transports were used to measure deflections of the girder due to traffic loads. The subsequent structural assessment covered a structural analysis, detailed examinations on site and long-term measurements of deflections, sampling of deck slab concrete and screening by electrical potential measurement.
In spite of severe deterioration of the steeper parts of the arches due to dropping water of the road draining system, the bridges still behave perfectly elastically and fulfil structural safety. In the transverse direction, however, the deck slab has inadequate load bearing capacity.

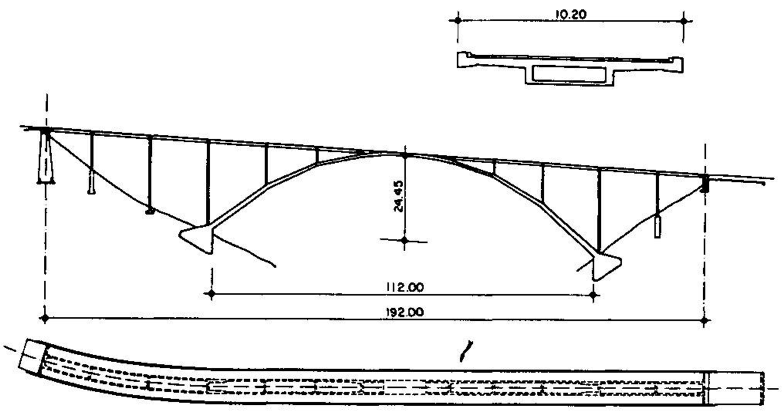

*Fig. 4* Section, elevation and plan of Nanin Bridge

The actual rehabilitation started with the Cascella bridge in 1994 and will end up with the Nanin Bridge in 1996, including replacement of parapets and asphalt layer, strengthening of the deck slab by an additional concrete surfacing with additional reinforcement, fixing the downhill bearings to the abutments and enclosing the steeper parts of the arches with shotcrete on the lower and special cast concrete on the upper side.

## 6. CONCLUSIONS

As a result of the work in progress and illustrated by the examples, it can be stated, that
- assessment and evaluation are demanding engineering tasks,
- mostly, at least two options are conceivable and have to be considered carefully,
- the final decision on how to proceed, however, often depends on other non-technical requirements.

That is why a stepwise procedure with milestones for decisions is reasonable.

## 7. ACKNOWLEDGMENTS

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