Design for maintenance

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Objekttyp: **Article**

Zeitschrift: **IABSE reports = Rapports AIPC = IVBH Berichte**

Band (Jahr): **55 (1987)**

PDF erstellt am: **02.07.2024**

Persistenter Link: https://doi.org/10.5169/seals-42731

Design for Maintenance

Projet de la maintenance

Entwerfen für die Unterhaltung

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SUMMARY
Maintenance-oriented activities are not only regarded as technical problems, but also under cultural aspects. This is especially necessary for future concrete structures. There are two main problems to be solved : future maintenance of contemporary structures and maintenance of structures to be designed for future demands. General conclusions are drawn for future-oriented maintenance activities. Special recommendations are formulated for the maintenance-oriented design of future concrete structures.

RÉSUMÉ
La maintenance des ouvrages d'art ne peut pas être considérée comme une activité technique exclusivement, mais elle doit tenir compte d'aspects culturels. Cela est particulièrement nécessaire pour les constructions en béton de l'avenir. Deux problèmes doivent être résolus : la maintenance future des structures contemporaines et la maintenance des structures devant répondre à des besoins futurs. Des conclusions générales sont tirées pour les activités futures de maintenance. Des recommendations particulières sont faites en vue du projet orienté vers une maintenance adéquate des structures en béton de l'avenir.

ZUSAMMENFASSUNG
Die Unterhaltung von Bauwerken wird nicht nur als eine technische Aufgabe gesehen, sondern unter Einbeziehung kultureller Aspekte diskutiert. Dies ist für zukünftige Betonbauwerke besonders notwendig. Zwei Aufgaben sind zu lösen : Die künftige Unterhaltung von bereits bestehenden Bauwerken und die Unterhaltung von Bauwerken, die unter Beachtung zukünftiger Anforderungen zu entwerfen sind. Es werden allgemeine Schluszfolgerungen für zukunftsorientierte Bauwerksunterhaltung gezogen. Für den auf die Bauwerksunterhaltung orientierten Entwurf von zukünftigen Betonbauwerken werden spezielle Empfehlungen gegeben.

1. THE FUNDAMENTAL QUESTIONS

Some weeks ago I was strolling through the ruins of buildings the Romans passed on to us two thousand years ago.

Some years ago I was admiring the pyramids and the temple of Abu Simbel the Egyptians passed on to us more than four thousand years ago.

Some months ago I was staying in the caves of Lascaux in front of the outstanding pictures our ancestors passed on to us some ten thousand years ago.

My feeling were always the same:

GREAT RESPECT AND DEEP ADMIRATION

But there were also some thoughts I could not put aside:

- Those works were done for eternity and have been endangered by ignorance, negligence and even destruction in our time.

- Those works have only been maintained in the last historical second of our man-related "eternity".

Mankind now, only five minute before twelve have developed consciousness of cultural responsibility and started maintenance-oriented activities to protect outstanding cultural values.

Bearing this in mind I considered and reconsidered the theme I have to deal with and the questions I have to answer in this presentation.

At the first glance it seems to be very easy to deal with

DESIGN FOR MAINTENANCE

only by answering the questions

- WHAT to maintain?
  and
- HOW to maintain?

Such a point of view leads straight to a technically oriented confrontation and to only technically oriented answers.

Those answers can be found more or less easily by running the chain of maintenance activities from field inspection, inspection with visual, destructive or non destructive examination, damage evaluation, damage assessment up to damage qualification and -quantification and so starting the decision-making-process to ensure an optimal maintenance concept.

Considering the theme a little bit deeper, one can add two more questions:

- WHY to maintain?
  and
- WHETHER or not to maintain?

By asking such questions one goes beyond technical aspects and enters into a greater, more demanding and more culture-oriented field of considerations. One is passing from maintenance of STRUCTURES into maintenance of ENVIRONMENT, from RESTORATION of structures to their DESTRUCTION.

I would like to ask you to follow me in that direction and to deal with our problem not only out of the classical technically-oriented attitude of repair and reconstruction, but to also incorporate cultural and human aspects into our consideration.

That means it is taken for granted in this presentation that engineers are able to handle the technical aspects of maintenance of concrete structures using effective methods to improve damaged concrete surfaces, to repair cracked concrete structures and to strengthen such structures, if their load capacity is insufficient for further usage or structural safety.

Maybe we should also modify the theme a little bit and not only deal with design FOR maintenance but also with design AGAINST maintenance.

2. THE FUNDAMENTAL PROBLEMS.

In dealing with our subject in the frame of this symposium we have to consider three terms:

STRUCTURE FUTURE MAINTENANCE .

And we have to answer two questions:

- What is the future of the contemporary concrete structures ?
  or more precise:
- What is the future of concrete structures already built?
  and
- What are the characteristics of concrete structures to be planned, designed, constructed, used and maintained in the future?

We are therefore confronted with two MAIN TASK:

- the FIRST one is to maintain contemporary concrete structures,
- the SECOND one is to design concrete structures for the future based on our contemporary experience.

To fulfill the FIRST TASK we have to thoroughly analyze concrete structures, to evaluate their damage level and to synthesize effective methods of classical maintenance:

REPAIR, RECONSTRUCTION, STRENGTHENING.

To fulfill the SECOND TASK we have to deal with methods of technical, economical and social forecasting and we have to develop future-oriented, non classical attitudes.

So there are different features which characterize the two task:

Maintenance of CONTEMPORARY concrete structures can mainly be based on classical engineering quality and contemporary maintenance methods and tools.

Maintenance of FUTURE structures is challenging engineer's future-oriented imagination, his social responsibility and his creativity.

There are therefore different capabilities one has to develop to meet these demands:

Three of them I would like to highlight:

- The FIRST one is the

  CAPABILITY TO THINK

  in order to recognize and to formulate the present trends of development of society, technology, public demands and human needs,

- The SECOND one is the

  CAPABILITY TO DREAM

  in order to draw conclusions from the development of mankind and their needs and to formulate the demands, which concrete structures have to meet in the future,

- The THIRD one is the

  CAPABILITY TO ACT

  in order to create concrete structures which not only meet technical demands but ensure and possibly even upgrade the cultural level and the harmony between men and structure.

Our activities and our responsibility have to be evaluated by CRITERIA not only valid in our time but also in the future.

Let me propose three groups of such criteria:

- criteria out of interaction between

  STRUCTURE AND FUNCTION,

  that means: technical-economical criteria

- criteria out of interaction between

  STRUCTURE AND ENVIRONMENT,

  that means: sociological-ecological criteria

- criteria out of interaction between

  STRUCTURE AND MEN,

  that means: esthetical-ergonomical criteria

Maintenance of structures in the past was often only understood as the avoidence or repair of structural failures and damages.

More and more engineers are and will be confronted with additional future demands.
Those demands will not only be technically oriented but will include requirements resulting out of cultural considerations.

Additional demands result out of:

- Change of

  USERS' DEMANDS

  and therefore change of interaction between structure and function,

- Change of

  PUBLIC DEMANDS

and therefore change of interaction between structure and environment,

- Change of

  PEOPLES's DEMANDS

  for safety and convenience and therefore change of interaction between structure and men.

3. THE FUNDAMENTAL MAINTENANCE ACTIVITIES.

There are a lot of studies dealing with sources of failures and damages of concrete structures. Summarizing the conclusions of such studies one can find some main relationships between specific types of maintenance activities and decisions made during the process of preparation, construction and use of concrete structures (table 1).
Maintenance activities can be minimized by proper preparation of such activities.

INSUFFICIENT QUALITY OF:	MAIN INFLUENCE ON MAINTENANCE ACTIVITIES		
	REPAIRING	REDESIGNING	REMOVING
TENDERING		XXXXXXXX	XXXXXXXX
CONTRACTING	XXXXXXXX		
DESIGN	XXXXXXXX	XXXXXXXX	
CONSTRUCTION	XXXXXXXX	XXXXXXXX	
UTILIZATION	XXXXXXXX	XXXXXXXX	XXXXXXXX

Table 1: QUALITATIVE EVALUATION OF RELATIONSHIP BETWEEN INSUFFICIENT QUALITY OF PREPARATION, CONSTRUCTION AND UTILIZATION OF STRUCTURES AND MAINTENANCE ACTIVITIES.

A proper system of quality assurance and quality control has to be planned and exercised in all of these phases to minimize the necessity of maintenance activities.

With some restrictions, it seems to be possible to find some relationship out of interaction between structure, function and environment on the one hand and important types of structural failures and damages of concrete structures on the other.
Table 2 demonstrates those relationship taking into account:

- impacts of media
- temperature impacts
- dynamic impacts

resulting out of interaction between structure, function and environment under performance- and hazard condition.

IMPACTS	MAIN TYPES OF FAILURES AND DAMAGES			
	DEGRADATION	SPALLING	CRACKING	DESTRUCTION
MEDIA				
- AIR/GAS	XXXXXXXX	XXXXXXXX		
- LIQUIDS	XXXXXXXX	XXXXXXXX		
- MOISTURE	XXXXXXXX	XXXXXXXX	XXXXXXXX	
- SOLIDS				XXXXXXXX
TEMPERATURE				
- CONSTANT			XXXXXXXX	
- VARIABLE	XXXXXXXX	XXXXXXXX	XXXXXXXX	
- VERY LOW				XXXXXXXX
- VERY HIGH				XXXXXXXX
DYNAMIC				
- PERIODIC	XXXXXXXX	XXXXXXXX	XXXXXXXX	
- TRANSIENT	XXXXXXXX	XXXXXXXX		
- BLASTWAVE				XXXXXXXX
- IMPULSE				XXXXXXXX

Table 2: QUALITATIVE EVALUATION OF RELATIONSHIP BETWEEN IMPACTS AND MAIN TYPES OF DAMAGES.

The main activities to prepare maintenance of

CONTEMPORARY structures are:

- field inspection
- visual examinations
- non-destructive and destructive examinations
- damage assessment, - evaluation and - quantification
- evaluation of residual bearing and performance capacity
- updating users-, public- and men's demands
- optimization of life-cycle behaviour of structure.

The main activities to prepare maintenance of

FUTURE structures are:

- Future-oriented evaluation of users', public and peoples' demands
- Tendering and design on a full-life-cycle-basis instead of an initial-cost-basis
- Development of future-oriented maintenance concepts to adapt concrete structures on future structural demands
- Development of future-oriented maintenance concepts to adapt concrete structures to future cultural demands or to remove concrete structures.

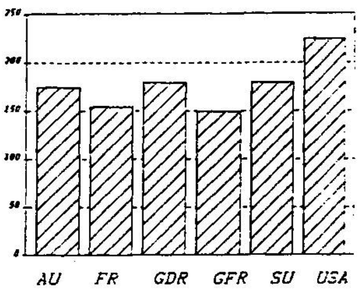
One of the most important task to carry out a maintenance-oriented design is to evaluate and to describe loads and impacts concrete structures have to withstand.

Norms, codes, regulations and recommendations give an initial orientation in this regard.

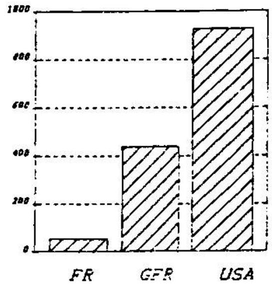
As it is shown in table 3 even in this basic and most traditional field of engineering activity one is confronted with quite different points of views and different orientation.

LOADS AND OTHER IMPACTS

SILO PRESSURE calculated by SILO NORMS of AU, FR,GDR,GFR,SU, USA (Cementsilo)



AIRCRAFT CRASHES upon CONTAINMENTS recommended by REGULATIONS of FR,GFR,USA

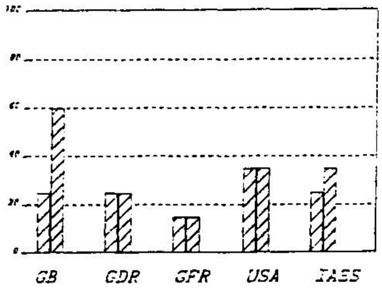


STRUCTURAL DETAILING OF COOLING TOWERS

MAIN STEEL PERCENTAGE

MINIMUM CONCRETE COVER

given by NORMS and RECOMMENDATIONS of GB, GDR, GFR, USA,IASS



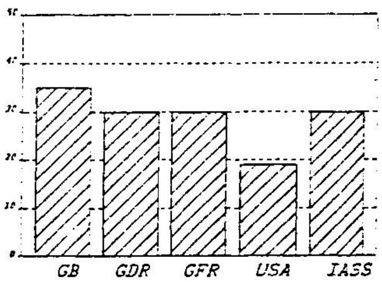


Table 3: EXAMPLES OF DISCREPANCIES IN INTERNATIONAL NORMS AND RECOMMENDATIONS

The same situation is given for some basic orientation concerning structural detailing, as it is also shown by examples in table 3.

This is one of the reasons, why even in such a most classical field of civil engineering like SILOS maintenance of different type and intensity is often necessary.
Table 4 shows results of a damage-oriented study comprising about two hundred grain concrete grain silos.
The damage level are defined as follows:

- Level 1: isolated cracks and small local deficiencies,
  TO BE INSPECTED
- Level 2: cracking patterns and concrete spalling,
  TO BE REPAIRED
- Level 3: serious cracking patterns with widespread concrete spalling and local compression failures
  TO BE RECONSTRUCTED

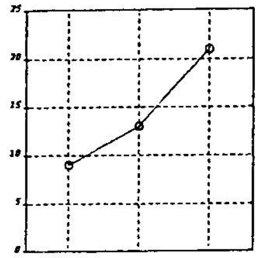
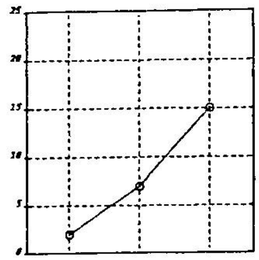
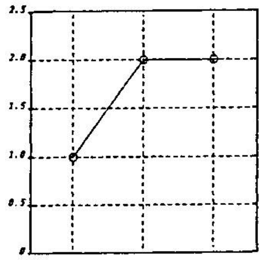
DAMAGE LEVEL	DAMAGED SILOS AFTER 1o, 15,25 YEARS	MAINTENANCE ACTIVITIES
1 (SMALL CRACKS)		OBSERVATION
2 (CRACKING PATTERN)		REPAIR
3 (HEAVY DAMAGES)		RECONSTRUC-TION

Table 4: EXAMPLES OF SILO DAMAGES DEPENDING ON SILO LIFE-TIME

Those examples demonstrate that even in the most classical and fundamental fields of civil engineering engineers are confronted with decisions which greatly can influence the necessity of maintenance activities.

Often enough engineers are not given support by norms and recommendations when they need it mostly.
That is especially true for structures with high risk potential and structures which have to meet special users demands.

It is therefore always necessary not only to respect regulations but to analyze and to evaluate the full life-cycle of structures to meet the demands of optimal maintenance.

4.CONCLUSIONS AND RECOMMENDATIONS

4.1 General conclusions

To optimize maintenance activities of structures the following GENERAL CONCLUSIONS can be drawn:

- Maintenance-oriented attitudes have to be developed and exercised during all phases of preparing, construction and using structures.

- Tendering and contracting have to ensure assessment of risk during construction and utilization and to define levels of duties, responsibilities and quality control.

- Maintenance activities should be minimized by establishing a system of quality-assurance and quality-control valid in all phases of preparing, constructing and using of structures.

- Tendering and design activities have to be carried out taking into account the full life-cycle-costs of structures and overall costs instead of only the initial costs.

- Criteria to evaluate the necessity and type of maintenance activities should be determined not only out of technical but also out of cultural demands and should consider interaction between structural behaviour on the one hand and future oriented users-, public- and men's demands on the other.

- Concepts of maintenance activities have to take into account that performance requirements, environmental conditions and public attitude may change in a wide range during the life-cycle of the structure.

4.2 Recommendations for concrete structures

DESIGN FOR or AGAINST maintenance of CONCRETE STRUCTURE should take into account characteristics of concrete structures. For the layout, analysis and structural detailing of concrete structures the following recommendations may be useful:

- Design has to consider change of structural systems, loads and other impacts as well as concrete properties during the erection of the concrete structure.

- Design has to consider that concrete is a material with long-term-deformation the intensity of which is time-, environment-,stress- and temperature-dependent.

- Design has to consider that long- and short-time deformation of concrete structures must not be restricted without taking into account possible redistribution of internal forces and development of cracks.

- Design has to consider that cracks not only may cause corrosion of steel but also can influence the stiffness, the stability and the dynamic behaviour of concrete structures in a wide range.

- Design has to consider that structural supports and interconnections of structural elements mostly are strongly idealized in structural analysis and that therefore great differences might be between assumption and reality.

- Design has to consider that behaviour of prestressed concrete structures is greatly influenced by the exactness of prestressing and that such structures are more sensitive against incorrect assessments of loads and other impacts and of restriction which may result out of restricted deformation or unrealistic assessment of structural stiffness.

- Design has to consider that maintenance activities in the future can make it necessary not only to repair, strengthen or reconstruct but also to demolish and replace concrete structures in order to maintain or restore harmony in natural or built environment.

To orient our design activities in such a direction may contribute to our general aim:

Development of CIVIL ENGINEERING
into
CIVILIZED ENGINEERING