KEYNOTE SPEAKER

Codes of Practice for the Assessment of Existing Structures
Normes pour l'évaluation de structures existantes
Normen für die Beurteilung existierender Bauwerke

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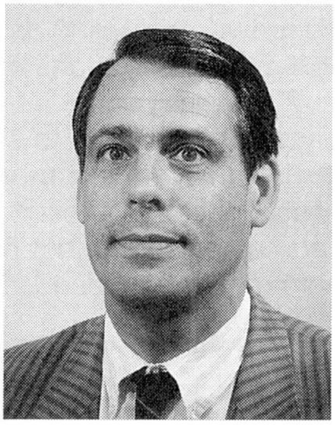

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SUMMARY
This paper summarizes the essential characteristics of the assessment of existing structures and the possibility of codification in this field. The present situation in various countries is summarised. An overview is given of those items that should be addressed by a code on existing structures. Suggestions for the development of such a code are presented.

RÉSUMÉ
Cet article présente un résumé des caractéristiques essentielles pour l'évaluation de structures existantes et les possibilités de normalisation. La situation actuelle dans différents pays est présentée sous forme de résumé. Les aspects importants qui devraient être traités dans une future norme pour les structures existantes sont présentés. Quelgues propositions sont faites en vue du développement d'une telle norme.

ZUSAMMENFASSUNG
Diese Publikation fasst die wichtigsten Merkmale der Beurteilung existierender Bauwerke und die Möglichkeiten der Normung auf diesem Gebiet zusammen. Sie enthält eine Zusammenfassung der heutigen Lage in mehreren Ländern. Es wird eine Übersicht des Hauptgesichtspunkte gegeben, die eine Norm über existierende Bauwerke ansprechen muss. Vorschläge für die Entwicklung solch einer Norm werden präsentiert.

1. INTRODUCTION

Most building codes deal with the design of new structures only. In many cases these codes are even quite explicitly referred to as design guides. The problems which are encountered when assessing existing structures are often not mentioned. In the historical and social context this is fully understandable. Especially in the period after the second world war, most countries experienced an enormous growth in building production of all kinds and there was a clear need to have this production guided by means of a system of codes.

This period of large building activity seems, at least to some extend, to have come to an end. On the other hand, there is an increasing number of existing structures that are questioned with respect to their fitness for use. As a result, assessment of existing structures is no longer an occasional job for some specialists, but becomes more and more a part of common engineering practice, which requires guidance in the same way as design.

2. PRESENT SITUATION

In discussing codification related to exisiting structures, it is useful to distinguish between code type documents and guidelines. At present, only a few countries have a general applicable and real code type document for the assessment of existing structures. As far as the author is aware, only in Czechoslowakia [1] and in The Netherlands [2] such a document exists. In Canada and USA codes are in preparation [21, 22]. Guidelines exist in a larger number of countries. Examples are references [3-5].

The typical difference between a code and a guideline is that codes essentially deal with minimum requirements on the structures, while guidelines primarily provide information about how to plan and carry out the assessment activities in a systematic and economic way. A guideline does not touch the subject of possible reductions in safety targets or load levels, or gives recommendations only. A code, on the other hand, has to tell explicitly what the acceptance criteria are. As a rule, it will not inform the engineer what particular inspections or calculations might be useful for an economic assessment within certain circumstances. As it is, there seems to be a need for both types of documents.

In the first paragraphs of this section only general documents were discussed. Many countries may have documents which deal with the assessment of particular aspects or special catagories of structures, like bridges [6-10], towers [11], seismic aspects [12, 13], offshore structures, remodelling [14], and so on. These documents are sometimes of a guideline and sometimes of a code type nature. It is clear that these documents have been developed from a special need. Many bridges, for instance, are confronted with much heavier loads than anticipated during design. Both with respect ot ultimate load capacity as to fatigue resistance, this has caused much concern. Apart from that, the maintenance of bridges is an activity where budgets are always limited, and priorities have to be set in a very careful way.

Considering the present state of codification, it is also interesting to have a look at international codes. In the revision of ISO-2394 [15] on Reliability of Structures some general statements will be given, indicating on what type of arguments criteria and rules should be based. Some of the recommendations in the further sections of this paper will be based on the present draft of this document.

In the present draft of Eurocode 1, Basis of Design [16], the statement is present that Eurocodes, without appropriate modification, cannot be used for the assessment of existing structures. It was decided that further guidance would require too much prenormative research to be ready for the present edition.

In this respect it is also worthwile to point to prenormative research that has been carried out by CEB [17-19] and that is under progress by the Joint Committee on Structural Safety [20]. This may raise the expectation that in the next editions of Eurocode and ISO the situation will be improved. Also the present paper is intended to stimulate this process.

3. FUNDAMENTAL DIFFERENCES BETWEEN DESIGN AND ASSESSMENT

In the design situation, the engineer has many degrees of freedom to adapt the structural dimensions or even the concept of the structural system. This way he may, with relatively little effort, prove that the structure meets all the design requirements. If necessary he can, without much additional costs, strengthen a structure which does not fulfil the (calculatory) requirements.

This situation, however, changes fundamentally once the structure has been build. Compare for example the possibility to add a single reinforcement bar to a concrete beam in the design stage to the same modification in an existing structure. In the first case the additional costs are very small, in the second case they may prove to be prohibitive. Furthermore, the history of a building and all the changes and damages that have occurred, may lead to a complex and often fuzzy structural system. In addition there may be a great uncertainty with respect to the geometrical and material properties in the structure. This means that even if an existing structure meets the requirements, it may be very difficult to prove it. The conclusion should be that all requirements that are used in the design situation, and with good reason, are not automatically applicable in the 'as built' situation. We will come back to this in chapter 5.5.

On the other hand, the advantage of existing structures compared to structures to be designed is the possibility to measure their properties: one can measure the geometrical dimensions, the material properties, some of the loads and loading parameters, the structural behaviour, the structural response, it's degree of deterioration, and so on. In practice these possibilities of course are limited, because of the costs involved. But even visual inspection or the observation that a structure has survived some heavy load situations without any damage, may help to get a better view on the properties of the structure than is possible in the design stage.

Finally, in the design stage one has to prove that a structure is fit for a certain intended period of use, the design working life. This may lead to special and often implicit durability requirements. In some design concepts even the reference period for the design loads is related to the design working life. If a designed structure does not meet these requirements the design should be changed. It will be clear that the same requirements, implicit or explicit, do not hold for an existing structure: if an existing structure does not fulfil a long term durability requirement, it does not mean that the structure should be rejected immediately. One should consider the costs: it might be more economical to leave the structure as it is and accept a (possible) shorter remaining life time.

Summarizing this section, the following fundamental differences between structures to be designed and existing structures have been observed:

- the increased cost to strengthen the structure
- the increased difficulty of structural analysis
- the possibility to do measurements and observations
- the possibility to reduce the reference period

What further may be concluded is that the process of assessment the existing structure is a far more diffuse process than the process of design. The design process is much more universal, while problems encountered in the appraisal of exising structures seems to be more of a unique nature. This means that, for the case of assessment, it will be more difficult to give detailed guidance to the engineer. As an example, consider the following statement from the Czech code [1]:

> "The extend of tests depends on the type of materials, structural system, execution method, homogeneity of the material, technical possibilities of sampling and also on the purpose of the tests."

A statement of this type certainly may help the engineer to find the right way of thinking, but it leaves on the other hand many possiblities where he has to find the answers on the basis of his own judgement. Design guides may be expected to give more specific information.

4. GENERAL ASPECTS OF CODIFICATION

The conclusion of the previous discussion is that a design code can not be used directly for the assessment of existing structures: some clauses will need modification, some may not apply at all and a number of additional clauses may prove to be necessary. This seems to justify the writing of a special assessment code. In order to be complete and operational, such a code should adress at least the following aspects:

1. Criteria to do an assessment
2. Structural properties and loads
3. Evaluation of inspection results
4. Structural analysis
5. Acceptance criteria

The first item already indicates a typical difference between a design code and a code for existing structures: every new structure should simply be accounted for in one way or another but when exactly an existing structure should be assessed and to what detail is already a difficult matter in itself. The most essential difference, however, between the two types of codes becomes manifest in the last item: to what degree can it be justified to release the design requirements and to accept reduced criteria in the case of assessment. All five items mentioned above will be discussed to some detail in section 5.

Additional to the specification of a set of minimum requirements in a code type document, there is, as stated in section 2, a need for giving some guidance to the engineer how to tackle the assessment. Such a guidance will, according to section 3, necessarily be of some global nature. Most problems related to existing structures are of a rather unique nature and guidance for that reason cannot be very specific. It will leave more detailed decisions to the judgement of the engineer. What guidance can be given will be discussed in section 6.

5. DISCUSSION OF A CODE TYPE DOCUMENT

In the previous section five aspects have been mentioned that should be covered by a code on existing structures. In this sections these five items will be discussed one by one.

5.1 Criteria to do an assessment

The code should list the various reasons that might exist to start an assessment procedure for an existing structure. A distinction should be made between situations where the assessment is required by the code and situations where the need to assess comes form other sources, but the code nevertheless applies. The most typical cases where a code could require an assessment are:

- Routine

A routine assessment can as a rule be relatively simple: the structure is inspected and if the result is within predefined limits, the assessment is that the structural capacity is still sufficient. If the result is outside the predefined limits a further investigation might follow, or it might be decided to repair or maintain the structure immediately.

Nowadays, routine inspections are performed by owners on their own initiative (public bodies for instance) or on the basis of a requirement by insurance and classification companies (offshore platforms). The degree and nature of the inspections might differ substantionally, varying from looking into appearance aspects only to intensive searches for fatigue cracks.

A country, having a code on existing structures, could require routine assessments for all types of buildings, or alternatively for certain classes, for instance public buildings. The degree in which this is possible, of course, depends on the legal status of the code.

- Deterioration or (suspected) damage

When there is obvious damage to the structure, for instance corrosion, spalling of concrete, cracks, leakage, heavy settlements, and so on, a structural appraisal should be required by a code. The difficult point of course is to indicate the markation between "innocent deterioration" and "deterioraton demanding further investigation". A code should provide as much guidance as possible, but this typically will remain one of the cases where engineering judgement will be decisive.

The code may also require investigations in the case of "suspected damage". Suppose that a structure has been loaded by some extreme load (earth quake, fire, tornado, explosion). In those cases there might be a request for further investigation, even if this particular structure does not show any visible damage at first sight. The same may hold for other types of shortcomings, resulting for instance from construction errors, bad workmanship, unexpected behaviour and so on. In those cases the defects observed on a single structure often brings a large group of similar structures under suspicion. The interesting advantage in such cases is that the available budget for research and analysis is usually relatively high, enabling the use of advanced engineering tools in the assessment.

Finally, a code should specify that only the parts suffering from real or suspected damage (deterioration) should be checked. There is no reason to inspect all parts if only some parts or aspects are under suspicion.

- Increased loads/extended life/change of use

Structures loaded by higher loads than anticipated during design or structures being at the end of their intended service life, should be investigated. This is an actual problem in many countries as far as bridges are concerned [23, 24]. Many bridges have been designed for traffic loads that are much smaller than the present day traffic loads. Many engineers have the feeling that no further investigation is required if the bridge does not give signs of distress. This is a dangerous way of reasoning. If all structures give proper signs of distress before collapsing, the argument would be valid, but this certainly is not the case. It should at least be verified that the structure indeed will show signs of distress in due time.

- Reconstruction

If a structure is to be reconstructed for whatever reason, an assessment should be mandatory. The mere fact that the building is reconstructed makes it necessary to assess the present situation: the dimensions and properties of the present structure should be known in order to be able to make an analysis of the reconstructed building.

5.2 Structural properties and loads

If the original drawings and specifications still exist and if there is no reason to doubt them, the code should specify that these can be used to assess the geometrical and material properties. Deterioration effects, of course, should be taken into account. Reasons for doubt could be: damage under otherwise normal circumstances, premature aging, bad performance of the structure or of similar structures elsewhere. In cases of doubt measurements are always necessary.

Values for material properties should be taken according to the present day codes. If a material is no longer used, actual codes may not provide relevant information. In that case properties as specified in old codes can be used. Sometimes it will be necessary to make some transformation, for instance from an allowable stress value to a design value or characteristic value. For the sake of analysis it may be sometimes worthwile to do additional tests. For instance in the case that use of plastic properties is made, but for the original material only the elastic properties are known. In such a case ductility tests may be necessary.

If no data is available with respect to the grade of the material used, one may do tests, but it might turn out that it is more economical to take the lowest possible grade, used at the time of construction. A code could allow such an approach.

Loads should always be taken according to the new codes and according to the situation to be expected in the reference time for the assessment. Load reductions may follow from measuring some load model parameters (see 5.3), from economic criteria (see 5.5), or from a reduced reference period.

5.3 Evaluation of inspection results

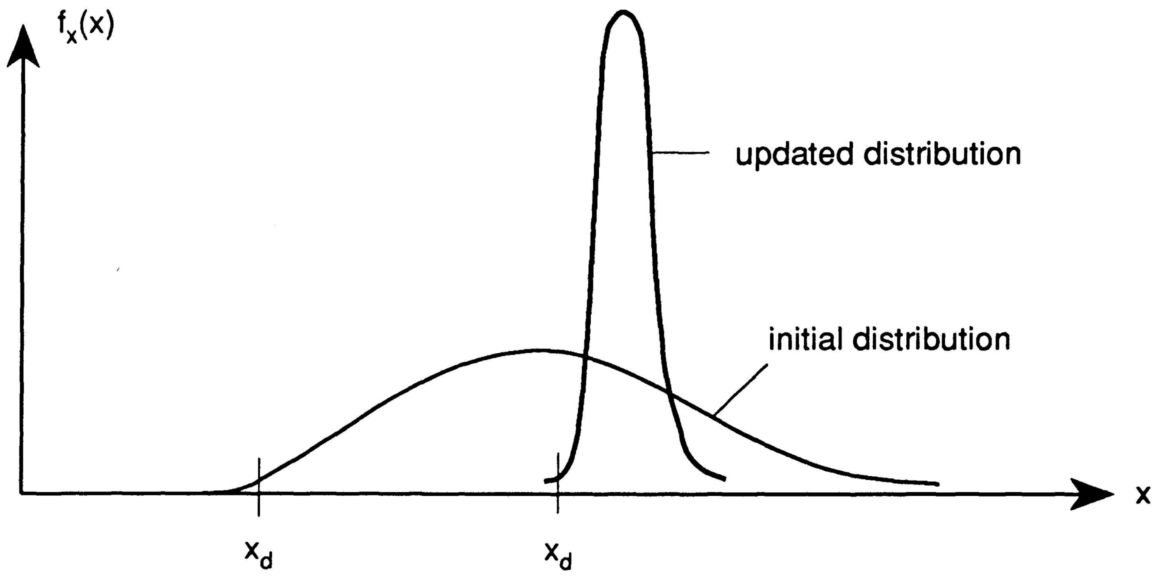
Inspections can be of various types:

- visual
- direct measurement
- non destructive testing
- response measurements
- proof load

The code should specify how data obtained from inspection can be used in the subsequent analysis. A starting point should be that all available data is of value: all information can lead to a better estimate of the structural capacity and to a reduction of the uncertainties. In principle one should combine all information: visual observations, performance in the past, measurements of various kinds and so on. This may require the use of an expert system [25]. From a theoretical point of view, probabilistic methods [26, 27] offer an ideal framework for such a procedure (see Figure 1). In an operational code these formal procedures should be translated into operational methods within a load and resistance factor design approach.

Note that the conclusions of an inspection should not only be concerned with the structure or structural part under consideration. Inspection of one part of a structure always tells something about other parts which are in similar circumstances. Finding a bad concrete quality in one column may increase the probability of finding a bad concrete in another one. In order to use information from tests and measurememts, the accuracy of the inspection method should be known. This is a weak point in the present state of the art. There is a great variety of inspection techniques, but only in a limited number of cases (for instance crack detection in offshore structures) investigations have been done into the so called probability of detection curves and into the quantification of measurement errors.

Figure 1: Original and updated probability density function for an inspected variable x.



Also inspections on the loading side may be of help in the assessment. The research will depend on the type of loading. For offshore structures one may check the local wave climate. For wind loading on special shaped structures one may measure the shape coefficients. For industrial loads measurements may indicate differences from the original design assumptions. Of course one should be careful: loads in codes are intended to repesent the maximum in say 50 year values. In general it is of course not possible to measure this directly.

5.4. Structural analysis

The analysis of existing structures may differ form the analysis of a structure under design. Especially if a structure has been damaged, some of the assumptions which are normally correct in design might be no longer true and other failure mechanisme might become important. As an example, consider a standard steel section. For a new section, the check on local buckling is normally not necessary, but if dimensions are reduced because of corrosion this might be decisive. In the case of repair and reconstruction, the cooperation between old and new members should be given extra attention. One should keep in mind that strengthening members in general will only help for the additional load. For full profit of the strengthening the ductility requirement for the old structure is more important than normal. These items require a detailed and material oriented approach.

In cases of damage it is necessary that the damage can be explained by analysis. Only if the present status of the structure can be simulated from construction, observed loads and structural data, further meaningful steps can be set [28].

If the analysis of an existing structure leads to the conclusion that the structure is not safe enough, a more advanced analysis may be of help. Sometimes the question is raised wether this can be justified. The argument is that the addtional safety hidden in normal design should be considered as an integral part of the required structural safety. This argument has some truth. If all structures would be analysed on the edge of the theoretical possibilies, the average safety would probably be lower. On the other hand, a carefull analysis may be expected to indicate the weak spots in the analysis which are normally overlooked. Anyway, the code has to come up with some statement about this matter. It is the authors' conviction that both in design and in assessment simple and advanced models can be used to meet the safety requirements. The errors made in both models should be taken care of by introducing the proper model uncertainties.

Quite another point is it wether it is allowed to include nonstructural compontens like separating walls in the analysis. This, to the authors opinion, should be done only with great care and as a kind of emergency measure.

5.5 Acceptance criteria

Criteria for acceptance of an existing structure should be based on present day codes. The mere fact that the structure fulfils the code of its time of construction can never be decisive. Codes have changed and in general for good reasons. This of course does not mean that a if a new code comes into practice with on some point more severe requirements than the old one, this should lead to immediate disapproval of all old buildings. Reasons for possible reductions of the requirments for existing structures will be discussed in this paragraph.

The possible reduction of requirements for existing structures can best be discussed in terms of a probability based code. In a probability based code the design is based on partial factors that depend on the degree of uncertainty and on the required life time reliability. Three items can be taken into consideration:

- the information (inspections, observations) that is available
- the reference period
- the cost benefit ratio of safety measures

If the assessment of an existing structure is based upon the results of extensive measurements, one may reason that the uncertainty has been reduced (see figure 1). This reduction in uncertainty may lead to the use of lower partial factors. In fact this does not mean any reduction of the real safety at all. Note further that measurements not only affect the partial factor, but also the characteristic value. This may lead to much higher values for the material properties than those to be assured in design.

A similar reasoning may be set up for the reference period. New structures are designed for a period of at least 50 years. This long period may lead to a number of requirements which are useless in the assessment of existing structures. There is no point in rejecting an existing structure because we do not expect it to last a period of 50 years from now on. Again this does not really mean a reduction in reliability.

Finally there is the item of cost. It has already been explained that the cost of improving a new structure is generally much lower than the costs involved in upgrading an existing one. This means that if the upgrading of an old structure is considered to be uneconomical, this need not be the case for a new one and vice versa. This argument may lead to a difference in requirements between new and existing structures. Of course, if the safety of human lifes is at stake, some care must be taken with this argument. We will not go into the details, but for instance see [29].

There are many examples from practice where the above type of reasoning has been followed: in many guides for existing structures reduced requirements have been introduced, for instance for fire, earth quake, and so on.

A final fundamental question is: what is an existing structure? The only logical answer can be that a structure should be regarded and judged as an existing structure, the very day that it has been erected. The criteria might even be applied for those parts that have been constructed, even if the total building is not yet completed. In combination with the proposed reduction in the requirements, this might lead to the conclusion that the contractor of a new building can produce a reduced quality without punishment. This of course cannot be true: the contractor is obliged by a contract to deliver the design quality. But if he fails, it might be better that he pays a fine than that he starts to make repairs.

6. GUIDANCE TO THE DECISION PROCESS

In section 5 of this paper the code type assessment requirements have been adressed. More than in normal cases, however, the engineer also wants guidance in the way of attacking the problems, in the decisions he has to make, even if it is of a very global nature. Typically two types of decisions have to be made by the engineer:

-one with respect to the depth of the assessment itself
-one with respect to the measures to be taken

In both cases the engineer should look for the most economical solution, keeping in mind that the total costs include assessment costs, costs of measures and the costs or benefits in the subsequent exploration of the building.

Normally it makes sense to start with a global assessment. Refinements should be done only if (1) the global assessment leads to unfavourable results and (2) the costs of the refinement are not prohibitive compared to the expected profits. Note that the expected profits depend on the probability that the outcome of the refined assessment is positive.

In the choice of possible measures, given a certain amount of information, the time aspect is very important. In general, the decison to build a new structure will lead to higher direct costs than a repair decision. In those cases, however, one should also look for the long term costs: a new building may be good for 50 years while the repair may only only solve the problem for about 10 years.

In giving guidance to these problems, a distinction should be made between the "individual assessment" and a "long term inspection and maintenance program".

The individual assessment occurs in case of damage, remodelling, and so on. A typical guidance for such cases is often provided in the form of a flowchart for activities [3, 5]. Figure 2 gives an example. The chart is based on the principles stated above.

In the long term inspection and maintenance planning one formulates the criteria for repair, maintenance, inspection periods, etc in advance. The criteria should be formulated in such a way that the total cost expectation is a minimum. To get a grip on this problem, a presentation on the basis of an event tree could be of help, see figure 3. Of course, for a quantitative optimization, the costs of inspections, repair and failures should be known, as well as the probability of failure between one inspection and the next one. Of course, in most cases the costs, let alone the failure probabilities, are only vagely known. Nevertheless a clear picture of what the ideal decision criteria are can help to improve the decision quality, even in the absence of exact data.

Figure 2: Simple flow chart for decision making in the case of individual assessment

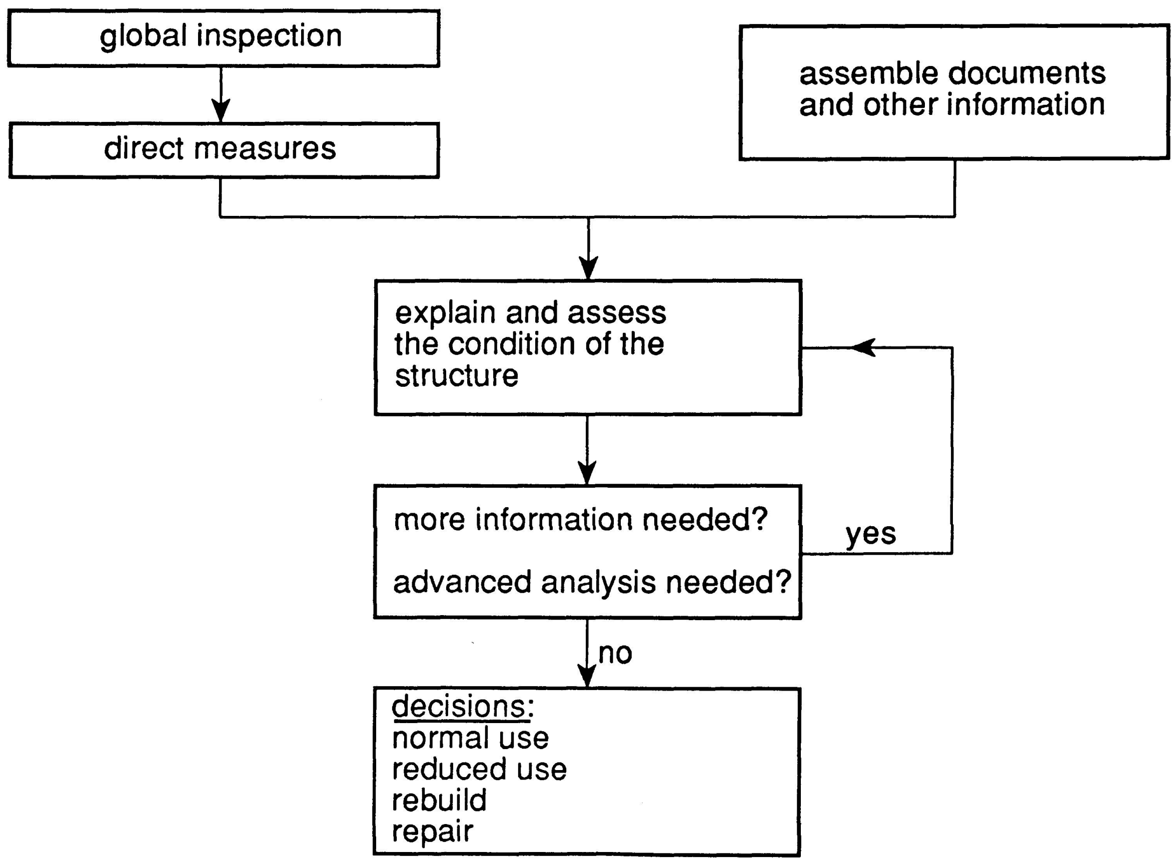
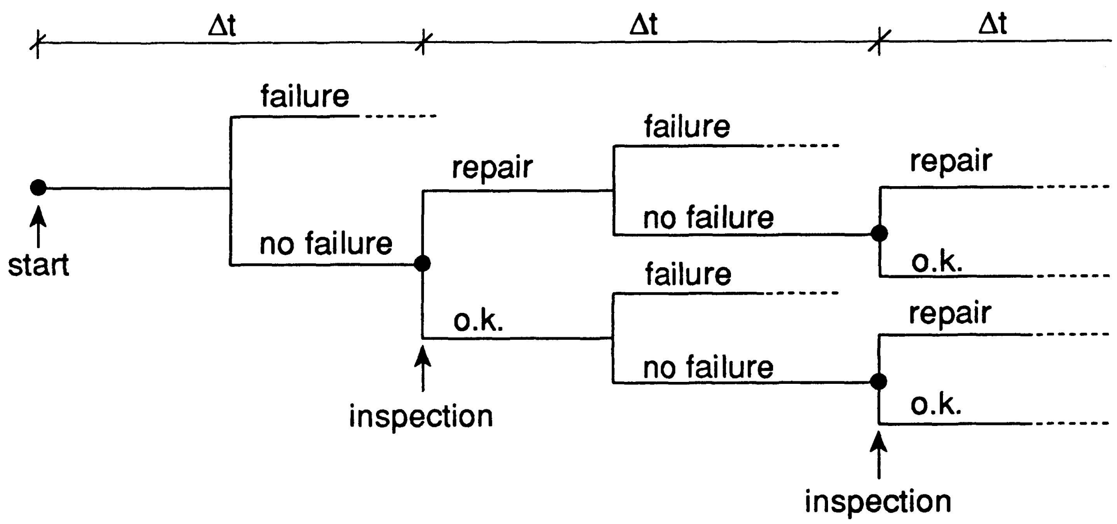


Figure 3: Event tree for a structure subject to a long term inspection and repair program; after every inspection the structure may be o.k. or need repair; during the inspection intervals the structure may fail



7. CONCLUSIONS

The codification of assessment procedures for existing structures is a relatively new field of development. Although an increasing number of codes and guidelines is published, the feeling in most countries is that making a code for existing stuctures still requires additional prenormative research. To stimulate this research this paper has tried to sum up the basic items that should be adressed by such a code. These items are:

1. Criteria to do an assessment
2. Structural properties and loads
3. Evaluation of inspection results
4. Structural analysis
5. Acceptance criteria

The most difficult items probably are the incorporation of inspection results into the total analysis and the possible reductions in performance requirements. Rational ways to deal with these problems seems possible only within the framework of probability based methods. Of course, for the application in every day practice, the results of those methods need to be translated into standard load and resistance factor procedures.

In addition to the typical code type items mentioned above, an engineer needs some guidance to judge in what circumstances what inspections or what measures should be chosen. Here a cost optimization approach should be followed. This requires a guideline type of document, telling the engineer what decisions are the most economical, given the requirements in the code and the costs of the various alternatives.

REFERENCES

1. CSN 73-0083 1986, Czechoslovak Code for the Design and Assessment of Building Structures

Subjected to Reconstruction. (English Translation available), Prague.
2. Regeling Bouwbesluit Constructieve Veiligheid. (Legal Rules for Structural Safety) Ministry of Housing and Environment. The Netherlands, 1992.
3. Structural appraisal of existing buildings for change of use, Building Research Establishment. United Kingdom, 1991.
4. ISE 1980, Appraisal of Existing Structures. The Institution of Structural Engineers, London, 1980.
5. ASCE 11-90, Guideline for Structural Condition Assessment of Existing Buildings.
6. CSA S6-1990, Supplement No. 1 (Existing Bridge Evaluation) to CSA Standard CAN/CSA-S6-88: Design of Highway Bridges. Canadian Standards Association, Rexdale, January 1990.
7. AASHTO, Manual for Maintenance Inspection and Bridges, American Association of State Highway and Transportation Officials, Washington D.C., 1983.
8. OHBDC 1983, Ontario Highway Bridge Design Code: Clause 14-Evaluation of Existing Bridges. Ontario Ministry of Transportation, Downsview, Ontario.
9. AASHTO, Guide Specifications for Strength Evaluation of Existing Steel and Concrete Bridges, American Association of State Highway and Transportation Officials, Washington D.C., 1983.
10. AASHTO, Manual for Maintenance Inspection of Bridges (draft), American Association of State Highway and Transportation Officials, Washington D.C., 1991.
11. CSA S37 1990, Antennas, Towers and Antenna-Supporting Structures, New Clause 3.2: Evaluation of Existing Towers. Canadian Standards Association, Rexdale Ontario.
12. FEMA, U.S. Handbook of Seismic Evaluation of Exisiting Buildings (Preliminary). FEMA-178, Federal Emergency Management Agency, Washington, D.C., 1989.
13. NZNSEE, Earthquake Risk Buildings: Recommendations and Guidelines for Classifying, Interim Securing and Strengthening. New Zealand National Society for Earthquake Engineering, Wellington, New Zealand, 1985.
14. CIRIA, Construction Industry Research and Information Association, Structural renovation of traditional buildings. Report 111, CIRIA, 1986.
15. ISO, Reliability of Structures, IS 2394, 7th Draft, 1992.
16. CEN, Eurocode 1, Basis of Design and Actions, draft, 1992.
17. CEB, Assessment of Concrete Structures and Design Procedures for Upgrading. Comité Euro-International du Béton. Bulletin d'information No. 162, Lausanne, 1982.
18. CEB, Assessment of Concrete Structures and Design Procedures for Upgrading. Comité Euro-International du Béton. Bulletin d'information No. 163, Lausanne, 1982.
19. CEB, Diagnosis and Assessment of Concrete Structures. Comité Euro-International du Béton. Bulletin d'Information No. 192, Lausanna, 1989.
20. JCSS, Project on Existing Structures, Discussion Note, 1991.
21. ALLEN D.E., Criteria for Structural Evaluation and Upgrading of Existing Buildings. Institute for Research in Construction, National Research Council Canada, Ottawa, Ontario. Can. T. of Civil Engineering, December 1991.
22. TURKSTRA C.J., Evaluation of Existing Buildings and Design by Testing. A Review of Related North American Codes Recommendations and Research Work. Department of Civil Engineering, Polytechnic University, Brooklyn, New York, April 1990.
23. MOSES F. and VERMA D., Load Capacity Evaluation of Existing Bridges. Report No. 301, National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 1987.
24. ALLEN D.E., Reliability Index for Bridge Evaluation. Institute for Research in Construction, National Research Council Canada, Ottawa, Ontario.
25. ZHANG X.J. and YAO J.T.P., The Development of Speril Expert Systems for Damage Assessment. Structural Engineering, Ce-STR-86-29, 1983.
26. MADSEN H.O., Model Updating in Reliability Theory. Proceedings, ICASP5, Vancouver, B.C., May 1987.
27. DIAMANTIDIS D., Reliability assessment of existing structures. A.S. Veritas Research, Høvik, Norway, September 1986.
28. STEPHENS J.E. and YAO J.T.P., Survey of Available Structural Response Data for Damage Assessment. Structural Engineering, CE-STR-83-23.
29. DITLEVSEN O., Decision Criteria in Reliability Updating of Existing Structures. Appendix B, Structural Reliability of Existing Bridges, Report no. 1, The Road Directorate, Ministry of Transport, Denmark, 1986.