***Part II – GUIDELINES***

Part II

**GUIDELINES**

## 1 General criteria

A combination of both scientific and cultural knowledge and experience among those involved is indispensable for the study and care of architectural heritage. Only in this context can these guidelines help towards better conservation, strengthening and restoration of buildings and other structures.* The purpose of all studies, research and interventions is to safeguard the cultural and historical value of the building as a whole. Structural engineering involves the scientific support necessary to obtain this result. These guidelines have been prepared to assist this work and facilitate communication between those involved.

Any planning for structural conservation requires both qualitative data, based on the direct observation of material decay and structural damage, historical research etc., and quantitative data based on specific tests and mathematical models of the kind used in modern engineering. This combination of approaches makes it very difficult to establish rules and codes. While the lack of clear guidelines can easily lead to ambiguities and arbitrary decisions, codes prepared for the design of modern structures are often inappropriately applied to historic structures. For example, the rigid application of seismic and geotechnical codes can lead to drastic and often unnecessary measures that fail to take account of real structural behaviour. Engineering judgement is an essential element in this work imposing a responsibility on those making such judgements.

The subjective aspects in the study and the safety assessment of an historic building, the uncertainties in the data assumed and the difficulties of precise evaluation of phenomena, may lead to conclusions of uncertain reliability. It is important, therefore, to show all these aspects clearly, noting particularly in an *EXPLANATORY REPORT* the care taken in the development of the study and the reliability of the results. This report requires a careful and critical analysis of the safety of the structure in order to justify any intervention measures. It will facilitate the decisions to be taken and the final judgement on the safety of the structure.

The evaluation of a building requires a holistic approach considering the building as a whole rather than just the assessment of individual elements.

## 2 Acquisition of data: information and investigation

### 2.1 Generally

The investigation of the structure requires an interdisciplinary approach that goes beyond simple technical considerations because historical research may explain aspects of structural behaviour while

* Note that the term ‘building’ is used subsequently in this document for brevity only and implies other structures.

structural behaviour may answer some historical questions. Therefore it is important that an investigating team be formed that incorporates a range of skills appropriate to the characteristics of the building and which is directed by someone with adequate experience.

Knowledge of the structure requires information on its conception, on its constructional techniques, on the processes of decay and damage, on changes that have been made and finally on its present state. This knowledge can usually be reached by the following steps:

- a description of the structure's geometry and construction;
- definition, description and understanding of the building's historic and cultural significance;
- a description of the original building materials and construction techniques;
- historical research covering the entire life of the structure including both changes to its form and any previous structural interventions;
- description of the structure in its present state including identification of damage, decay and possible progressive phenomena, using appropriate types of test;
- description of the actions involved, structural behaviour and types of materials;
- a survey of the site, soil conditions and environment of the building.

A 'pre-survey' of both the site and the building should guide these studies.

Because these can all be carried out at different levels of detail, it is important to establish a cost-effective plan of activities proportional to the structure's complexity and architectural value, which takes into account the benefit to be obtained from the knowledge gained. In most cases it is appropriate to undertake these studies in stages beginning with the simplest and broadest, moving on to the more detailed.

### 2.2 Historical and architectural investigations

The purpose of the historical investigation is to understand the conception and the significance of the building, the techniques and the skills used in its construction, the subsequent changes in both the structure and its environment and any events that may have caused damage. Such events include additions or changes of use, failures, reconstructions and restoration work or structural modifications that might have been recorded.

Documents used for this should be noted and the sources assessed for their reliability as a means of reconstructing the history of construction. Their careful interpretation is essential if they are to produce reliable information about the structural history of a building. It should be remembered that documents that might be available were usually prepared for purposes other than structural engineering and may therefore include technical information which is incorrect and/or may omit or misrepresent key facts or events which are structurally significant. Assumptions made in the interpretation of historical material should be made clear.

## 2.3 Investigation of the structure

Direct observation of the structure is an essential phase of the study, usually carried out by a qualified team to provide an initial understanding of the structure and to give an appropriate direction to the subsequent investigations.

The main objectives include:

- identifying decay and damage,
- determining whether or not the phenomena have stabilised,
- deciding whether or not there are immediate risks and therefore urgent measures to be undertaken,
- identifying any ongoing environmental effects on the building.

The study of structural faults begins by mapping visible damage. During this process interpretation of the findings should be used to guide the survey, and the expert already developing an idea of the possible structural behaviour so that critical aspects of the structure may be examined in more detail. Record drawings should map different kinds of materials, noting any decay and any structural irregularities and damage, paying particular (but not exclusive) attention to crack patterns and crushing phenomena.

Geometric irregularities can be the result of previous deformations, or can merely indicate the junction between different building phases or alterations to the fabric.

It is important to discover how the environment may be damaging a building, since this can be exacerbated by poor original design and/or workmanship (e.g. lack of drainage, condensation, rising damp), the use of unsuitable materials, and/or inadequate (or non-existent) maintenance. For example, observation of areas where damage is concentrated as a result of high compression (zones of crushing) or high tensions (zones of cracking or the separation of elements) and the direction of the cracks, together with an investigation of soil conditions, may indicate the causes of this damage. This may be supplemented by information acquired by specific tests.

## 2.4 Field research and laboratory testing

The schedule of tests should be based on a clear preliminary view of which phenomena are the most important to understand. Tests usually aim to identify the various mechanical, physical and chemical characteristics of the materials, the stresses and deformations of the structure and the presence of any discontinuities within it. The first of these will include the materials' strength and elastic properties the second such characteristics as their porosity.

As a rule, the schedule of tests should be divided into stages, starting with the acquisition of basic data, followed by a more detailed examination with tests based upon an assessment of the implications of the initial data. However, testing should not be undertaken until its need has been established.

Non-destructive tests should be preferred to those that involve alterations to a structure. If these are not sufficient, it is necessary to assess the benefit to be obtained by opening up the structure in terms of reduced structural intervention against the loss of culturally significant material (a cost-benefit analysis).

Tests should always be carried out by skilled persons able to gauge their reliability correctly and the implications of test data should be very carefully assessed. If possible different methods should be used and the results compared. It may also be necessary to carry out tests on selected samples taken from the structure.

### 2.5 Monitoring

Structural observation over a period of time may be necessary, not only to acquire useful information when progressive phenomena is suspected, but also during a step-by-step procedure of structural renovation. During the latter, the behaviour is monitored at each stage (observational approach) and the acquired data used to provide the basis for any further action. A monitoring system usually aims to record changes in deformations, cracks, temperatures, etc. Dynamic monitoring is used to record accelerations, such as those in seismic areas. Monitoring can also act as an alarm bell.

As a general rule, the proposed adoption of a monitoring system should be subjected to a cost-benefit analysis so that only data strictly necessary to reveal progressive phenomena are gathered. The simplest and cheapest way to monitor cracks is to place a ‘tell-tale’ across them. Some cases require the use of computerised monitoring systems to record the data in real time.

## 2 Structural behaviour

### 3.1 General aspects

The behaviour of any structure is influenced by three main factors:

a) the construction, i.e. the structural form, its quality and the connections between structural elements;

b) the construction materials and

c) both the mechanical actions (forces, accelerations and deformations) and the chemical and biological actions.

These factors are examined here in detail

### 3.2 The structural scheme and damage

The real behaviour of a building is usually too complex to fully model so that it is necessary to represent it with a simplified 'structural scheme', i.e. an idealisation of the building, which shows, to the required degree of precision, how it resists the various actions.

The structural scheme shows how the building transforms actions into stresses and deformations and ensures stability. A building may be represented under varying actions by different schemes with different complexity and different degrees of approximation to reality. The scheme used in the structural analysis is usually a compromise between one close to reality but too complex for calculation and one easy to calculate but too far from the reality of the building. Judgement is essential in choosing an appropriate scheme.

The original structural behaviour may have changed as a result of damage (cracks, etc.), reinforcements, or other modifications of the building. The scheme used has to take into account any alterations and weakening, such as cracks, disconnections, crushing, leaning, etc., which may significantly influence the structural behaviour. These alterations may be produced either by natural phenomena or by human interventions. The latter includes the making of openings, niches, etc.; the elimination of arches or other structural elements, which create unbalanced forces; increases in height of the structure, which increase weights; excavations, galleries, nearby buildings, etc., which reduce the soil bearing capacity and induce movements. The scheme should consider to an appropriate degree the interaction of the structure with the soil, except on those cases where it is judged to be irrelevant.

Structural damage occurs when the stresses produced by one or more action exceed the strength of the materials, either because the actions themselves have increased or because strength has been reduced. Substantial changes in the structure, such as partial demolition, may also be a source of damage. Manifestation of damage is related to the kinds of actions and construction materials. Brittle materials will fail with low deformations while ductile materials will exhibit considerable deformation before failure.

The appearance of damage, and in particular cracks, is not necessarily an indication of risk of failure in a structure because cracks may relieve stresses that are not essential for stability and may, through changes in the structural system, allow a beneficial redistribution of stresses. Damage may also occur in non-structural elements, such as cladding or internal partitions, as a result of stresses developed within those elements due to deformations or dimensional changes within the structure.

### 3.3 Material characteristics and decay processes

Material characteristics (particularly strength and stiffness), which are the basic parameters for any calculation, may be reduced by decay caused by chemical, physical or biological action. The rate of decay depends upon the properties of the materials (such as porosity) and the protection provided (roof overhangs, etc.) as well as maintenance. Although decay may manifest itself on the surface, and so be immediately apparent from superficial inspection (efflorescence, increased porosity, etc.), there are also decay processes that can only be detected by more sophisticated tests (termite attack in timber, etc.).

Material decay is brought about by chemical, physical and biological actions and may be accelerated when these actions are modified in an unfavourable way (e.g. by pollution). The main consequences are the deterioration of surfaces, the loss of material and a reduction of strength. Stabilisation of material characteristics is therefore an important task for the conservation of historic buildings. A programme of maintenance is an essential activity because, while preventing or reducing the rate of change may be possible, it is often difficult or even impossible to recover lost material properties.

### 3.4 Actions on the structure and the materials

'Actions' are defined as any agent (forces, deformations, etc.) which produce stresses and strains in the structure and any phenomenon (chemical, biological, etc.) which affects the materials, usually reducing their strength. The original actions, which act from the beginning of construction and the completion of the building (dead loads, for example), may be modified during its life, and it is often these changes that produce damage and decay.

Actions have very different natures with very different effects on both the structure and the materials.

Often more than one action (or, change to the original actions), will have affected the structure and these must clearly be identified before selecting the repair measures.

Actions may be divided into mechanical actions that affect the structure and chemical and biological actions that affect the materials. Mechanical actions are either static or dynamic the former being either direct or indirect (see Table 1).

<u>Table 1 – Classification of the different kinds of action on structures and their materials</u>

<table>
<tr><td rowspan="3">1 - Mechanical actions –<br>acting on the structure</td><td rowspan="2">i) Static actions</td><td>a) Direct actions<br>(i.e. applied loads)</td></tr>
<tr><td>b) Indirect actions<br>(i.e. applied strains)</td></tr>
<tr><td colspan="2">ii) Dynamic actions<br>(imposed accelerations)</td></tr>
<tr><td colspan="3">2 Physical, Chemical and Biological actions – acting on the materials</td></tr>
</table>

**<u>1 Mechanical actions</u>** acting on the structure produce stresses and strains in the material possibly resulting in visible cracking, crushing and movement. This can be static or dynamic.

**<u>i) Static actions</u>** can be of two kinds:

**<u>a) Direct actions</u>** i.e. applied loads such as dead loads (weight of the building, etc.) and live loads (furniture, people, etc.). Changes in loads - mainly increases - are sources of increased stresses and thus of damage to the structure. However reductions in load can also be a source of damage to the structure.
**<u>b) Indirect actions</u>** are either deformations imposed on the boundaries of the structure, such as soil settlements, or produced within the body of the materials, such as thermal movements, creep in timber, shrinkage in mortar, etc. These actions, which may vary continuously or cyclically, only produce forces if deformations are not free to develop. The most important and often most dangerous of all indirect actions are soil settlements (produced by change in the water table, excavations, etc.) which may create large cracks, leaning, etc.

A number of indirect actions are cyclic in nature. These include temperature changes and some ground movements due to seasonal variation in ground water levels. The effects are usually cyclic too, but it is possible for there to be progressive deformation or decay if each cycle produces some small but permanent change within the structure.

The temperature gradient between external surfaces and the internal body may cause differential strains in the material and therefore stresses and micro-cracks, which further accelerate decay.

Indirect actions can also be produced by the progressive reduction of the stiffness of elements of an indeterminate (hyperstatic) structure resulting in a redistribution of stresses.

**ii) <u>Dynamic actions</u>** are produced when accelerations are transmitted to a structure, due to earthquakes, wind, hurricanes, vibrating machinery, etc.

The most significant dynamic action is usually caused by earthquakes. The intensity of the forces produced is related to both the magnitude of the acceleration and to the natural frequencies of the structure and its capacity to dissipate energy. The effect of an earthquake is also related to the history of previous earthquakes that may have progressively weakened the structure.

**2) Physical, chemical, and biological actions** are of a completely different nature from those described above and act on the materials changing their nature, often resulting in decay and in particular affecting their strength. These actions may be influenced and accelerated by the presence of water (whether in the form of rain, humidity, ground water), by wetting and drying cycles, organic growth, variations in temperature (causing expansion and contraction) frost action, etc.). They may also be affected by micro-climatic conditions (pollution, surface deposition, changes in wind speeds due to adjacent structures, etc.).

Fire can be considered as an extreme change of temperature producing both rapid and permanent changes in the materials. While this might not result in immediate structural distress it may leave latent weaknesses.

Material properties may also change over time due to natural processes characteristic of the material, such as slow hardening of lime mortar or slow internal decay. While chemical changes may occur spontaneously because of the inherent characteristics of the material they may also be produced as a result of external agents, such as the deposition of pollutants, or the migration of water or other agents through the material.

A very common action is the oxidation of metals. This may be visible on the surface or may be occurring to metal reinforcing placed inside another material (such as concrete) and therefore only apparent through secondary effects, such as splitting and spalling of the other material.

Biological agents in timber, i.e. rot and insect attack, are often active in areas not easily inspected.

# 4 Diagnosis and safety evaluation

## 4.1 General aspects

Diagnosis and safety evaluation of the structure are two consecutive and related stages undertaken to determine the need for and extent of treatment measures. If these stages are performed incorrectly, the resulting decisions will be arbitrary; poor judgement may result in either conservative, and therefore heavy-handed conservation measures, or conversely, inadequate safety levels.

Evaluation of the safety of the building should be based on both qualitative methods, based on documentation and observation of the structure, and quantitative methods based on experimental and mathematical techniques that take into account the effect of the various phenomena on structural behaviour.

Any assessment of safety is influenced by two types of problem:

- the uncertainty attached to data describing actions, resistance and deformations, and the laws, models and assumptions used in the research;
- the difficulty of representing real phenomena in a precise way with an adequate mathematical model.

It therefore seems reasonable to try different approaches, each providing its own contribution, but which when combined produce the best possible ‘verdict’ based on the data at our disposal.

When assessing safety, it is necessary to include some indication, even if only qualitative, of the reliability of the assumptions made, and hence of the results, and of the degree of caution implicit in the proposed measures.

Modern legal codes and professional codes of practice adopt a conservative approach involving the application of safety factors to take into account the various uncertainties.  This is appropriate for new structures where safety can be increased with modest increases in member size and cost. However, such an approach is not appropriate in historic structures where requirements to improve the strength may lead to the loss of historic fabric or to changes in the original conception of the structure. A more flexible and broader approach, where calculations are not the only means of evaluation, needs to be adopted for historic structures to relate the remedial measures more clearly to the actual structural behaviour and to retain the principle of minimum intervention while avoiding risk to human life.

The verdict on a structure's safety is based on an evaluation of the results obtained from the three diagnostic procedures that will be discussed below. This acknowledges that the qualitative approach plays a role, which is as important as the quantitative approach.

It also has to be noted that the safety factors established for new buildings take into account the uncertainties of construction. In existing buildings these uncertainties are often reduced because the real behaviour of the structure can be observed and monitored. If more reliable data can be obtained, theoretically reduced factors of safety do not necessarily correspond to a real reduced safety. However there are cases where the contrary is true and data are more difficult to obtain for historic structure. (This is dealt with in more detail in paragraphs 4.3.1 & 4.3.4 below)

### 4.2 Identification of the causes (diagnosis)

Diagnosis identifies the causes of damage and decay, on the basis of the acquired data. This comes under three headings:

- Historical analysis (see 4.3.2)
- Qualitative analysis (see 4.3.3)
- Quantitative analysis, which includes both mathematical modelling (see 4.3.4) and testing (see 4.3.5).

Diagnosis is often a difficult phase, since the data available usually refer to the effects, while it is the cause or, as it is more often the case, the several contributory causes that have to be determined. This is why intuition and experience are essential components in the diagnostic process. A correct diagnosis is indispensable for a proper evaluation of safety and a rational decision on the treatment measures to be adopted.

### 4.3 Safety evaluation

#### 4.3.1 The problem of safety evaluation

Safety evaluation is the next step towards completion of the diagnostic phase. Whilst the object of diagnosis is to identify the causes of damage and decay, safety evaluation must determine whether or not the safety levels are acceptable, by analysing the present condition of both structure and materials. The safety evaluation is therefore an essential step in the project of restoration because this is where decisions are taken on the need for and the extent of any remedial measures.

However, safety evaluation is also a difficult task because methods of structural analysis used for new construction may be neither accurate nor reliable for historic structures and may result in inappropriate decisions. This is due to such factors as the difficulty in fully understanding the complexity of an ancient building or monument, uncertainties regarding material characteristics, the unknown influence of previous phenomena (for example soil settlements), and imperfect knowledge of alterations and repairs carried out in the past. Therefore, a quantitative approach based on mathematical models cannot be the only procedure to be followed. As with the diagnosis, qualitative approaches based on historical research and on observation of the structure should also be used. An approach based on specific tests may also be useful in some situations.

Each of these approaches, which are discussed below, can inform the safety evaluation, but it is the combined analysis of the information obtained from each of them, which may lead to the 'best judgement'. In forming this judgement both quantitative and qualitative aspects should be taken into account having been weighed on the basis of the reliability of the data and the assumptions made. All this needs to be set out in the EXPLANATORY REPORT already referred to.

It must be clear, therefore, that the architect or engineer charged with the safety evaluation of an historic building should not be legally obliged to base his decisions solely on the results of calculations because, as already noted, they can be unreliable and inappropriate. This is a matter for building regulations and control and again highlights the need for experience and judgement.

Similar procedures have to be followed to evaluate the safety levels after the design of any proposed interventions in order to assess their benefits and to ensure that their adoption is appropriate, neither insufficient nor excessive.

#### 4.3.2 Historical analysis

Knowledge of what has occurred in the past can help to forecast future behaviour and can be a useful indication of the level of safety provided by the present state of the structure. History is the most complete, life-size, experimental laboratory. It shows how the type of structure, building materials, connections, joints, additions and human alterations have interacted with different actions, such as overloads, earthquakes, landslides, temperature variations, atmospheric pollution, etc., perhaps altering the structure's original behaviour by causing cracks, fissures, crushing, movement out-of-plumb, decay, collapse, etc. The structural task is to discard superfluous information and correctly interpret the data relevant to describing the static and dynamic behaviour of the structure.

Although satisfactory behaviour shown in the past is an important factor for predicting the survival of the building in the future, it is not always a reliable guide. This is particularly true where the structure is working at the limit of its bearing capacity and brittle behaviour is involved (such as high compression in columns), when there are significant changes in the structure or when repeated actions are possible (such as earthquakes) that progressively weaken the structure.

#### 4.3.3 Qualitative analysis

This approach is based on the comparison between the present condition of the structure and that of other similar structures whose behaviour is already understood. Experience gained from analysing and comparing the behaviour of different structures can enhance the possibility of extrapolations and provide a basis for assessing safety.

This approach (known in philosophical terms as inductive procedure) is not entirely reliable because it depends more upon personal judgement than on strictly scientific procedures. Nonetheless, it can be the most rational approach where there are such uncertainties inherent in the structure that other approaches only give the appearance of being more rigorous and reliable but are not so in fact

Having observed the behaviour of different structural types in varying stages of damage and decay caused by different actions (earthquakes, soil settlement, etc.), and having acquired experience of their soundness and durability, it is possible to extrapolate this knowledge to predict the behaviour of the structure under examination. The reliability of the evaluation will depend on the number of structures observed and, therefore, on the experience and skills of the individuals concerned. Reliability can be increased by an appropriate programme of investigation and monitoring of progressive phenomena.

#### 4.3.4 The quantitative analytical approach

This approach uses the methods of modern structural analysis which, on the basis of certain hypotheses (theory of elasticity, theory of plasticity, frame models, etc.), draws conclusions based on mathematical calculations. In philosophical terms it is a deductive procedure. However, the uncertainties that can affect the representation of the material characteristics, and the imperfect representation of the structural behaviour, together with the simplifications adopted may lead to results that are not always reliable and may even be very different from the real situation. The essence of the problem is the identification of meaningful models that adequately depict both the structure and the associated phenomena with all their complexity, making it possible to apply the theories at our disposal. Naturally the complexity of the model used is likely to depend upon the scale and importance of the monument.

Structural analysis is an indispensable tool commonly using mathematical models. Models describing the original structure, if appropriately calibrated, allow comparison of the theoretical damage produced by different kinds of action with the damage actually surveyed, providing a useful tool for identifying their causes. Mathematical models of the damaged, and the subsequently reinforced structure, will help to evaluate present safety levels and to assess the benefits of proposed interventions.

Even when the results of calculations and analysis cannot be precise, they can indicate the flow of the stresses and possible critical areas. But mathematical models alone are usually not able to provide a reliable safety evaluation. Grasping the key issues, and correctly setting the limits for the use of mathematical techniques, depends upon the expert's use of his scientific knowledge. Any mathematical model must take into account the three aspects described in section 3: the structural scheme, the material characteristics and the actions to which the structure is subjected.

#### 4.3.5 The experimental approach

Specific tests (such as test loading a floor, a beam, etc.) will provide a direct measure of safety margins, even if they are applicable only to single elements rather than to the building as a whole. However one, or even a few test may not necessarily be representative of the behaviour and hence the adequacy of the overall building.

### 4.4 Judgement on safety

Judgements about a structure's safety are based on the results of the three (or four) main approaches described above (the fourth having a limited application). If analysis shows inadequate safety levels, it should be checked to see if it is based on either insufficiently accurate data or excessively conservative assumptions. This might lead to the conclusion that more investigation is necessary before an assessment can be made.

As safety is of a probabilistic nature, the greater the uncertainties the more severe will be the level of intervention. As methods of investigation and structural analysis improve one would expect the analytical approach to become more reliable and so play a more prominent part in safety evaluation. Nevertheless, other methods will remain indispensable for a full understanding of the structural behaviour of the monument.

Note that time factors may be an important aspect of safety and deadlines may have to be set for decisions on interventions. The factors affecting any deadline will depend on three types of phenomena:

- continuous processes (for example decay, slow soil settlements, etc.) which will eventually reduce safety levels to below acceptable limits. Measures must be taken before that occurs;
- phenomena of cyclical nature (variation in temperature, moisture content, etc.) that produce increasing deterioration;
- unpredictable events (such as earthquakes, hurricanes, etc.). The probability of these occurring at any defined level increases with the passage of time, so that the required degree of safety can theoretically be linked to the life expectancy of the structure. (That the one hundred year storm is more severe than the fifty-year storm is true for other phenomenon such as earthquakes and floods.)

## 5 Decisions on interventions – the Explanatory Report

Decisions regarding the nature and extent of any interventions should be made by the team as a whole and take into account both the safety of the structure and considerations of historic character, i.e. they must draw a balance between ensuring structural stability and preserving the cultural values of the fabric. These decisions must be communicated to the owners (or other parties responsible for the building) in a simple non-technical manner and should be the result of collaboration between all members of the conservation team. Qualitative judgements may play a role that is as important as the quantitative data contained in engineering advice.

The EXPLANATORY REPORT is a commentary upon the more detailed specialist reports and is a synthesis of all their findings. It needs to be a critical analysis of the steps taken by the team and an explanation of the decisions reached. Therefore it is essential that any assessments of safety and possible recommendations for structural intervention are set out in this report and written in a form that is understandable to non-engineers, so that they can be considered together with the cultural social and economic factors.
The purpose of the explanatory report is to explain those things that cannot be reduced to formal calculations, making clear the reliability of the data and any uncertainties, the hypotheses used and the degree of caution being exercised at each stage. It should provide an assessment of the safety of the monument and, if insufficient the proposed interventions that will improve it.

More that one intervention option should be considered and analysed. The report should consider the *pros and cons* of each, which could involve case-by-case considerations of authenticity, the possible rebuilding of collapsed parts, the relative advantages of traditional or modern repair methods and so on, but in particular the safety levels associated with each. The different proposals must also consider the costs and benefits associated with each given that improvements in safety may lead to a loss of cultural values and *vice-versa*. The choices made in the design must be clearly explained showing the improvement obtained in the structural behaviour. Such a detailed analysis justifies the final proposal and provides the best guarantee of the quality of the project.

Where the application of current design codes would lead to excessive interventions that would involve the loss of historic fabric or historic character, it is necessary to clearly describe the situation and to explain how adequate safety is provided by alternative means.

Where the complexities of the problem prevent clear and reliable solutions without extensive interventions a ‘design in process’ may be the best course of action. This begins with minimum intervention, which may then be increased or modified, either during the works or later, on the basis of observations of the building’s behaviour. Such a method involves some form of monitoring system

Any proposed intervention must take into account the temporary situation during the works when there may be a higher level of risk. Such situations are particularly frequent when the structure has already suffered considerable damage, as in post–earthquake works.

The proposals should distinguish between works that are urgent, those that are essential to both the immediate and long-term stability of the structure and those that are desirable as a means of reducing levels of maintenance or improving levels of safety above the minimum required.

All recommendations must be based on logically consistent reasoning. Many of the steps in the process will involve a number of uncertainties, which must be discussed and explained in the report. Uncertainties include:

- The nature of the structural scheme
- Knowledge of any inherent weaknesses
- The properties of the materials
- The nature of the loading and other actions upon the structure

Uncertainties in the data used and/or difficulties in modelling the complex nature of the structure may affect the reliability of the analysis. In such cases the nature of the resulting uncertainties should be made clear. Also the degree of caution being exercised in making an assessment of the present safety of the structure should be made clear and should be expressed in a way that will allow others to engage in a discussion of whether or not the structure is adequately safe.

There may be two alternative courses of action: to proceed on the basis of the data available or to delay any decision and extend investigation of the structure to obtain more reliable information and so reduce the level of intervention necessary. The likely benefits of the second course of action should be clearly set out, but the increased risks associated with delaying action should also be explained.