Robustness of Structural Systems

A new Focus for the Joint Committee on Structural Safety (JCSS)

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Robustness of structural systems – a new focus for the Joint Committee on Structural Safety (JCSS)

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ABSTRACT: The importance of robustness as a property of structural systems has been recognised following several structural failures, such as that at Ronan Point in 1968, where the consequences were deemed unacceptable relative to the initiating damage. A variety of research efforts in the past decades have attempted to quantify aspects of robustness such as redundancy and identify design principles that can improve robustness. This paper outlines the progress of recent work by the Joint Committee on Structural Safety (JCSS) to develop comprehensive guidance on assessing and providing robustness in structural systems. Guidance is provided regarding the assessment of robustness in a framework that considers potential hazards to the system, vulnerability of system components, and failure consequences. Several proposed methods for quantifying robustness are reviewed, and guidelines for robust design will be proposed. The document adopts a probabilistic risk assessment framework and includes guidance for decision-making related to robustness.

1 INTRODUCTION

Robustness of structural systems has gained renewed interest following the collapse of the World Trade Centre towers on September 11, 2001. This disaster happened at a time when regulatory requirements related to disproportionate collapse were considered to be adequate and related research was petering out, except for a few initiatives such as that of the UK described by (Reeves et al. 1999), (Canisius et al. 2001) and (Matthews et al. 2005). As a result of the 9/11 incidents stakeholders worldwide have now begun to re-examine relevant issues, including malicious attacks, holistically by incorporating associated risks. Another reason for increased interest in robustness is that most failures of structures are due to unexpected loads, design errors, errors during execution, unforeseen deterioration and poor maintenance which is not possible to design against using conventional component based code checking formats.

Several significant initiatives in the field of robustness have already been initiated by the Joint Committee on Structural Safety (JCSS). The first was an International Workshop on Robustness of Structures, co-sponsored with IABSE and held at BRE in England in November 2005. The two-day workshop which had nearly thirty presentations was attended by nearly fifty international experts.

The JCSS's second initiative, the development robustness-related guidance, is described in this paper. This guidance document is expected to bridge the significant gap that exists between the philosophical and practical aspect of providing and assessing robustness. From among the many aspects covered in the guidance document, which is currently titled '*Provision and Assessment of Structural Robustness*', the following issues are briefly described in the rest of this paper:

- The issue of disproportionate failure
- The current principles of designing for robustness.
- The contents of the guidance document.
- System approaches to robustness
- Methods of quantifying robustness
- Decision making related to robustness, and
- Effects of quality and gross errors.

2 DISPROPORTIONATE FAILURE

Disproportionate failure of a structural system can be described as the situation where the total damage (or risks) resulting from an action is much greater than the initial damage caused by the action which acted upon only a local region or a component of the structure system. Progressive collapse, where the initial failure of one or more components results in a series of subsequent failures of components not directly affected by the original action is a mode of failure that can give rise to disproportionate failure.

Progressive collapse issues came to the fore of engineering thinking following the partial collapse of the Ronan Point building in London in 1968, due to an internal gas explosion (H.M. Stationery Office 1968). Although progressive failure, especially of structures during construction, had occurred previously (Taylor and Schriever 1976), they had not interested engineers and regulators in the way the failure of the occupied 22-storey Ronan Point building did. The main reason for the sudden importance was not only the potential for fatalities and injuries during failure of a residential building of this kind, but also the public perception issues given rise to by the major parliamentary inquiry that took place (Ministry of Housing and Local Government, 1968c).

Following the recommendations of the official inquiry into the Ronan Point failure, the world's first-ever robustness related regulations came into force in the UK. These were initially issued via Circulars of the Ministry of Housing and Local Government (1968a, b) and then, in 1970, via the Amendment 5 to the Building Regulations (Canisius 2006). Although those requirements had been developed in relation to the hazard of internal gas explosions, they were also considered to provide a minimum safety level under impact actions and other extra-ordinary action situations (*op cit.*).

The principles behind the robustness related requirements currently implemented in various countries originated from the UK requirements which were developed via much theoretical and experimental studies and professional debate. The UK's robustness requirements have been later also tested on some full-scale buildings for specific situations, by BRE, for example, see (Canisius et al. 2001) and (Matthews et al. 2005). These requirements have been also indirectly (and successfully) tested with respect to a new hazard, bomb explosions, during the mainland UK bombing campaigns of the IRA.

2.1 *The post-9/11 situation*

With the end of the IRA campaigns, the relative peacefulness of the world and the lack of significant collapses in the western world resulted in a gradual reduction of progressive collapse related research in the 1990s although some work still continued in various countries such as that in the UK described above. This research work, however, related to the loss of a single load bearing member due to a single action.

Whereas renewed interest in robustness was generated by the bombing of the Alfred Murrah Federal Building in Oklahoma, USA in 1995 (Hinman and Hammond 1997), it was the 2001 World Trade Centre incidents that created, like no other in the past, a significant interest on robustness issues. The reason for the unparalleled importance of the 9/11 incidents in Manhattan were many, including the amount of deaths and destruction caused, the symbolic nature of the buildings, the targeted country and reasons for the attack, and real-time television transmission of the disaster. That is, it was a combination of safety and public perception issues that made the world look at robustness of structures and progressive collapse again with a renewed interest.

The 9/11 incidents disaster has made engineers and regulators ask questions on:

- the adequacy of national building regulations;
- the adequacy of current knowledge in relation to severe malicious attacks and combinations of serial extraordinary actions;
- decision making in the presence of alternative solutions; and
- public perception issues related to safety.

It is such concerns that made the attendees of the JCSS/IABSE International Workshop on Robustness of November 2005 decide on the need for a guidance document that addresses relevant issues. As result an Expert Task Group of international experts were formed by the JCSS in April 2006 with the aim producing the document *Provision and Assessment of Structural Robustness* which is introduced in the rest of this paper.

3 CURRENT PRINCIPLES OF DESIGNING FOR ROBUSTNESS

The currently used methods of designing for robust structural systems that originated in the UK have now been adopted by various countries with slight modifications, where appropriate, by other countries and international codes such as the Eurocodes.

The philosophy of design, as provided in the Eurocodes suite, is presented below. A comprehensive list of different countries' requirements will be available in the guidance document.

In Eurocode 1991-1-7 (CEN 2006), where designing for robustness is introduced, there are two design situations to be considered:

1. designing against identified accidental actions, and
2. designing against unidentified actions (where the designing against disproportionate collapse, or for robustness, is important).

As obvious from their names, these are situations where the designer is aware or not aware, respectively, of the possible hazards that could test the robustness of a particular structural system. The hazard(s) to be so considered can be

– known ordinary and extraordinary actions,
– known and unknown quality and gross errors from human inactivity or activity, and
– unknown hazards that may pose a danger to a particular structure or structures in general.

The methods used to design for robustness of a structural system can be divided into several levels based on the potential consequences of structural failure, categorised in terms of a building's Consequence Class (CC):

CC1: Low consequences: No special requirements
CC2: Medium consequences: Handled using simplified equivalent static analysis methods or by prescriptive rules
CC3: High consequences: Case by case reliability or risk analysis. It may require refined methods of structural analysis.

The strategies for designing a robust structural system can include one or more of the following:

1. Prevent or reduce the action
2. Design the structure/key elements to sustain the action
3. Design the structure to have a minimum level of robustness by either providing alternative load paths or using prescriptive rules which provide sufficient redundancy and ductility.

In the third method above, the principle of prevention of disproportionate collapse is utilised. According to this principle, *a localised failure due to an (accidental) action may be acceptable, provided it will not endanger the stability of the whole structure, and that the overall load-bearing capacity of the structure is maintained and allows necessary emergency measures to be undertaken*. The proportionality of failure can be checked in practice by assessing the additional damage that can result when each load-bearing member is notionally removed, one at a time, from the structure. The damage is considered to be disproportional if it exceeds that given in the code. If the damage is disproportional, then the particular load-bearing member is either designed as a strong 'Key Element' or protective measures are undertaken to reduce its probability of failure to an acceptable lower level.

For unidentified actions, the Key Element design is carried out against a pressure of $34\,kN/m^2$, which is the UK Regulations' requirement based on vented internal gas explosion pressures (Canisius, 2006). *Note: Whether this over-pressure, which was originally intended for the design of walls of large panel concrete buildings, should be used also as the general minimum requirement for the design of Key Elements against any (unidentified) action is subject to some debate at present: for example, in relation to situations where a column may have 'wrap-around' effects of explosion pressure and a component may be subject to concentrated (impact) forces*.

In addition, the need to consider public perception issues when determining the accidental actions to be taken into account is specifically mentioned in EN1991-1-7.

It should be noted that robustness should be distinguished from accidental loads although some of the design procedures and measures are similar. As described above all structures should be robust regardless on the likelihood of accidental loads.

While the Eurocode and other national building codes such as the UK Building Regulations (ODPM 2004) and (DS409 2006) provide comprehensive details for designing structures against disproportionate failure, and consider consequences indirectly, no guidance is available in them for conducting comprehensive analyses of structural systems and the consideration of risks on a probabilistic basis. The JCSS document intends to fill this gap as described in the later sections of this paper.

4 THE JCSS GUIDANCE DOCUMENT ON ROBUSTNESS

A general introduction to the draft JCSS robustness guidance document, *Assessment and Provision of Robustness*, is presented in this section. The document is comprehensive in that the many facets of the issue of structural robustness are covered in it. It is felt by the JCSS Task Group that the desire of the engineering community for a state-of-the-art guidance on robustness issues will be satisfied by this document. The final draft of the document is expected to be ready for publication in January, 2008.

As mentioned previously, the JCSS guidance document is expected fill the important gap between the philosophy and practice of providing robustness, which usually is addressed in isolation by theoreticians and practising engineers, respectively. Therefore, the target audience of the document consists of those who fall between philosophers and practising engineers: for example code developers, specialist designers, Competent Authorities and those involved in research and development activities. However, although the guidance document is not particularly written for practising engineers, they too can make use of it as appropriate.

The JCSS guidance document will comprise ten main chapters that deal with the following important aspects:

- Historical and current practices
- Basic issues and parameters
- Robustness quantification and decision making
- A framework for designing for robustness

- Assurance of robustness from conceptual design to end-of-life of a structure.

Some particular topics the Guidance Document intends address include:

1. The structural safety basis for current robustness requirements.
2. Adequacy of current 'deemed to satisfy' rules that describe various levels of tying of components of a building, in a situation where multiple load-bearing members can be lost.
3. Issues arising from 'too much' tying of a structure, especially under 'deemed to satisfy' rules – for example, non-confinement of collapse and 'drag down' of a structure.
4. For the post 9/11 era, the adequacy of the assessment of robustness by the notional (quasi-static) removal of a single load bearing member, one at a time. The possible extension of this method to consider simultaneous multiple member loss.
5. The acceptability of currently specified limits on additional damage due to the removal of a single load bearing member, for situations where simultaneous loss of multiple members may need to be considered.
6. Definition of structural systems for evaluating robustness and related decision making.
7. Methods of quantifying robustness of a building or a structural system to aid decision making.
8. The importance of non-structural consequences, e.g. economical consequences and public morale, in assessing risks and their relation to Consequence Classes in EN1991-1-7 (and the UK Building Regulations).
9. Decision making in relation to robustness issues. Determination of optimum solutions, with or without the inclusion of hazard elimination or reduction measures.
10. Consideration of situations of changing risk within a changing political and economical climate.
11. Consideration of multiple, serial actions. For example, a fire or gas explosion after an earthquake and a bomb explosion following a distracting fire.
12. Load combination issues and partial factors when considering item 11 above or malicious actions that may be deliberately initiated at peak load occasions.
13. Quality control during execution (construction) and provision of maintenance regimes as means for providing and assuring robustness.
14. Effects of human errors on robustness during various stages from conception to end-of-life of a structure.
15. 'Over-strength' materials and components that can modify structural behaviour (robustness) especially when capacity design is involved.

Four of the main topics of the JCSS guidance document, viz. system approaches, quantification of robustness, decision making and quality/human error issues are briefly introduced in the rest of this paper.

5 SYSTEMS APPROACHES TO ROBUSTNESS

Consideration of system effects is particularly important when modelling robustness. Building code criteria primarily focus on designing individual elements or subsystems of a larger engineered system. This design philosophy has generally been successful, except in those instances where systems have suffered cascading system failures due to a lack of robustness. These potential failure mechanisms are the reason why robustness criteria require system-level analysis.

A system-reliability approach to robustness assessment is being considered by the Joint Committee on Structural Safety. This approach takes advantage of the considerable developments in probabilistic system reliability analysis achieved in the past few decades. By working in a reliability format, the randomness and uncertainties inherent in robustness assessment can be explicitly included, and decision analysis tools can be used to balance the costs of robustness provision against the benefits of increased system reliability. While system reliability methods are most often used to model physical structures, here it may be useful to broaden a system to include the structure as well as its associated inspection, maintenance and repair procedures. This allows one to capture, for example, the effect of various maintenance strategies on the robustness of deteriorating systems.

A variety of system-reliability-based robustness quantification methods have been considered by researchers, and they are briefly described in the following section.

6 METHODS OF QUANTIFYING ROBUSTNESS

Risk- and reliability-based quantification approaches address the shortcomings of the practical approaches by explicitly considering the many uncertainties associated with the problem, such as uncertainties in future loading and uncertainties in system properties. These approaches have the potential to provide a more comprehensive picture of a system's robustness, but they are generally too complex to be useful in typical design situations. Further, most approaches of this type require a probabilistic model for future loading on a structure, and this can be difficult to determine for some events of interest such as sabotage. Despite these limitations, reliability-based approaches show great promise in helping to understand system properties that lead to robustness, and they will also aid in benchmarking the performance of simplified robustness requirements found in building codes. Several proposed methods are briefly described here.

Recognizing that present code-based analysis procedures can not give a complete picture of a structure's robustness, a variety of probability-based quantification procedures has been proposed. Common aspects of these approaches include attempts to quantify the complete range of potential loading on structures, as well as associated probabilities of occurrence for those load scenarios, and quantification of uncertainty in structural properties or structural response.

Note that redundancy in systems is closely related to the concept of robustness. While redundant systems are generally believed to be more robust, there are additional methods of providing robustness that are not related to redundancy. The approaches described briefly below relate to both redundancy and robustness, with individual approaches placing more emphasis on one aspect or another.

(Frangopol and Curley 1987) and (Fu and Frangopol 1990) considered probabilistic indices to measure structural redundancy, based on the relation between damage probability and system failure probability. Fu and Frangopol proposed a redundancy index (RI) defined as

$$RI = \frac{P_{f(dmg)} - P_{f(sys)}}{P_{f(sys)}} \tag{1}$$

where $P_{f(\mathrm{dmg})}$ is the probability of damage occurrence to the system and $P_{f(sys)}$ is the system failure probability. This index indicates the reserve strength of a system (i.e., the residual strength of a system that has sustained damage). Frangopol and Curley considered deterministic safety factors to measure redundancy, but their alternative systems-reliability approach is most relevant here. They studied the following redundancy factor

$$\beta_R = \frac{\beta_{intact}}{\beta_{intact} - \beta_{damaged}} \tag{2}$$

where β_{intact} is the reliability index of the intact system and $\beta_{damaged}$ is the reliability index of the damaged system. The index varies between 0 and ∞, with 0 indicating a failed structure and ∞ representing a very robust structure.

(Lind 1995,1996) proposed a generic measure of system damage tolerance, based on the increase in failure probability resulting from the occurrence of damage. The vulnerability (V) of a system is defined as

$$V = \frac{P(r_d, S)}{P(r_0, S)} \tag{3}$$

where r_d is the resistance of the damaged system, r_0 is the resistance of the undamaged system, and S is the prospective loading on the system.$P(\cdot)$ is the probability of failure of the system, as a function of the load and resistance of the system. This vulnerability parameter indicates the loss of system reliability due to damage.

(Baker and Faber 2006) proposed a metric for robustness of an engineered system. The approach divides consequences into direct consequences associated with local component damage (that might be considered proportional to the initiating damage) and indirect consequences associated with subsequent system failure (that might be considered disproportional to the initiating damage). An index is formulated by comparing the risk associated with direct and indirect consequences. The index of robustness (I_{Rob}) is defined as

$$I_{Rob} = \frac{R_{Dir}}{R_{Dir} + R_{Ind}} \tag{4}$$

where $R_{Dirand} R_{Ind}$are the direct and indirect risks, respectively. The index takes values between zero and one, with larger values indicating larger robustness.

The motivation for this index is that systems having high risk associated with indirect consequences are more likely to suffer disproportionate damage consequences and thus be less robust. In addition to quantifying the effect of the physical system's design, this approach can potentially account for the effect of inspection, maintenance and repair strategies as well as preparedness for accidental events, because those actions can reduce failure consequences and thus risk. The authors present a discussion of how decision analysis theory can be used to make decisions regarding acceptable robustness.

In a study related to reliability based methods, (Ben-Haim 1999) proposed a robustness quantification approach using information-gap theory. This approach does not require the complete probabilistic description of loading that is needed for reliability-based assessments, and it can be applied to general systems. The cost associated with this advantage is that it is no longer possible to explicitly balance robustness improvements with their associated costs.

Several researchers have considered vulnerability of specific classes of structures to specific damage scenarios [(Agarwal et al. 2003), (Ellingwood and Leyendecker 1978), Feng and Moses 1986)]. A relatively well-studied case is the progressive collapse of frame structures. This work is important for characterizing robustness of specific structures, but it is often difficult to generalize these findings to other types of systems or other sources of damage.

Another aspect that quantification of robustness could help in is the determination of acceptable levels of additional (indirect) damage that can be permitted when using the notional load-bearing member removal method of design. For this semi-probabilistic limit-state design method, the limits on indirectly damaged floor area are usually specified in both real and relative terms. The real value limit for damage to one floor, that results from the removal of a single load-bearing member, is not unique in different building codes/regulations: for example, $100\,m^2$ in Eurocode 1991-1-7, $75\,m^2$ in the UK Building Regulations and $240\,m^2$ in the Danish code (DS 409, 2006). However, this difference is acceptable because the value is nationally determined to suit an individual country. However, the current limits (both real and relative) used within a country may become unacceptable, or too stringent, if semi-probabilistic design is to be used for assessing robustness against terrorist attacks by considering the simultaneous loss of several members, for example as proposed by (Alexander 2004). Their direct use to assess buildings against a multiple member loss situation can easily lead to uneconomical structures. Therefore, (Canisius 2006) has proposed a probabilistic method of evaluating acceptable levels of damage to be used in multiple-member loss situations. This method allows the use of protective measures as a means of improving robustness of the structural system. To check the method's usefulness (or not), it is being currently applied to a practical example in relation to the UK's Building Regulations.

7 DECISION MAKING RELATED TO ROBUSTNESS

Robustness is related to scenarios where exposures including unintentional loads and defects result in a damage to the structural system, and where this damage may lead to collapse of the structure. In a probabilistic formulation this can be related to the following framework, see e.g. also (Sørensen and Christensen, 2006):

- Exposure no i: E_i with probability $P(E_i)$. Examples of unintentional loads and defects: changed load case; wrong structural modelling; wrong computational model; error related to material.
- Damage no j: D_j: probability of damage no j given exposure no i: $P(D_j|E_i)$. Examples: loss of column and failure of 15% of storey area
- Consequence: C implying the total probability of collapse:

$$P(C) = \sum_i \sum_j P(C|E_i \cap D_j)P(D_j|E_i)P(E_i) \tag{5}$$

where the summations are over all exposures and damages and $P(C|E_i \cap D_j)$ is the probability of collapse given exposure no i and damage no j. Example: collapse of major part of structural system (building, bridge, ...).

Based on equation (5) decisions related to increase robustness can be made. It seen that the probability of collapse can be reduced (and robustness increased) by:

- Reduce one or more of the probabilities of exposures $P(E_1)$, $P(E_2)$, ...
- Reduce one or more of the probabilities of damages $P(D_1|E_1)$, $P(D_2|E_2)$, ... or reduce the extent of the damages. Examples: strengthen vital structural elements – key elements (e.g. column): implying that $P(D_j|E_i)$ is reduced; strengthen/redesign reinforced concrete slab in order to reduce extent of storey damage.
- Reduce one or more of the probabilities $P(C|E_1 \cap D_1)$, $P(C|E_2 \cap D_2)$, ... Example: increase redundancy of structure.

It is noted that for damages related to key elements: $P(C|E_i \cap D_j) \cong 1$.

Increasing the robustness at the design stage will in many cases only increase the cost of the structural system marginally – the key point is often to use a reasonable combination of a suitable structural system and materials with a ductile behaviour. In other cases increased robustness will influence the cost of the structural system. If more alternatives to increase the robustness are considered, then from a decision theoretical point of view, the optimal alternative k is that which results in the smallest expected total costs:

$$E[C_k] = C_F P(C|\text{alternative } k) + C_{R,k} \tag{6}$$

where C_F is the cost of a collapse, $P(C|\text{alternative } k)$ is the probability of collapse given that alternative k is chosen and $C_{R,k}$ is the cost of alternative k.

8 EFFECTS OF QUALITY OF CONSTRUCTION AND GROSS ERRORS

It is known that nearly 90% of structural failures have been caused by poor quality or human error (Allen 1992).

There are two main issues that need to be addressed in controlling the quality of structures (Canisius 2000):

- Gross errors, or 'human errors', which may occur at any stage of the life of a structure, such as design, detailing, construction, inspection and maintenance, and even in use.
- Quality errors in materials and fabrication.

In addition errors can occur during research and codification, potentially leading to deficient design guidance. Poor quality material or components can be present in a structure due to various reasons, including damage, attempts at excessive saving of resources at any stage of the design-resourcing-manufacture-supply-construction-inspection-maintenance chain, and pure negligence (*op cit.*).

Code specified actions and load combinations for verification of sufficiency of safety generally take into account the loads, including accidental actions, to which a structure is normally exposed. However, unintentional and, sometimes, intentional defects may occur in a structure and robustness should aid to limit the possible consequences of such situations. Interestingly, while robustness can help to nullify some effects of quality errors, the errors and defects themselves can detrimentally affect the robustness of a structural system. Therefore robustness should not be considered as designing against gross errors that can be avoided by other means.

Design and execution errors are found in most structures in various degrees and to various extents, but normally these errors are within the acceptable inaccuracies covered by the safety factors in the structural codes. Fatal defects can in many cases be traced back to gross / human errors. The consequences of a damage caused by such gross / human errors may be limited by suitable structural robustness. Unintentional and unforeseen loads and load effects may also appear due to human errors, for example due to wrong handling or wrong manoeuvres. As an example imposed loads may change in time compared to the predictions at the time of design of the structure. One example is increased storey loads because of change in use of the building. Another example is the change of ship types that has lead to a dramatic increase of possible impact loads for bridges and bridge piers. These types of load conditions may be prevented or limited by a skilled and responsible administration of the structures. However, suitable built-in robustness would most likely limit the consequences of such unforeseen loads.

The quantification of quality issues is a difficult exercise and may not be that desirable for many situations. While the quality issues related to materials and fabrication is relatively easy to deal with by considering past data, it is not so that easy for gross errors which can be affected by reasons such as lack of training, lack of motivation, over-work, and a simple disregard for quality. In many situations, prevention of the detrimental causes and the design of the structure to be insensitive to errors (which itself is a way of making it robust) can be efficient ways of preserving structural robustness for its later mobilisation against other identified or unidentified actions.

Another quality issue that needs to be kept in mind is the provision of over-strong materials or components to a 'capacity-designed' structure. In this case, instead of preventing disproportionate failure, the stronger material can become the cause of a disproportionate failure.

The above and other important issues are addressed in the JCSS guidance document by also considering them as hazards to be considered in a formal reliability analysis.

9 CONCLUSIONS

The Joint Committee on Structural Safety (JCSS) is actively contributing to the advancement of knowledge on robustness of structural systems.

The JCSS Guidance Document on Robustness of Structural Systems, *Provision and Assessment of Robustness of Structural Systems*, would fill the gap between the philosophical and practical approaches to robustness. This would be achieved by putting philosophical aspects of robustness into a format useable for solving practical engineering problems and, where possible, converting practical methods into probabilistic formats to formalise them.

The Guidance Document addresses various issues by

- taking a systems approach to robustness, so that complete chains of events from hazards to consequences of failure can be considered in a manner complementary to current codes and regulations,
- allowing the consideration of issues that can arise throughout the life of a structural system, i.e. from its conceptive design to the end-of-life, including deterioration and maintenance issues,
- giving importance to public perception issues and quality/human error aspects of robustness.

In considering these aspects together, rational holistic solutions can be developed for robustness problems that arise in structural engineering.

The JCSS guidance document would also present a probabilistic methodology for decision making to aid in the selection of optimum solutions, based on cost or risk criteria. The various aspects mentioned above will be incorporated within a Framework for Designing for Robustness. Owing such contents, the guidance document is expected to become an invaluable resource for the target audience and others.

Where a topic cannot be addressed comprehensively within the available timescale, guidance will be provided on possible approaches to adopt. These topics are expected to be taken up later for further development within the JCSS' latest initiative: a four-year European COST Action on Robustness. This initiative, which started in April 2007 and brings together also non-European experts, would research and develop methods for dealing with robustness issues of structural systems.

The JCSS guidance document is scheduled to be published in January 2008.

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