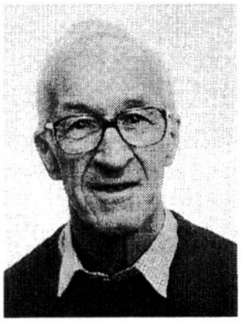
Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 74 (1996)

Artikel: Design philosophy for accidental actions
Autor: Holand, Ivar
DOI: https://doi.org/10.5169/seals-56088

Design Philosophy for Accidental Actions

Ivar HOLAND
Professor, dr. techn.
SINTEF
Trondheim, Norway



Ivar Holand, born 1924, was awarded his civil engineering degree at the Norwegian Institute of Technology in 1948. He received his doctoral degree from the same institution in 1958, and became a Professor of Structural Mechanics in 1963, and Director of the Cement and Concrete Research Institute in 1981. He retired in 1992 and is now a senior research consultant to SINTEF.

Summary

The objective of a design for accidental actions is to give the structure an adequate robustness, reducing the risk of a structural catastrophe to an acceptable level. As a consequence, such a design is not needed for categories of structures with a limited risk potential. For traditional structures with a medium risk potential, the robustness may be obtained by prescriptive detailing rules or a simplified analysis, whereas an analysis-based design for defined accidental actions is needed for structures with a high risk potential.

1. ENV 1991 Eurocode 1: Part 2.7 Accidental Actions

A draft for Eurocode 1: Part 2.7 Accidental Actions was completed in January 1996. The author has been a member of the Project Team, and the present paper has been influenced by the work there, and in broad terms reflects the attitude of the Project Team. However, the author is solely responsible for the formulations, which have not been discussed in the Project Team, except to the extent they are identical with formulations in the draft for Part 2.7.

Parts 2.1 to 2.7 should ideally only prescribe load values. Since the design philosophy for accidental actions differs from the design philosophy for permanent and variable actions, it has been unavoidable to also consider design to a limited extent in the draft. Thus, in the development of ENV 1991-1 [1] to EN, it should be considered if certain parts ought to be transferred from Part 2.7 to Part 1.

2. Definition of accidental design situations and accidental actions

2.1 Formulations in ENV 1991 Part 1 and Part 2.7

The term "Design situation" is defined in ENV 1991-1 to mean the circumstances in which the structure may be required to fulfil its function. The selected design situations are to be sufficiently severe and varied enough to encompass all conditions which can reasonably be foreseen to occur during the execution and use of the structure.

The phrase "which can reasonably be foreseen" is somewhat ambiguous in the case of accidental situations, the characteristics of which are that they cannot easily be foreseen. The PT has therefore qualified this phrase by saying that in the present case this shall be interpreted as "which have a reasonable probability of occurrence and can be counteracted in an economical way".

2.2 Probability of Accidental Actions. Residual Risk

With regard to accidental actions, the structure is designed to resist, with appropriate degrees of reliability, actions with low probability of occurrence, with severe consequences of failure and usually of short duration.

Only in some cases can the probability of occurrence of an accidental action and the probability distribution of its magnitude be determined from statistics and risk analysis procedures. Thus, design values in practice are often nominal values.

The PT has not defined any annual probability for an accidental action, but refers in a note to ISO DP 10252 "Accidental Actions due to Human Activities" [2], which specifies that the representative value of an accidental action should be chosen in such a way that there is an assessed probability less than $p = 10^{-4}$ per year for one structure that this or a higher impact energy will occur.

Hence, there will always be a residual risk which will have to be accepted. The residual risk will refer to accidental actions on a low probability level, which are not considered at all in the design, as well as actions that are identified and considered, but for which the design nevertheless will necessitate the acceptance of a residual risk. The residual risk will be determined by the cost of safety measures weighed against the consequences of a serious failure, including the conceivable public reaction after an accident.

2.3 Causes of Accidental Actions. Risk Analysis

Causes of accidental situations include:

- failure of equipment (cranes, gas piping, vehicle brakes etc.) due to poor design, fabrication or maintenance
- improper use or operation (due to insufficient teaching or training, indisposition, negligence or unfavourable external circumstances)
- natural hazards like tornadoes, earthquakes, avalanches, landslides etc.

A risk analysis may be a valuable tool to study risk scenarios, in particular when accidental situations developing through a complex chain of events have to be considered. However, the complexity needed will be dictated by the problem at hand, and risk analysis in a rigorous form including extensive statistical analyses will be used only in special cases. Risk analysis ideas may, however, also be applied to provide a systematic procedure for identification of risks, and, furthermore, for assessment of accidental actions to be included. The actual assessments may often be made by comparison with known structures, and with risks implied in accepted designs for which experience exists.

A severe consequence requires the consideration of extensive hazard scenarios, while less severe consequences allow less extensive hazard scenarios. Consequences are to be assessed in terms of injury to humans, or unacceptable change to the environment, or large economic losses for the society.

2.4 Man-Made Accidents and Natural Accidents

Accidental design situations are defined in ENV 1991-1 to include (Article 1.5.2.5) "design situation involving exceptional conditions of the structure or its exposure, e.g. fire, explosion, impact or local failure". Thus, accidental actions arising from the natural environment like waves and tides, flooding, tornadoes, extreme erosion or dropping rocks are not included. In accordance with this, the draft for Part 2.7 states that "This part refers to exceptional conditions applicable to the structure or its exposure caused by human activities, e.g. fire, explosion or impact. " However, in ENV 1991-1 Article 4.1(4) states that "Some actions, for example from seismic actions and snow loads, can be considered as either accidental and/or variable actions ...". The restriction to man-made accidents is thus a choice, presumably motivated by a need to restrict the number of sources of accidental actions to be considered in Part 2.7.

Regarding design principles, there is no reason to distinguish between man-made accidents and acts of God, neither in the striving for reducing risks of structural failures, nor in the design philosophy to reach this objective. The logical consequence is that design to mitigate accidental actions should follow the same principles, irrespective of the source of the accidental action. Accordingly, the Project Team has formulated the principles of their draft as generally valid for all categories of accidental actions. Future versions of the Prestandards "Earthquake resistant design of structures" (ENV 1998) and "Actions on structures exposed to fire" (ENV 1991-2-2) should thus comply with ENV 1991-2-7, also where this may not fully be the case in the present documents.

2.5 Acceptance of Local Damage

It is an essential premise for the definition of an accidental action that localised damage (cross section failure/component failure) will be acceptable, provided that it will not endanger the whole structure (i. e. cause system failure), or that the loadbearing capacity is maintained long enough for necessary emergency reactions to be taken, for instance evacuation of the building and its environs. This philosophy will govern the choice of accidental situations to be considered. As a result, some types of events which are generally denoted as accidents, like persons falling through windows or ceilings, are not classified as accidental actions in the present context, since they have no potential to damage the structural system.

Distinguishing between component failure and system failure allows a systematic discrimination between design for variable actions, essentially focusing on cross section/component failure, and for accidental actions, essentially focusing on system failure.

2.6 Accidental and variable actions from the same source

As indicated in ENV 1991-1 Article 4.1(4), accidental actions as well as variable actions may originate from the same sources of action in some cases. This may for instance be the case for impact from ships, where a ship out of control may be the source of an accidental action, whereas actions from fendering and mooring of ships are variable actions.

If abnormal values may occur for actions in the category variable, with the result that the catastrophe safety is not sufficiently taken care of by the load factors and the normal check of component failure under variable loads, a check for such abnormal loads may be needed. Examples are:

- wave and wind loads on offshore structures
- wind and ice loads on masts and towers
- wave and tide loads on dikes

The corresponding safety checks may follow the principles described for accidental situations, even if the loads are not classified as accidental actions according to ENV 1991 Part 2.7.

3. Application of accidental actions in design. Safety Categories

3.1 Objective of design

Risk may be defined as the danger that undesired events represent. Risk is expressed in terms of the probability and consequences of undesired events. Thus, risk reducing measures consist of probability reducing and consequence reducing measures, including contingency plans in the event of an accident. Risk reducing measures should be given high priority in design for accidental actions, and also be taken into account in design. No structure can be expected to resist all actions that could arise due to an extreme cause, but there is to be a reasonable probability that it will not be damaged to an extent disproportionate to the original cause.

A result of the acceptance of local failure (which in most cases may be identified as a component failure) provided that it does not lead to a system failure, is that redundancy and non-linear effects both regarding material behaviour and geometry play a much larger role in design to mitigate accidental actions than variable actions. The same is true for a design which allows large energy absorption.

3.2 Safety Categories

Design for accidental situations is implemented to avoid structural catastrophes. As a consequence, only structures where a collapse may cause large consequences in terms of injury to humans, damage to the environment or economic losses for society need to be designed for accidental situations. Exempted are thus in particular low-rise buildings, where the consequences of an accidental action are small. Nevertheless, consequence reducing measures like fire protection of steel members and design measures like favouring ductile design in earthquake areas are relevant also for low-rise buildings.

A convenient measure to decide what structures are to be designed for accidental situations is to arrange structures or structural components in categories according to the *consequences* of an accident.

The draft for Part 2.7 arranges structures in the following safety categories based on consequences of a failure:

- Safety category 1 Limited consequences
- Safety category 2 Medium consequences
- Safety category 3 Large consequences

Less important individual structural members or sub-systems may be placed in a lower safety category than the overall structural system.

Examples of placing structures in safety categories are shown in an informative annex to the draft, which also is included in Table 1 to illustrate the concept of categorization.

Table 1. Safety categories suggested in draft for EC 1 Part 2.7

Safety categories	Structure
1	Residential buildings of maximum three storeys and comparable structures Agricultural buildings
2	Buildings generally Small road and railway bridges
3	Industrial plants with high risk potentials Large road and railway bridges Dams and dikes implying heavy damage in case of flood Structures for large numbers of persons (e. g. large grandstands or very high-rise buildings) Nuclear reactors

Reliability differentiation is also discussed in ENV 1991-1, Section 2.2. As argued there, there may be various reasons for reliability differentiation, and the choice of categories or classes may to some extent depend on particular needs. A possible unification of safety categories suited for several applications may be a task in the development of ENV 1991 into an EN.

3.3 Design Strategies

Design with respect to accidental actions may pursue one or more as appropriate of the following strategies, which may be mixed in the same building design:

- preventing the action occurring or reducing the probability and/or magnitude of the action to a reasonable level. (The limited effect of this strategy must be recognised; it depends on factors which, over the life span of the structure, are commonly outside the control of the structural design process)
- protecting the structure against the action (e.g. by traffic bollards)
- designing in such a way that neither the whole structure nor an important part thereof will collapse if a local failure (single element failure) should occur
- designing key elements, on which the structure would be particularly reliant, with special care, and in relevant cases for appropriate accidental actions
- applying prescriptive design/detailing rules which provide in normal circumstances an acceptably robust structure (e. g. tri-orthogonal tying for resistance to explosions, or minimum level of ductility of structural elements subject to impact)

Partial load factors to be applied in analysis according to strategy no. 3 are defined for buildings in [1], Table 9.2, to be 1.0 for all loads (permanent, variable and accidental) with the following qualification in 9.4.2(4): "Combinations for accidental design situations either involve an explicit accidental action A (e.g. fire or impact) or refer to a situation after an accidental event (A = 0)". After an accidental event the structure will normally not have the required strength in persistent and transient design situations and will have to be strengthened for a possible continued application. In temporary phases there may be reasons for a relaxation of the requirements e.g. by allowing wind or wave loads for shorter return periods to be applied in the analysis after an accidental event. As an example Norwegian rules for offshore structures [3] are referred to.

For prescriptive rules Part 2.7 refers to the relevant ENV 1992 to ENV 1999.

3.4 Methods of Analysis

Analysis for accidental actions may be achieved with different levels of refinement, e. g. by:

- an appropriate (dynamic, non-linear etc.) analysis of the structure for an adequate model of the accidental action
- analysis for a static equivalent load model
- without analysis, if prescriptive detailing rules are applied

The different safety categories may be considered in the following manner:

- Safety category 1: no specific consideration of accidental actions
- Safety category 2: depending on the specific circumstances of the structure in question: a simplified analysis by static equivalent load models, or by applying prescriptive design/detailing rules, or, alternatively, as for safety category 3
- Safety category 3: extensive study of accident scenarios and using dynamic analyses and non-linear analyses if appropriate

The analysis and design for accidental actions is according to ENV 1991-1 [1] based on characteristic actions and material strengths as for check of cross section strength. The adequacy of this approach for check of system failure may, however, be questioned [4,5]. Since a system failure assumes a simultaneous failure in several sections, it may be more appropriate to base the analysis on mean values of material characteristics and use a global safety factor to establish a sufficient distance between the mean global strength and the loads. Such an approach is, however, not in accordance with the present ENV 1991-1.

References

1 ENV 1991-1 EUROCODE 1: Basis of Design and Actions on Structures. Part 1: Basis of Design. CEN 1994

2 ISO DP 10252 "Accidental Actions due to Human Activities" ISO 1995.

3 Norwegian Petroleum Directorate: Regulations concerning loadbearing structures in the petroleum activities 1992.

4 Eibl, J.: Fragen zum Nachweis der Tragsicherheit bei Berücksichtigung nichtlinearer Stoffgesetze. Tagung "Sicherheit von Bauwerken - Günter Breitschaft Symposium". Eigenverlag des IfBt, Berlin, März 1989.

5 Eibl, J., Schmidt-Hurtienne, B.: Grundlagen für ein neues Sicherheitskonzept. Bautechnik 72 (1995) Heft 8 pp 501-506.

Leere Seite
Blank page
Page vide