

Structural Reliability
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Lecture-230
Reliability Based Design Codes (Part-06)

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Reliability based design

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design codes

EN 1990:2002 & 2005 (amended 2008, 2010)

- High level expectations
 - Design to be reliability based
- Design to take care of
 - strength
 - with appropriately defined scope
 - serviceability
 - with appropriately defined scope
 - durability
 - progressive collapse
 - transient, accidental and normal operating situations
- Reliability check
 - to be component based and/or
 - system based
 - Can be direct calculation based, or
 - PSF based
- Target reliabilities
 - to vary with limit states
 - to depend on consequence
 - to have three levels
- Design calculations to consider
 - representative action
 - appropriate load combinations
 - Partial safety factors
 - good mechanical models
 - aging inspection and maintenance
 - expected service life

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So, after presenting this summary storyline, describing the high level expectations behind the structural Euro codes EN 1990, let us see in the next few slides how the code makers have expressed these expectations through codal provisions. And we are going to look only at the first few pages of EN 1990.

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[E] [C] Test altered by CEN Amendment A1 2005 to EN 1990:2002
 [E] [C] [S] Test altered by CEN Corrigendum December 2008
 [E] [C] [S] Test altered by CEN Corrigendum April 2010

2.1 Basic requirements

(1)P A structure shall be designed and executed in such a way that it will, during its intended life, with appropriate degrees of reliability and in an economical way

- sustain all actions and influences likely to occur during execution and use, and
- meet the specified serviceability requirements for a structure or a structural element.


(2)P A structure shall be designed to have adequate :

- structural resistance,
- serviceability, and
- durability.

(4)P A structure shall be designed and executed in such a way that it will not be damaged by events such as :

- explosion,
- impact, and
- the consequences of human errors,

to an extent disproportionate to the original cause.



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So, the very first set of requirements section 2.1 clearly lays down the context and the parameters behind the code. So, the code is reliability based we are very clear about that.

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We also see the issues related to the definition of reliability that we discussed early on in this course. They are all contained in this sentence; there is an intended service life.

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There are all service conditions and demands that are placed on the system. So, those are the loads and the structure should not fail under those loads.

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And the structure should also function. So, all the boxes are checked.

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And more specifically, so that there is no ambiguity the strength issue.

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The functionalities issue.

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And the longevity issue, the time dependent issues they are clearly spent out.
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Very early on it is interesting to see the code makers have been worried about and they have expressed the progressive collapse issue. So, this disproportionate collapse a progressive collapse has shown up quite early in the codal sentiments.
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(5)P Potential damage shall be avoided or limited by appropriate choice of one or more of the following :

- avoiding, eliminating or reducing the hazards to which the structure can be subjected;
- selecting a structural form which has low sensitivity to the hazards considered ;
- selecting a structural form and design that can survive adequately the accidental removal of an individual member or a limited part of the structure, or the occurrence of acceptable localised damage ;
- avoiding as far as possible structural systems that can collapse without warning ;
- tying the structural members together

(6) The basic requirements should be met :

- by the choice of suitable materials,
- by appropriate design and detailing, and
- by specifying control procedures for design, production, execution, and use relevant to the particular project.



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And in the next few provisions also we see more details on how this sort of progressive collapse can be prevented.

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And then the code says that all of this should be done by appropriate design. So, the importance of design has been not left to any ambiguity.

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2.2 Reliability management

(1)P The reliability required for structures within the scope of EN 1990 shall be achieved:

- a) by design in accordance with EN 1990 to EN 1999 and
- b) by
 - appropriate execution and
 - quality management measures.



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Now here we see the introduction of all the companion documents. So, EN 1990 shall be read with 91 through 99.

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EN 1990	Eurocode :	Basis of Structural Design
EN 1991	Eurocode 1:	Actions on structures
EN 1992	Eurocode 2:	Design of concrete structures
EN 1993	Eurocode 3:	Design of steel structures
EN 1994	Eurocode 4:	Design of composite steel and concrete structures
EN 1995	Eurocode 5:	Design of timber structures
EN 1996	Eurocode 6:	Design of masonry structures
EN 1997	Eurocode 7:	Geotechnical design
EN 1998	Eurocode 8:	Design of structures for earthquake resistance
EN 1999	Eurocode 9:	Design of aluminium structures



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And they are listed here that covers various materials, various loads and so on.

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(2) Different levels of reliability may be adopted *inter alia* :


- for structural resistance ;
- for serviceability.

(3) The choice of the levels of reliability for a particular structure should take account of the relevant factors, including :

- the possible cause and/or mode of attaining a limit state ;
- the possible consequences of failure in terms of risk to life, injury, potential economical losses ;
- public aversion to failure ;
- the expense and procedures necessary to reduce the risk of failure.

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Now we come to the point that different limit states, different types of expectations should have different levels of probability of exceedance or acceptable reliability.

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So, depending on the consequence these target liabilities should change or should be made different.

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So, that is also spelt out very clearly. So, far we have understood that the design has to be reliability based different consequences must have their respective acceptable reliabilities.

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(4) The levels of reliability that apply to a particular structure may be specified in one or both of the following ways :

- by the classification of the structure as a whole ;
- by the classification of its components.

(5) The levels of reliability relating to structural resistance and serviceability can be achieved by suitable combinations of :

- a) preventative and protective measures (e.g. implementation of safety barriers, active and passive protective measures against fire, protection against risks of corrosion such as painting or cathodic protection) ;
- b) measures relating to design calculations :
 - representative values of actions ;
 - the choice of partial factors ;
- c) measures relating to quality management ;

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And then we come to the point of how to do this safety check whether it should be done as the structure as a whole or on a component basis?

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Both options have been given and it so happens that we are still more tuned towards a component based design approach than whole systems based design approach.

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Then these design calculations becoming more specific have to be based on representative actions.

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The sort of quantities that we saw in those partial safety factor based equations.
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 - representative values of actions ;
 - the choice of partial factors ;
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And more specifically the choice of partial safety factors. So, the partial safety factors are also introduced very early on in the design document.
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d) measures aimed to reduce errors in design and execution of the structure, and gross human errors;

e) other measures relating to the following other design matters:

- the basic requirements;
- the degree of robustness (structural integrity);
- durability, including the choice of the design working life;
- the extent and quality of preliminary investigations of soils and possible environmental influences;
- the accuracy of the mechanical models used;
- the detailing;

f) efficient execution, e.g. in accordance with execution standards referred to in EN 1991 to EN 1999.

g) adequate inspection and maintenance according to procedures specified in the project documentation.



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Next we are reminded of the importance of inspection and maintenance because of all the time dependent issues related to aging and accumulating damage.

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2.3 Design working life


(1) The design working life should be specified.

NOTE Indicative categories are given in Table 2.1. The values given in Table 2.1 may also be used for determining time-dependent performance (e.g. fatigue-related calculations). See also Annex A.

Table 2.1 - Indicative design working life

Design working life category	Indicative design working life (years)	Examples
1	10	Temporary structures ⁽¹⁾
2	10 to 25	Replaceable structural parts, e.g. gassy pipes, bearings
3	(1) to 50	Aggregated and similar structures
4	50	Building structures and other common structures
5	100	Monumental building structures, bridges, and other civil engineering structures

(1) Structures or parts of structures that can be dismantled with a view to being re-used should not be considered as temporary.



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More specific things now, so the design working life depending on the type of structure that is Ranna needs to choose the service life, the intended life. And that is typically for the kind of structures that we undertake formal designs are of the order of 50 to 100 years.

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2.4 Durability

(1)P The structure shall be designed such that deterioration over its design working life does not impair the performance of the structure below that intended, having due regard to its environment and the anticipated level of maintenance.



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And then the issue of durability once again comes up and the designer is cautioned that all issues related to aging and environmental degradation have to be anticipated and considered.

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Section 3 Principles of limit states design

3.1 General

(1)P A distinction shall be made between ultimate limit states and serviceability limit states.


NOTE In some cases, additional verifications may be needed, for example to ensure traffic safety.

(2) Verification of one of the two categories of limit states may be omitted provided that sufficient information is available to prove that it is satisfied by the other.

(3)P Limit states shall be related to design situations, see 3.2.

(4) Design situations should be classified as persistent, transient or accidental, see 3.2.

(5) Verification of limit states that are concerned with time dependent effects (e.g. fatigue) should be related to the design working life of the construction.



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Finally more details on the type of limit states to be considered are spelt out. So, we see specifically that ultimate limit states and serviceability limit states have to be considered.

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(5) Verification of limit states that are concerned with time dependent effects (e.g. fatigue) should be related to the design working life of the construction.



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Not only that, the designer also needs to worry about not only the operating condition but transient situations and accidental situations as well. So, that presumably includes the construction phase as well.

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Section 3 Principles of limit states design

3.1 General

(1)P A distinction shall be made between ultimate limit states and serviceability limit states.


NOTE: In some cases, additional verifications may be needed, for example to ensure traffic safety

(2) Verification of one of the two categories of limit states may be omitted provided that sufficient information is available to prove that it is satisfied by the other.

(3)P Limit states shall be related to design situations, see 3.2.

(4) Design situations should be classified as persistent, transient or accidental, see 3.2.

(5) Verification of limit states that are concerned with time dependent effects (e.g. fatigue) should be related to the design working life of the construction.



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Once more time dependent issues are again brought out and the designer is reminded of that.

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3.2 Design situations

(1)P The relevant design situations shall be selected taking into account the circumstances under which the structure is required to fulfil its function.


(2)P Design situations shall be classified as follows:

- persistent design situations, which refer to the conditions of normal use;
- transient design situations, which refer to temporary conditions applicable to the structure, e.g. during execution or repair;
- accidental design situations, which refer to exceptional conditions applicable to the structure or to its exposure, e.g. to fire, explosion, impact or the consequences of localised failure;
- seismic design situations, which refer to conditions applicable to the structure when subjected to seismic events.

NOTE Information on specific design situations within each of these classes is given in EN 1991 to EN 1999.

(3)P The selected design situations shall be sufficiently severe and varied so as to encompass all conditions that can reasonably be foreseen to occur during the execution and use of the structure.

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Now the design situations, the normal and abnormal and the transient etcetera, so more details are given now. So, the persistent design situation.

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The transient design situation.

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The accidental design situation.

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And the seismic design situation. So, special place of mention has been there for the seismic loads.

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And then the designer is again reminded that he or she has to take care of all likely scenarios, so nothing should be left out of consideration at the design stage.

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3.3 Ultimate limit states

(1) The limit states that concern:

- the safety of people, and/or
- the safety of the structure

shall be classified as ultimate limit states.

(2) In some circumstances, the limit states that concern the protection of the contents should be classified as ultimate limit states.


NOTE The circumstances are those agreed for a particular project with the client and the relevant authority.

(3) States prior to structural collapse, which, for simplicity, are considered in place of the collapse itself, may be treated as ultimate limit states.

(4) The following ultimate limit states shall be verified where they are relevant:

- loss of equilibrium of the structure or any part of it, considered as a rigid body;
- failure by excessive deformation, transformation of the structure or any part of it into a mechanism, rupture, loss of stability of the structure or any part of it, including supports and foundations;
- failure caused by fatigue or other time-dependent effects.

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Now more details about the ultimate limit state and now we are getting more specifics that this limit state has to do with life safety or safety of very important assets.

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And more details about what sort of definition of this sort of failure? This ultimate limit state collapse should be considered.

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So, loss of equilibrium, creation of a mechanism, loss of stability, rupture etcetera, would all come under this sort of ultimate or collapse limit state.

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Time dependent effects should also not be forgotten. So, we are seeing again and again that the code makers want to remind the designer that time dependent effects have to be kept in mind. And then serviceability limit state is next.

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3.4 Serviceability limit states


(1)P The limit states that concern:

- the functioning of the structure or structural members under normal use;
- the comfort of people;
- the appearance of the construction works,

shall be classified as serviceability limit states.

(2)P A distinction shall be made between reversible and irreversible serviceability limit states.

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So, there the designer is reminded that everything to do with the proper functioning even though it does not interfere with safety, life safety, asset safety or any loss of stability but still the structure has to function. So, the designer is reminded of that and we see that the details.

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And 1 interesting distinction is drawn here between the reversible and irreversible service within limit states. And if you remember this would somewhat come under the consideration of whether we are talking about reliability or availability. So, if something is reversible then you remember that we said the term availability is more appropriate. So, here we see a broadening of the definition of reliability in certain situations.

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3.5 Limit state design

(1)P Design for limit states shall be based on the use of structural and load models for relevant limit states.

(2)P It shall be verified that no limit state is exceeded when relevant design values for


- actions,
- material properties, or
- product properties, and
- geometrical data

are used in these models.

(3)P The verifications shall be carried out for all relevant design situations and load cases.

(4) The requirements of 3.5(1)P should be achieved by the partial factor method, described in section 6.

(5) As an alternative, a design directly based on probabilistic methods may be used.



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Then we go a little deeper into this concept of limit state design. So, the limit states are more firmly defined and again the designer is reminded.

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That all relevant design situations must be considered.

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And the preference for partial safety factors is clearly stated.

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But the designer is also given the option of doing a direct reliability based analysis.
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(6) The selected design situations shall be considered and critical load cases identified.

(7) For a particular verification load cases should be selected, identifying compatible load arrangements, sets of deformations and imperfections that should be considered simultaneously with fixed variable actions and permanent actions.

(8) Possible deviations from the assumed directions or positions of actions shall be taken into account.

(9) Structural and load models can be either physical models or mathematical models.



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We have talked about models. So, here the code makers emphasize the importance of good modeling and this could be a combination of physical and mathematical models.
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Table B1 - Definition of consequences classes


Consequences Class	Description	Examples of buildings and civil engineering works
CC3	High consequence for loss of human life, or economic, social or environmental consequences very great	Concert halls, public buildings where consequences of failure are high (e.g. a concert hall)
CC2	Medium consequence for loss of human life, economic, social or environmental consequences considerable	Residential and office buildings, public buildings where consequences of failure are medium (e.g. an office building)
CC1	Low consequence for loss of human life, and economic, social or environmental consequences small or negligible	Agricultural buildings where people do not normally enter (e.g. storage buildings), greenhouses

(2) The criterion for classification of consequences is the importance, in terms of consequences of failure, of the structure or structural member concerned. See B3.3

(3) Depending on the structural form and decisions made during design, particular members of the structure may be designated in the same, higher or lower consequences class than for the entire structure.

NOTE: At the present time the requirements for reliability are related to the structural members of the construction works.

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Then details about the consequences. So, we have been told about limit states, we have been told about target reliabilities and now these target reliabilities have to be tied to consequence classes. So, 3 consequence classes have been defined early on and the designer has to decide which class their structure comes under.

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And again this note is actually very important, this tells the designer that so far all these requirements in terms of acceptable failure probability are to be applied to structural members or they are component based. So, these targets that we are going to see next, they are going to pertain to structural elements, components and not the entire structure. And that is actually consistent with the fact that I said that still most design verification is done at a component level.

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Table B2 - Recommended minimum values for reliability index β (ultimate limit states)

Reliability Class	Minimum values for β	
	1 year reference period	50 years reference period
RC3	5,2	4,3
RC2	4,7	3,8
RC1	4,2	3,3

B3.2 Differentiation by β values

- (1) The reliability classes (RC) may be defined by the β reliability index concept.
- (2) Three reliability classes RC1, RC2 and RC3 may be associated with the three consequences classes CC1, CC2 and CC3.
- (3) Table B2 gives recommended minimum values for the reliability index associated with reliability classes (see also annex C).

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Next comes the corresponding reliability classes. So, each consequence class gives rise to its corresponding reliability class. And here we see finally the explicit stating of the target beta values, the target reliability indexes. And it is given for 1 year reference period and 50 year reference period for each of the 3 consequence classes or reliability classes. So, this brings an end to our high level discussion and investigation of the philosophy behind the structural Euro codes. And now we will take up more details about reliability based design and what these partial safety factors are? How they come and how they are derived?