Structural Failures

- Structural failures can be attributed to different causes:
  - Human errors
  - Extreme events
  - Accidents
  - Deterioration
  - Poor workmanship
  - …

often occurring in combination

- Human error is a key factor in many structural failures
- Structures seldom experience their full design load, thus possible failure can remain 'hidden' for years
- To ensure structural safety we need to account for all possible causes of failure

Structural Failures: Causes

Inadequate appreciation of loads or response	43%
Inadequate execution of procedures	13%
Random variation in loading, structure, material, workmanship etc.	10%
Contravention of requirements in contract documents or instructions	9%
Unforeseeable abuse, misuse, sabotage etc	7%
Mistakes in drawings or calculations	7%
Others	11%

Walker, 1981 ICE Proc.

Structural Failures: Causes

Ignorance, Carelessness and Negligence	37%
Insufficient Knowledge	27%
Underestimating Influences	14%
Forgetfulness, Errors and Mistakes	10%
Unjustifiably trusting others	6%
Objectively unknown influences	6%

Schneider, 1997

Structural Failures: Causes

- From a survey of construction failures (about 800) by Matousek and Schneider
  - 25% of cases
  - 10% of amount of damage
  - 15% of casualties

  are attributed to consciously accepted risks (CAR)
- The rest (the majority!) attributed to human error
  - Unknown/ignored hazard
  - Unsuitable materials/ construction methods
  - Wrongly applied materials/methods
- **Structural reliability** deals with CAR's and helps us address the question ***'in designing a structure, how safe is safe enough?'***

Structural Failures: Comparisons

Activity	Hours of Exposure per Annum	Death rate (per 10^6 persons per hour of exposure)	Approximate prob. of death per person ($x10^{-6}$/year)
Alpine climbing	50	30-40	1500-2000
Car travel	300	0.7	200
Construction	2200	0.07-0.2	150-440
Air travel	20	1.2	24
Home accidents	6000	0.004	24
Structural failure	6000	0.00002	0.1

Melchers, 1986

Structural failure is associated with extremely low probability: how can we quantify the effect of safety measures on this probability?

Risk in Structural Engineering

- Exposure
- Vulnerability / Damage
- Failure
- Consequences

Consequence of failure

$$Risk = P(H_i)P(D_j|H_i)P(S_k|D_j \cap H_i)C_k$$

Probability of failure, p_f

Risk = Frequency x Consequences

Nature of Risk

- **Voluntary**
  - **Sports activities**
  - **Travel by car?**

  $p_f = 1{:}1000$ *per annum ?*

- **Involuntary**
  - **Living in seismic area**
  - **Crossing a bridge**

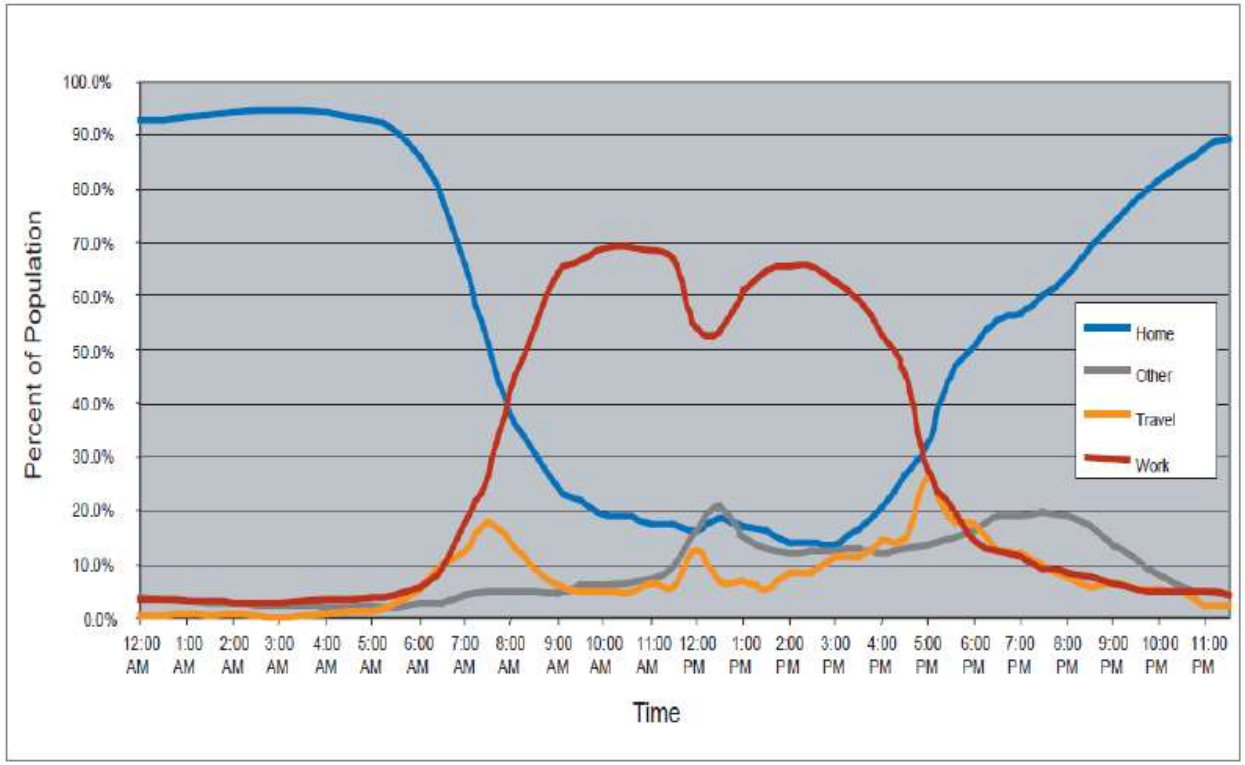
$p_f = 1{:}1000000$ *per annum ?*

- **Engineering risk is often involuntary**
- **ALARP principle**
- **Acceptable vs. Tolerable levels**
- **Low probability, large consequence events**

Consequences of failure

The consequences of failure vary significantly from structure to structure, and may depend on:

- Nature of the hazards
- Structural type/form
- Use/occupancy
- Location
- Time of day



Classification of consequences

	Direct Consequences	Indirect Consequences
Human	Injuries Fatalities	Injuries Fatalities Psychological Damage
Economic	Replacement/repair of structure Replacement/repair of contents	Replacement/repair of structure Replacement/repair of contents Loss of functionality Clean up costs Rescue costs Effect on share prices/market value Investigation/compensation Loss of reputation
Environmental	CO_2 Emissions Energy use Toxic releases Environmental Studies/Repair	CO_2 Emissions Energy use Toxic releases Environmental Studies/Repair

Failure consequences in the Eurocodes

- EN1991-1-7 classifies buildings according to their consequences of failure to determine how design situations should be dealt with
  - CC1: **Low** consequence for loss of human life, and economic, social or environmental consequences are **small or negligible**
  - CC2: **Medium** consequence for loss of human life, economic, social or environmental consequences are **considerable**
  - CC3: **High** consequence for loss of human life, ***or*** economic, social or environmental consequences are **very high**

Reliability Management in Eurocodes

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**	Grandstands, 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

Three reliability classes are associated with the above consequence classes