WG 2:

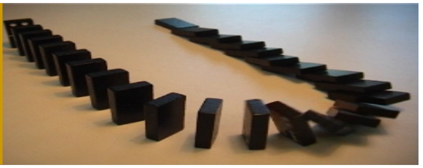
Exposures and Vulnerability

activity 4: exposure scenario models

activity 5: structural behaviour models

ton vrouwenvelder

tno/tu-delft, the netherlands



Risk based Robustness

Step 1

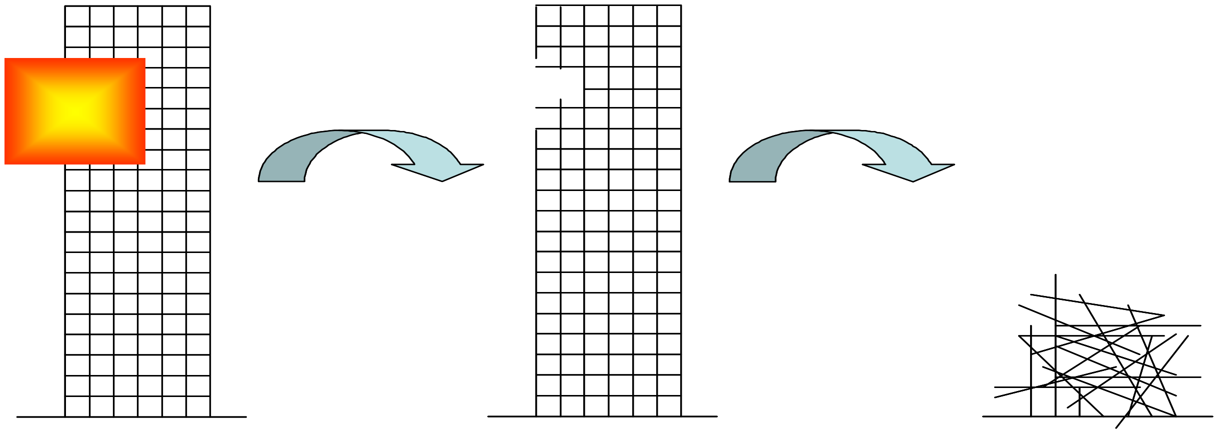
Identifical and modelling of relevant accidental hazards

Step 2

Assessment of damage states to structure from different hazards

Step 3

Assessment of the performance of the damaged structure

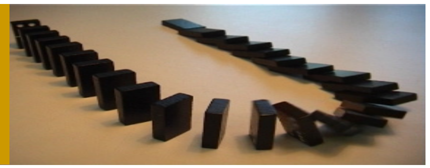


Assessment of the probability of occurence of different hazards with different intensities

Assessment of the probability of different states of damage and corresponding consequences for given hazards

Assessment of the probability of inadequate performance(s) of the damaged structure together with the corresponding consequence(s)

$$Risk = p(H_i)\,p(D_j \mid H_i)\,p(S_k \mid D_j)\,C(S_k)$$



$$Risk = p(H_i)p(D_j|H_i)p(S_k|D_j)C(S_k)$$

Exposure
Action/hazard models

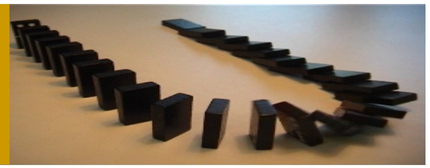
(activity 4)

Member models

Post failure models

(activity 5)

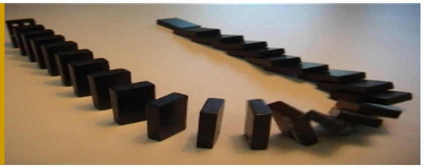
Model = physics + statistics



Activity 4: Exposure scenarios

Key words:

- normal loads
- accidental loads
- human actions
- human errors
- unforeseeable actions

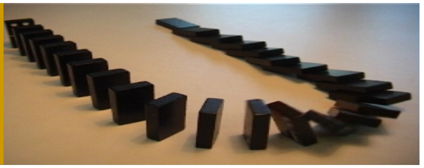


Activity 4: Exposure scenarios

Documents

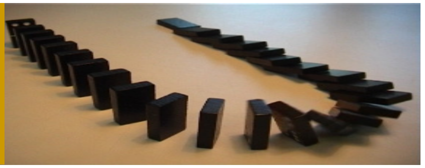
- **Probabilistic modeling of exposure conditions**
- **Modeling of human errors**
- **Modeling of explosions**

- **JCSS Model Code (normal loads, fire, impact, earth quake)**
- **List of reference documents (collapse data/human error)**



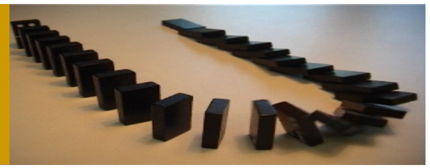
Activity 4: Exposure scenarios

- unforeseeable (objectively unknown)
- foreseeable
  not recognised
  ignored
  considered, but incorrectly
  considered correctly



foreseeable actions:

Accidental /natural	**Accidental/manmade**	**Human influences**	**Normal loads (including the tail values)**	**Human Errors**
Earthquake	Internal explosion	Vandalism	self weight	Design error
Landslide	External explosion	Demonstrations	imposed loads	Material error
Tornado	Internal fire	Terrorist attack	car park loads	Construction error
Avalanche	External fire		traffic	Misuse
Rock fall	Impact by vehicle etc		snow	Lack of maintenance
High groundwater	Mining subsidence		wind	Miscommunication.
Flood	Environmental attack		hydraulic	
Volcano eruption				

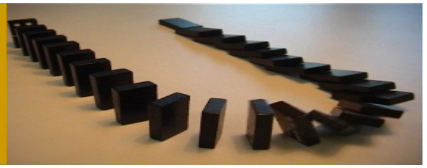


JCSS Probabilistic Model Code

1 Basis of Design
2 Loads Models
3 Resistance

2.0	General
2.1	Self weight
2.2	Live load
2.3	Industrial storage
2.4	Cranes
2.5	Traffic
2.6	Car parks
2.7	Silo load
2.8	Liquids/gasses
2.9	Temperature
2.10	Ground
2.11	Water/groundwater
2.12	Snow
2.13	Wind
2.14	Temperature
2.15	Waves
2.16	Avalanches
2.17	Earth quake
2.18	Impact
2.19	Explosion
2.20	Fire
2.21	Chem/Phys agencies

3.0	General
3.1	Concrete
3.2	Reinforcement
3.3	Prestr steel
3.4	Steel
3.5	Timber
3.6	Aluminium
3.7	Soil
3.8	Masonry
3.9	Model uncert.
3.10	Dimensions
3.11	Imperfections



INTERNAL NATURAL GAS EXPLOSIONS

p_d = max$\{3+p_v, 3+0.5p_v+0{,}04/(A_v/V)^2\}$

p_d = equivalent static pressure [kN/m^2]

A_v = area of venting components [m^2]

V = volume of room [m^3]

Validity:

$V < 1000$ m^3 ; 0.05 m$^{-1} \leq A_v/V \leq 0{,}15$ m^{-1}

load duration = 0.2 s

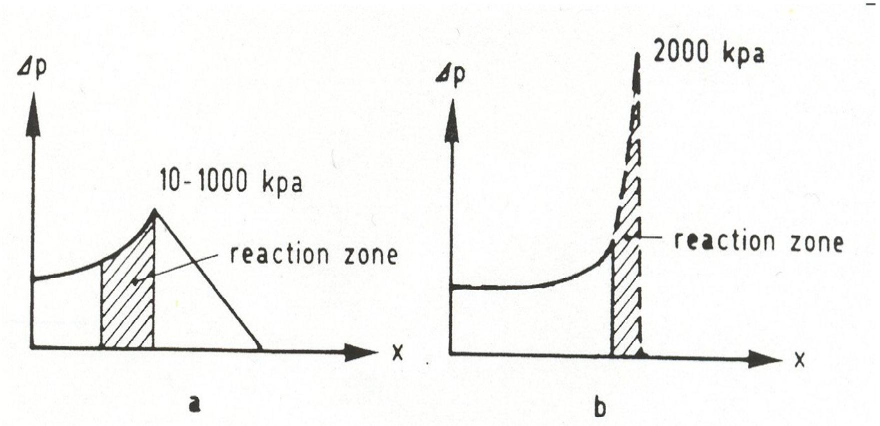
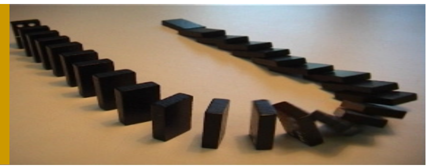
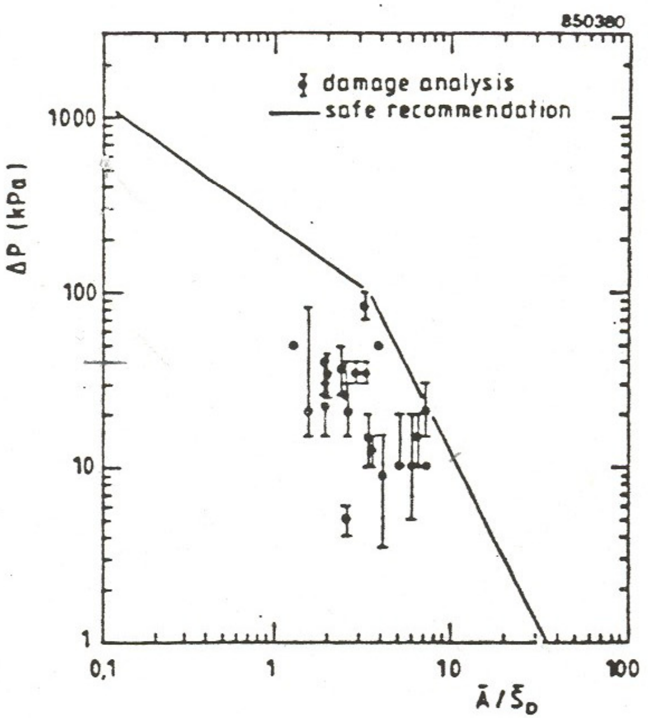
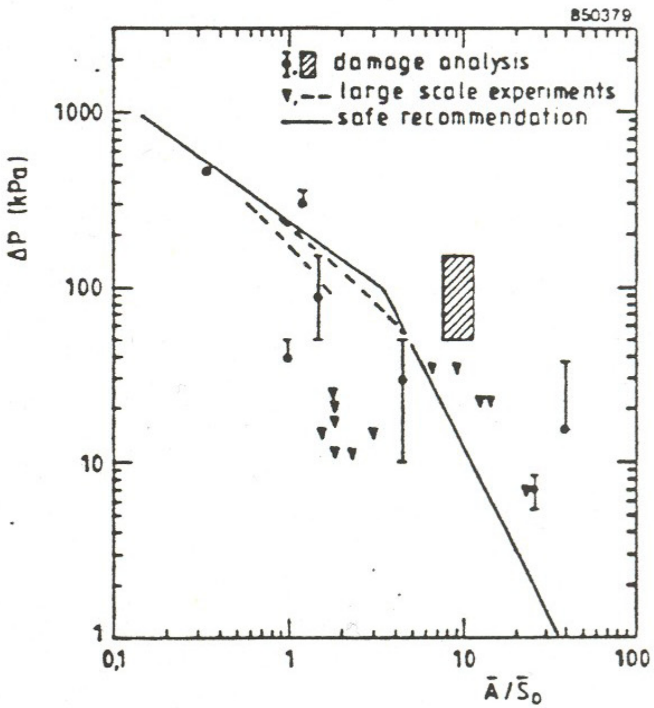


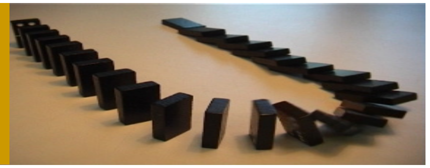
Figure 1: Pressure waves inside the explosion medium: (a) deflagration, (b) detonation



Observed scatter in explosions







Taylor and Alexander (1975, 122 explosions in UK, larger than 6 kN/m2 in 2 years time)

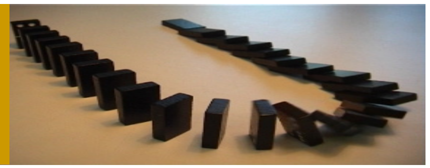
	Probability, given explosion	Explosion pressure
Significant	1.0	>6 kN/m2
Moderate	0.5-1.0	>10
Severe	0.05-0.3	>20
Very severe	0.02-0.05	>30

Assuming 10 million dwellings in UK one finds an annual probability of $6\ 10^{-6}$ per dwelling.

Leyendekker (1976, USA and Canada))

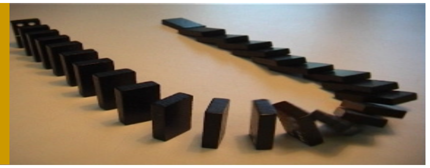
Probability per dwelling unit and per year and conditional damage probability

	p(H)	P(D|H)	P(D|H)
	/year	> 1000 $	>10 000 $
Gas explosion	$18\ 10^{-6}$	0.14	0.09
Bomb explosion	$2\ 10^{-6}$	0.16	0.11
Vehicle ipact	600.10^{-6}	0.14	0.01



UK statistics

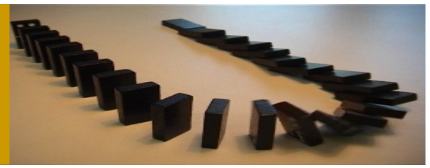
	Annual probability of occurrence in dwellings	Possible pressure
Reported explosion but not significant	0.064×10^{-4}	$<<17$ kN/m^2
Moderate explosion	0.010×10^{-4}	<17 kN/m^2
Severe explosion	0.005×10^{-4}	>17 kN/m^2
Very severe explosion	0.0002×10^{-4}	$>>17$ kN/m^2



Statistics The Netherlands (Ligtenberg, 1969)

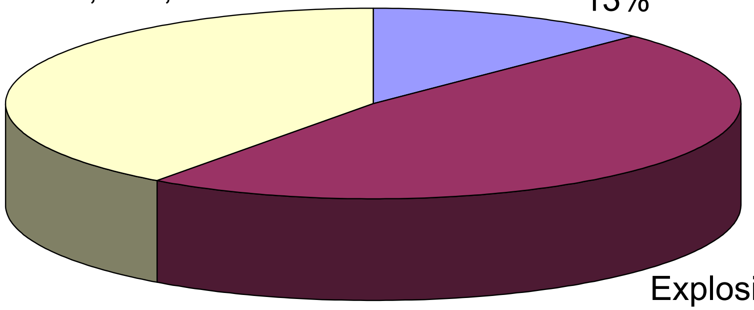
- fire 10^{-2} in 50 a per building
- errors 10^{-3}
- wind 10^{-3}
- explosion 10^{-3}
- impact $3\ 10^{-4}$
- overload $3\ 10^{-4}$

(collapse factor 10 to 100 lower)



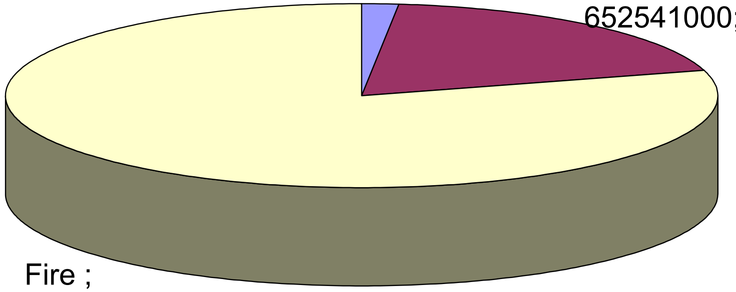
MAN-MADE CATASTROPHIES (EUROPE)

1900-2005



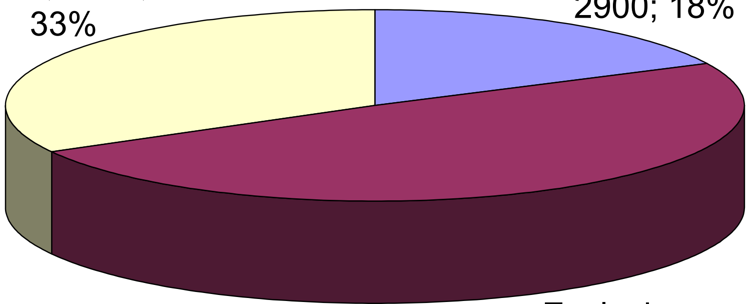
NUMBER OF EVENTS

312



ECONOMIC LOSSES

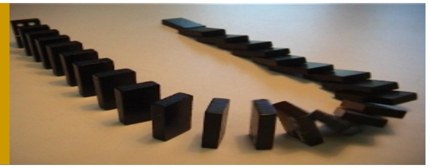
$ 3.413.841.000



NUMBER OF FATALITIES

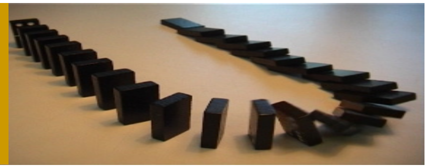
16399

□ Collapse □ Explosion □ Fire

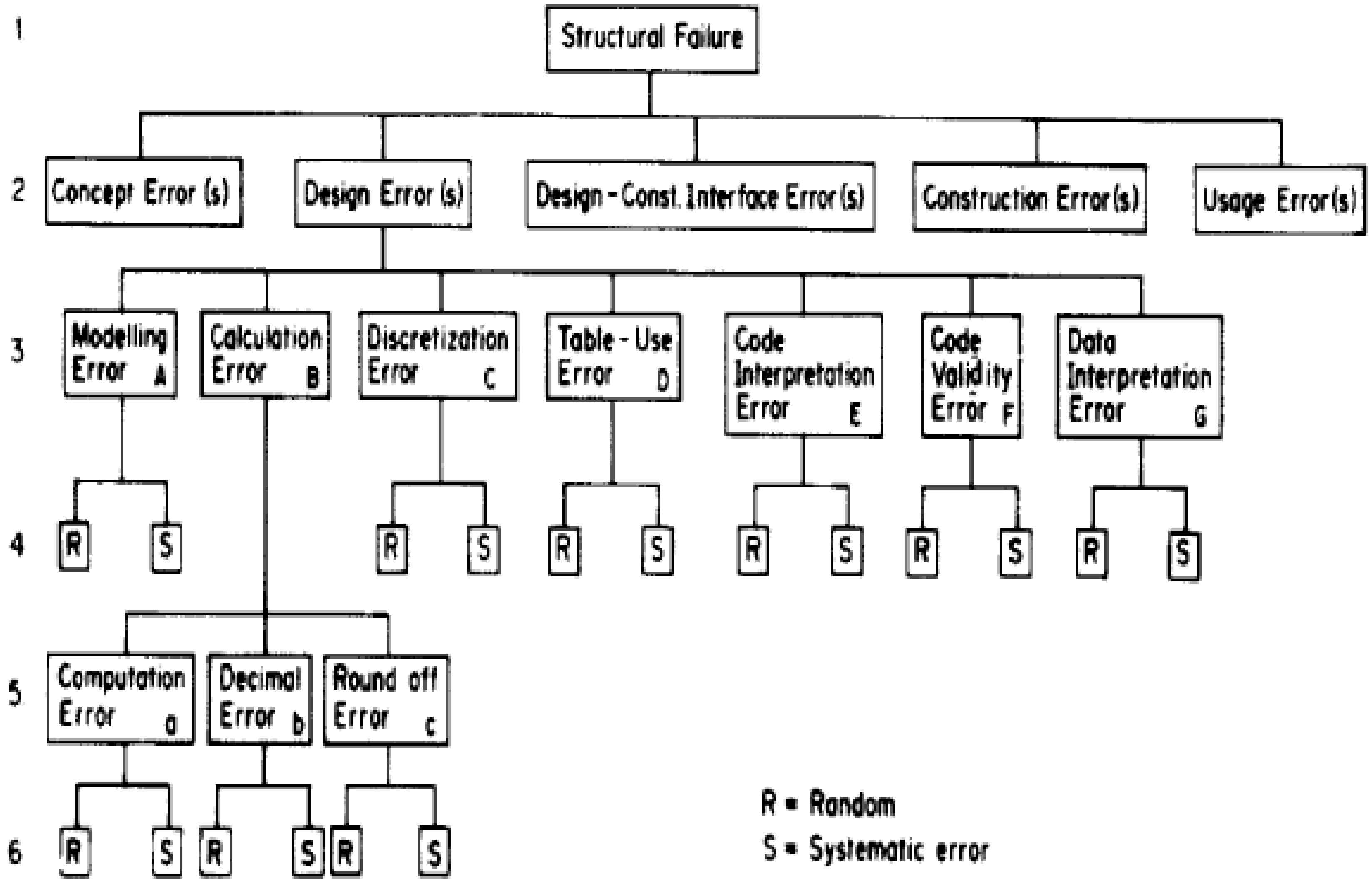


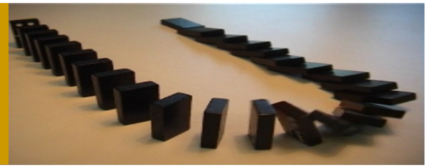
distribution over structural members [%]

	Ayyub	Yam
• Foundation	6	20
• Column and walls	11	30 (mostly walls)
• beams and trusses	11	30
• slabs and plates	34	10
• Connections	9	
• others	33	10



Human error / Rob Melchers





Ellingwood / Distribution of errors over the building Process by Phase:

Reference	Planning and design	Construc tion	Utilization mainte-nance	Others	Total
CEB 157 (1983)	50[b]	40[c]	8	-	98
Matousek (1982)	45[d]	49	6	-	100
Talylor (1975)	36[e]	12[f]	-	-	-
Yamamoto and Ang (1982)	36	43	21	-	100
Rackwitz and Hillemeier (1983)	46	30	23	-	99
AEPIC	67	33	-	-	100
Melchers, et al. (1983)	55	24	21	-	100
Fraczek (1979)	55	53	-	-	108[g]
Allen (1979)	55	49	-	-	103[g]
Hadipriono (1985)	19	27	33	20	99
Hauser (1979)	37	35	5	23	100
Gonzales (1985)	29	59	-	13	101[g]

[a] Broken Includes cases where failure cannot be attributed clearly to any one factor

[b] Broken down as planning 25%; design 25%.

[c] Broken down as materials 15%; execution 25%.

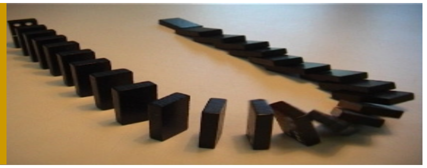
[d] Broken down as planning 11%; design 34%.

[e] Identified as design, not planning.

[f] Does not differentiate between construction and utilization.

[g] Multiple erros for single failure.

On the average this leads to: design errors 40 %, construction errors 40% and utilization errors 20%.



Scheider/Matousek (500 cases)

Lack of knowledge	25 %
Careless engineering	30 %
Real error	15 %
Accepted risk	20 %

Imam/Chryssanthopoulos (156 failures bridges, steel)

design	24 %
limited knowledge	23 %
natural hazard	19 %
human error	14 %
accidents	13 %

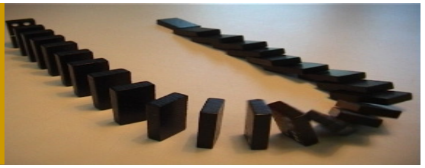
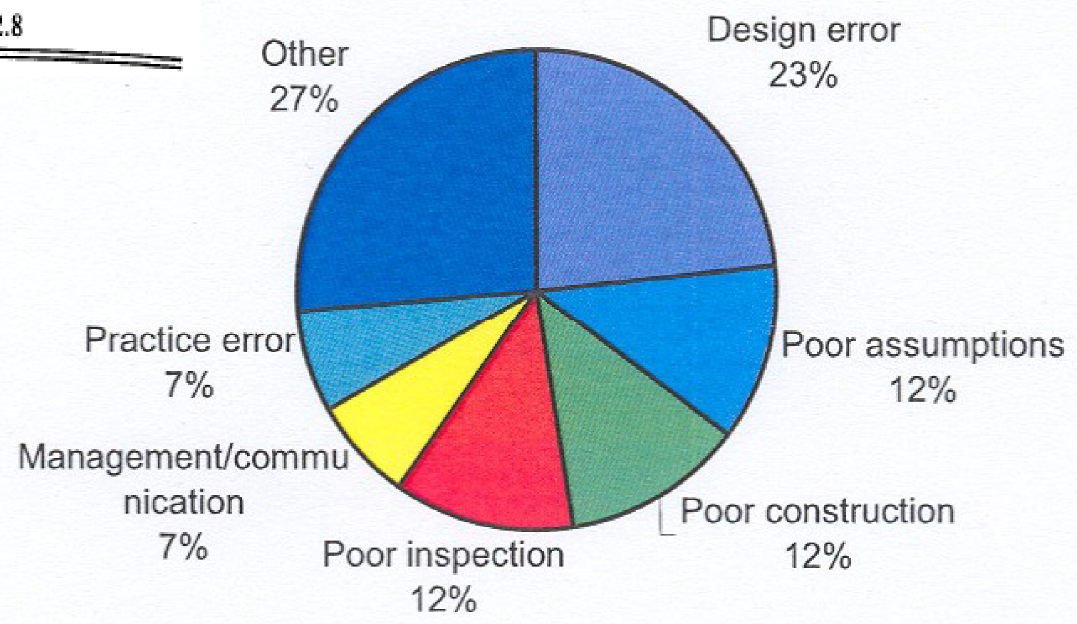
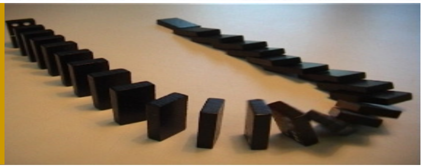


TABLE 8. Distribution of Failure Cases with Respect to Sources of Error by Participant

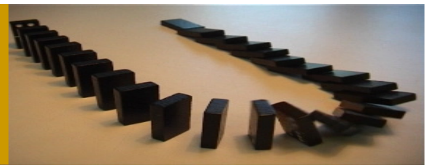
Description of the participant (1)	Failure cases (%) (2)
Project architect	3.0
Structural designer	48.2
Resident engineer	31.1
Inspector	27.6
Contractor (head office)	3.8
Contractor (site staff)	59.6
Contractor (workmen)	17.4
Operator (crane, vehicle, ship)	2.8





Publications on Accidental Statistics

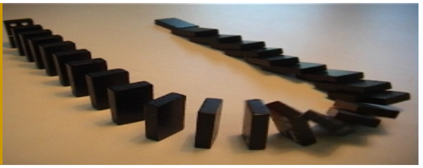
1968 Pugsley
1969 Ligtenberg
1975 Taylor
1976 Moffat
1976 Leyendekker
1979 Fraczek
1979 Allen
1979 Hauser
1980 Yam
1982 Ferry Borges / Silveira
1982 Yamamoto / Ang
1982 Matousek / Schneider
1983 CEB
1983 Rackwitz / Hillemeier
1983 Melchers et all
1985 Hadipriono
1985 Gonzalez
1987 Ellingwood
1991 Ayyub
1998 WOAD (Offshore)
2008 Imam/Chryssanthopoulos



Activity 5: Structural models

Key words:

- alternative load path
- catenary action,
- rotation capacity,
- dynamics



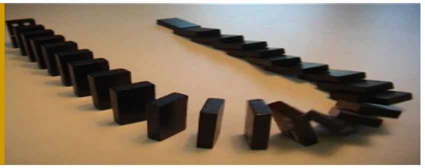
Activity 5 Structural models

Documents

- **Cover note (draft)**
- **Note on steel structures (Kuhlman/Rolle)**
- **Note on concrete slabs (Taerwe/Decan)**
- **Note on timber structures (Theleanderson)**
- **Note on composite structures (Kwasniewski)**
- **Note on existing timber structures (Markova)**
- **Historical structures (promise, Julio)**

Zurich papers:

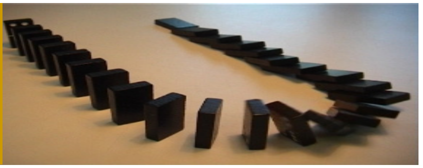
- **Izzudin (sudden column failure)**
- **Byfield (requirement on joint ductility)**
- **Kuhlman (joint ductilty steel structures)**
- **Cichocky (concrete damage models / blast loading)**
- **Gizejowski/Kwasnieuwski (joints in comp struc)**
- **Taerwe (catenary action in slabs)**



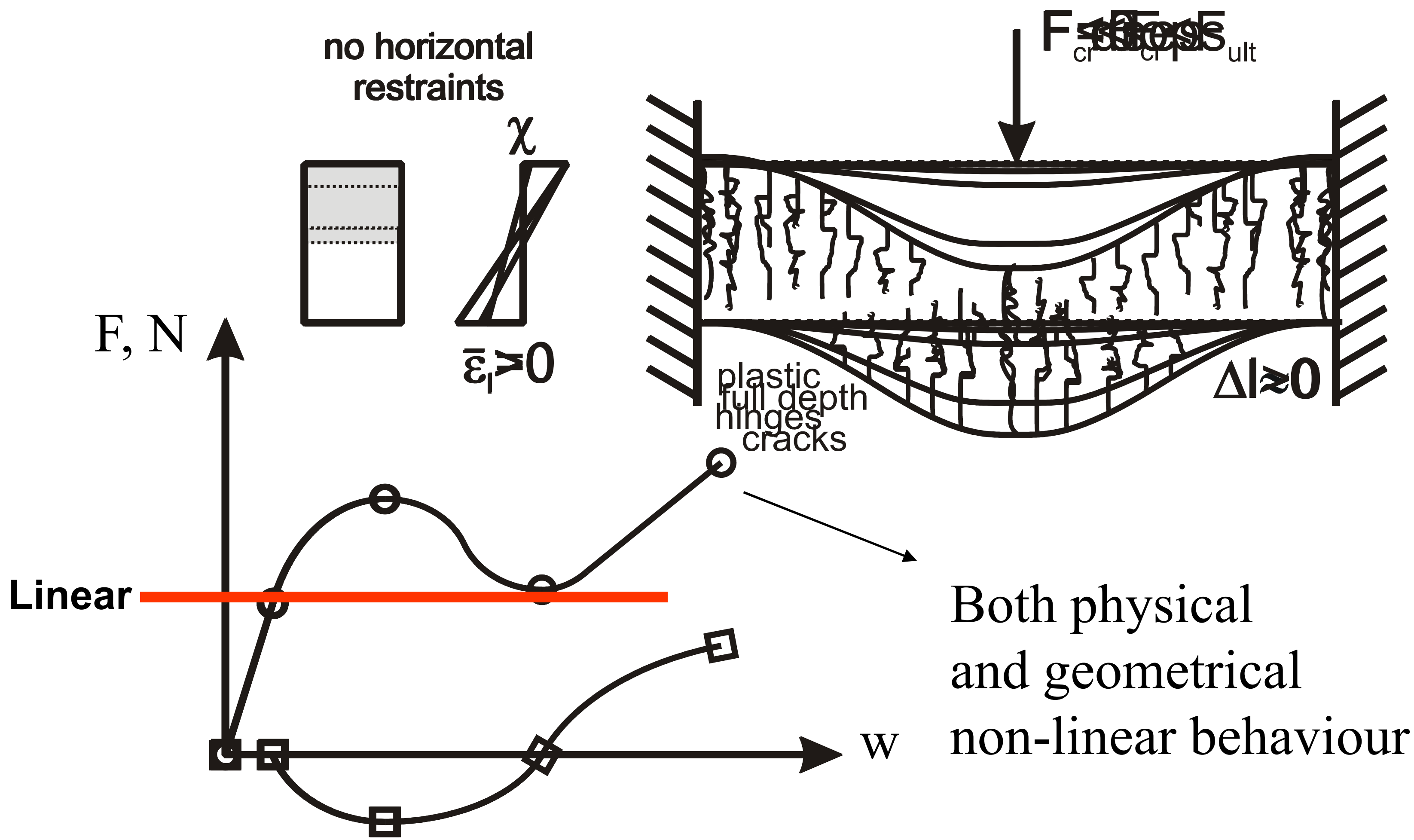
Activity 5 Structural models

Information in basic notes for each material:

- **material properties for large deformations**
- **element behaviour for large deformations (columns, beams, plates, joints)**
- **system behaviour for large deformation**
- **experimental data**
- **computer codes (geo + physical nonlinear AND/OR dynamic)**
- **comparison to design rules**



RC slabs: laterally restrained



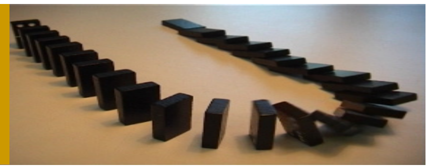
Both physical
and geometrical
non-linear behaviour

Act 4/5 Demonstration case: Removed column

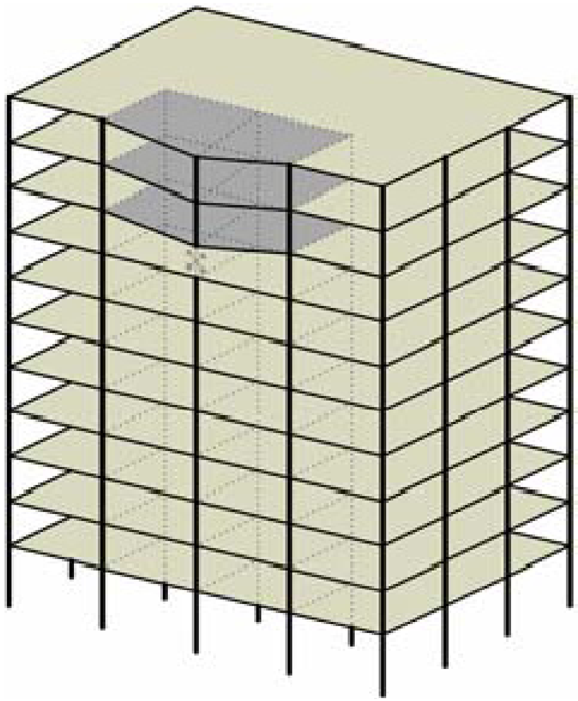
- **Mean value analysis**
- **Sensitivity analysis**
- **Estimate P(F|D)**

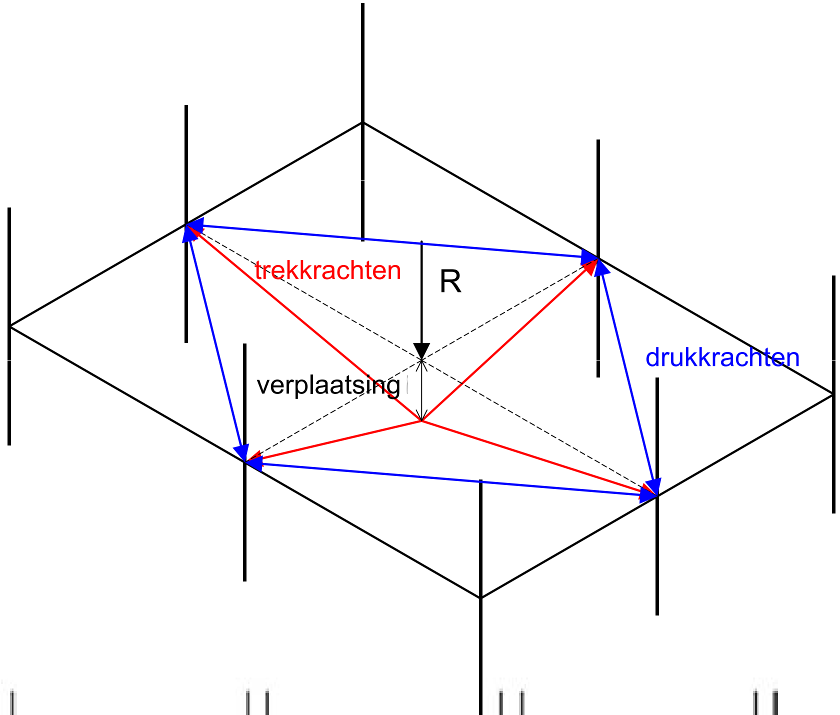
- **Apply EC1991-1-7 tying rules for consequence class 2-HIGH**
- **Recalculate P(F|H)**

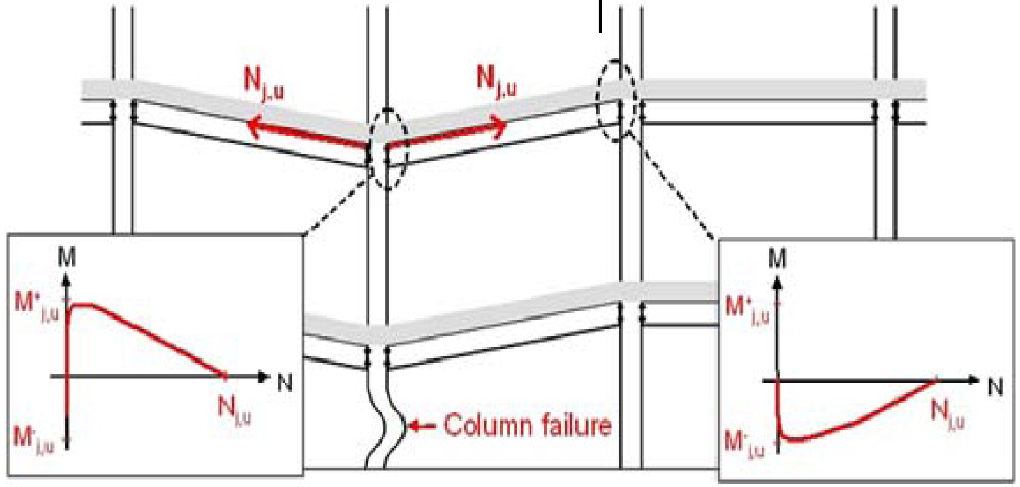
- **Estimate probability of basic event p(D) = P(D|H)P(H)**
- **Estimate Consequences**
- **Compare robustness measures**
- **Estimate costs of Eurocode rules**
- **Estimate cost effectiveness of EC rules**

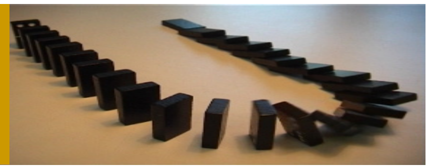


Removed column case







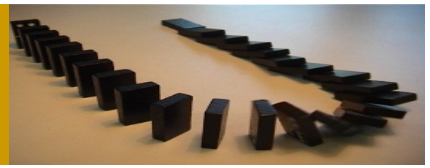


$$Risk = p(H_i)p(D_j|H_i)p(S_k|D_j)C(S_k)$$

explosion
fire
human errror

removed column

collapse



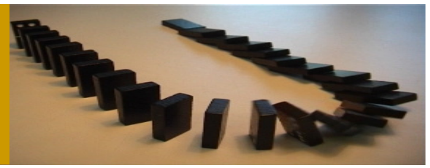
$$Risk = p(H_i)\,p(D_j|H_i)\,p(S_k|D_j)\,C(S_k)$$

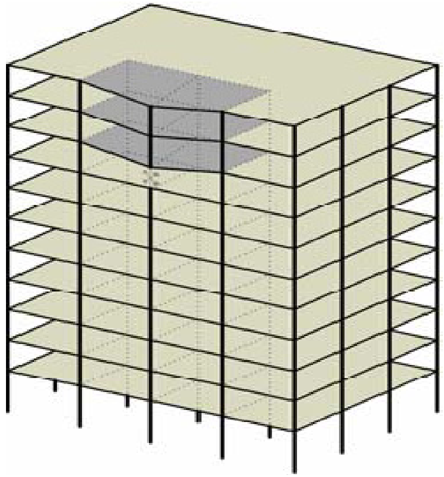
explosion
fire
human errror

removed column

collapse

	p(H) [50 year]	P(D|H))
explosion	$2x10^{-3}$	0.10
fire	$20x10^{-3}$	0.01
human error	$2x10^{-3}$	0.10





Demonstration of:

- deterministic model
- probabilistic model
- robustness measures
- cost effectiveness of measures