EN 1991-1-7

Eurocode 1
Accidental Actions

Ton Vrouwenvelder

TNO Bouw / TU Delft

EN 1990 Section 2.1 Basic Requirements

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

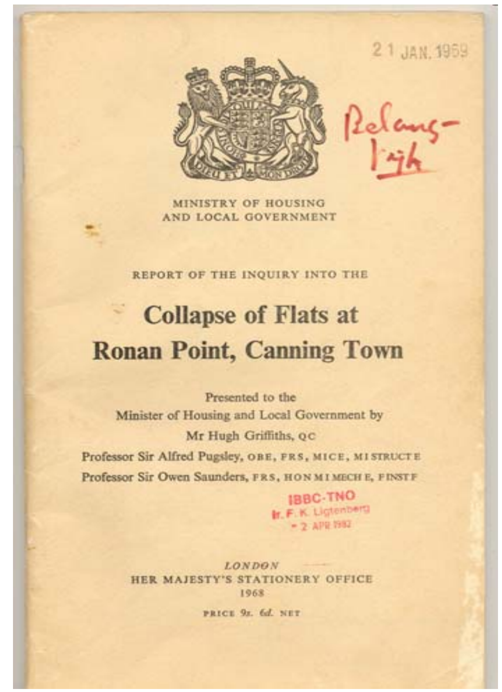
- explosion
- impact and
- consequences of human errors

to an extent disproportionate to the original cause

Note: Further information is given in EN 1991-1-7

EN 1990 guidance:

- reducing hazards
- low sensitive structural form
- survival of local damage
- sufficient warning at collapse
- tying members


MINISTRY OF HOUSING
AND LOCAL GOVERNMENT

REPORT OF THE INQUIRY INTO THE

Collapse of Flats at
Ronan Point, Canning Town

Presented to the
Minister of Housing and Local Government by
Mr Hugh Griffiths, QC
Professor Sir Alfred Pugsley, OBE, FRS, MICE, MIStructE
Professor Sir Owen Saunders, FRS, HON MIMechE, FInstF

IBBC-TNO

LONDON
HER MAJESTY'S STATIONERY OFFICE
1968

PRICE 9s. 6d. NET

(25) Progressive collapse is not an inevitable feature of high system-built blocks. It can be avoided by the introduction of sufficient steel reinforcement to give continuity at the joints, and the adoption of a plan-form which provides for the arrangement of the load-bearing walls in such a way that the load is carried by alternative paths if part of the structure fails (paragraphs 129 and 188).

World Trade Center
USA, 2001

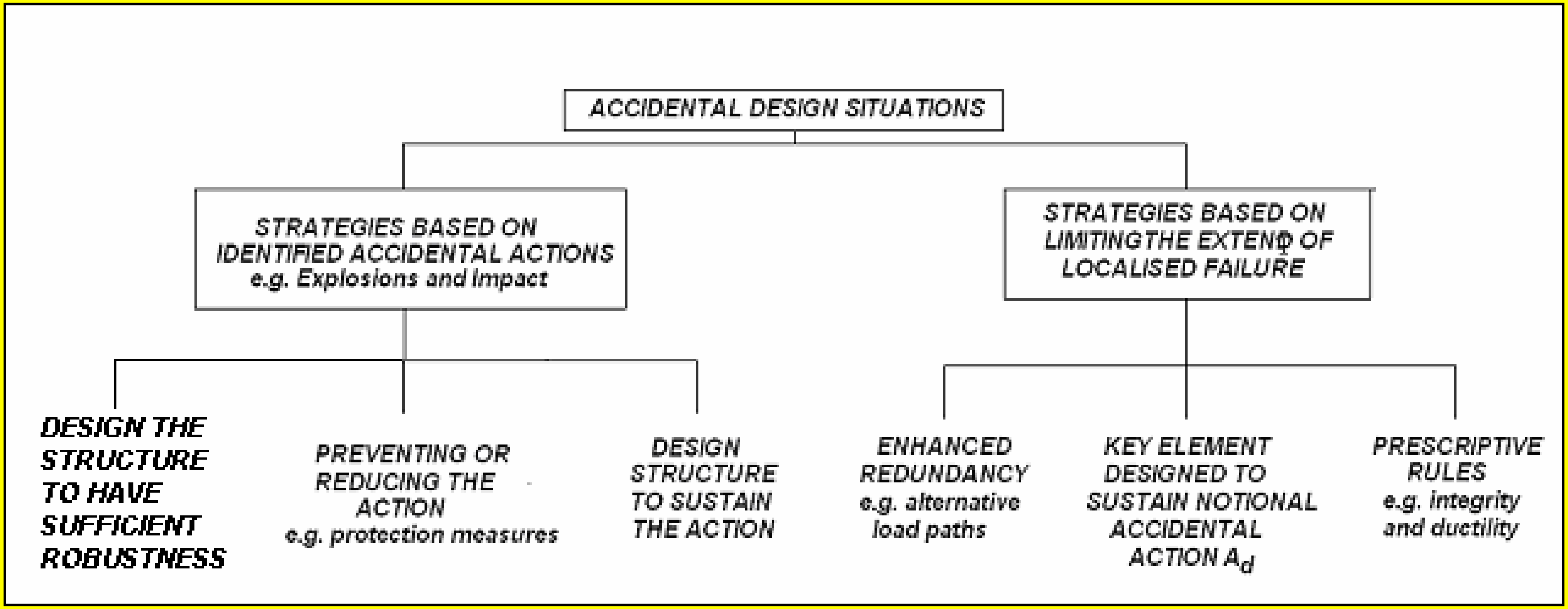
Eurocode EN 1991-1-7

1. General
2. Classification
3. Design situations
4. Impact
5. Explosions

Annexes

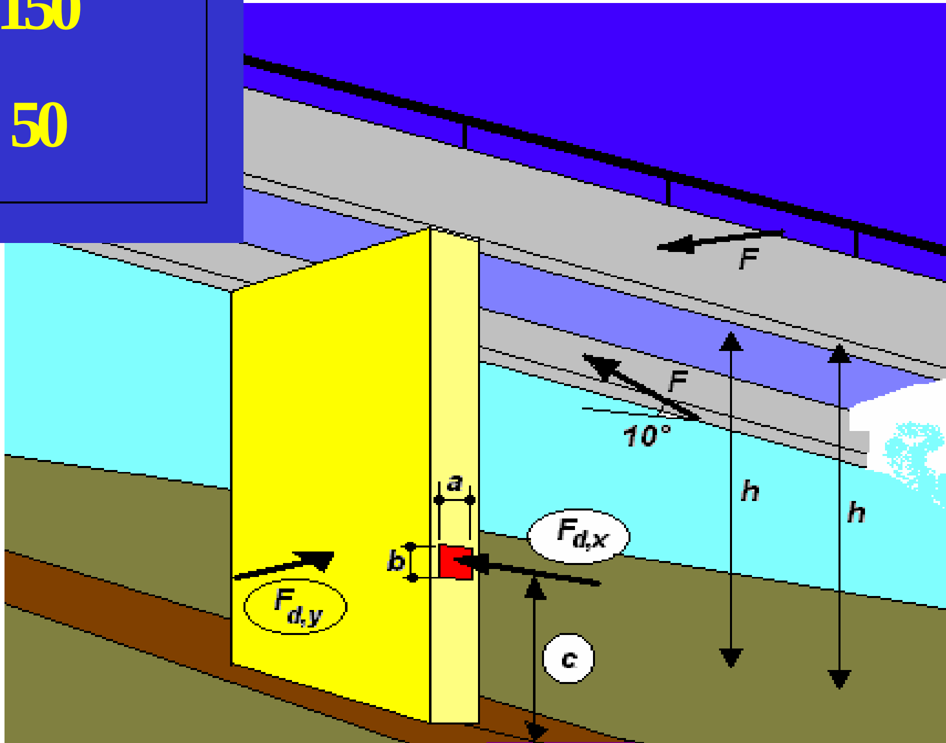
A. Design for localised failure
B. Risk analysis
C. Dynamics
D. Explosions

3 Design strategies

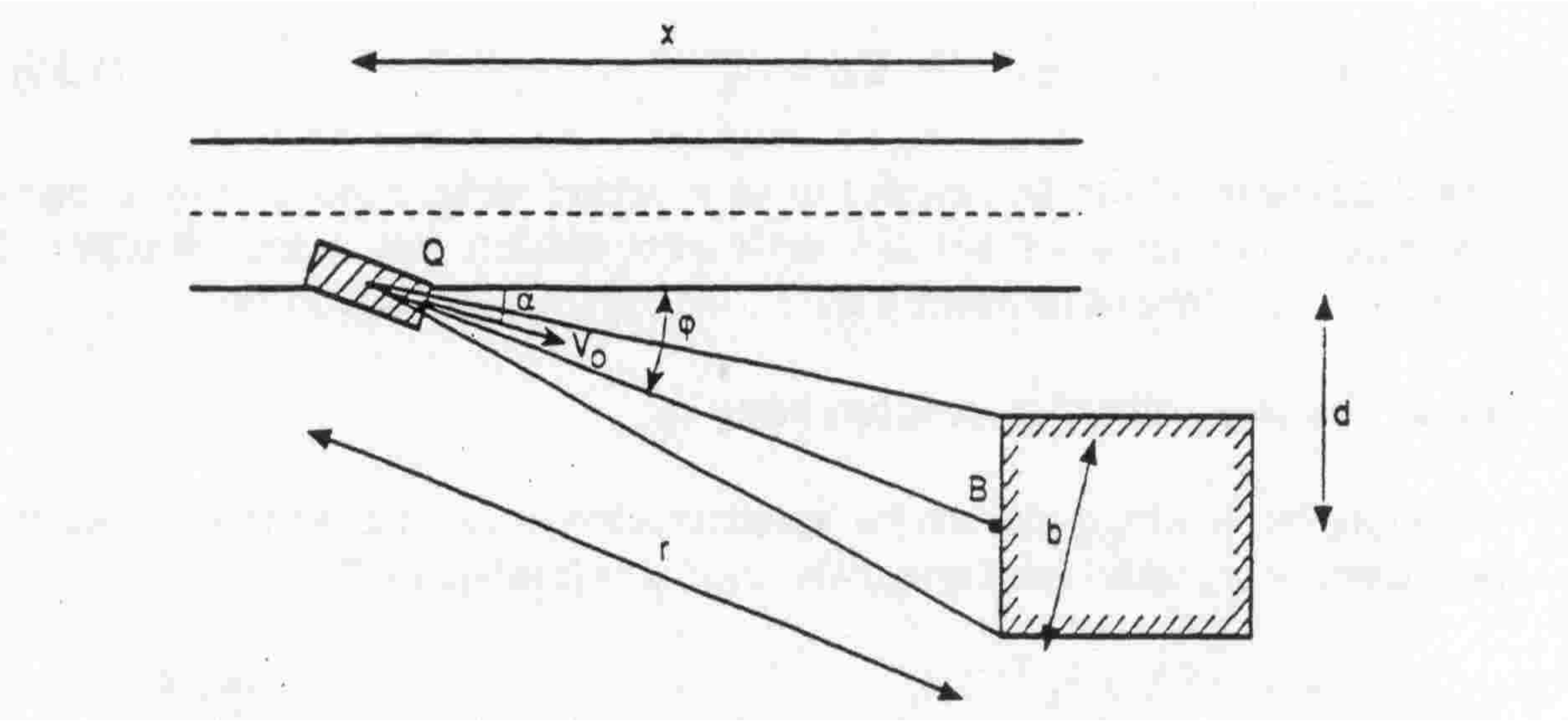


4. Impact

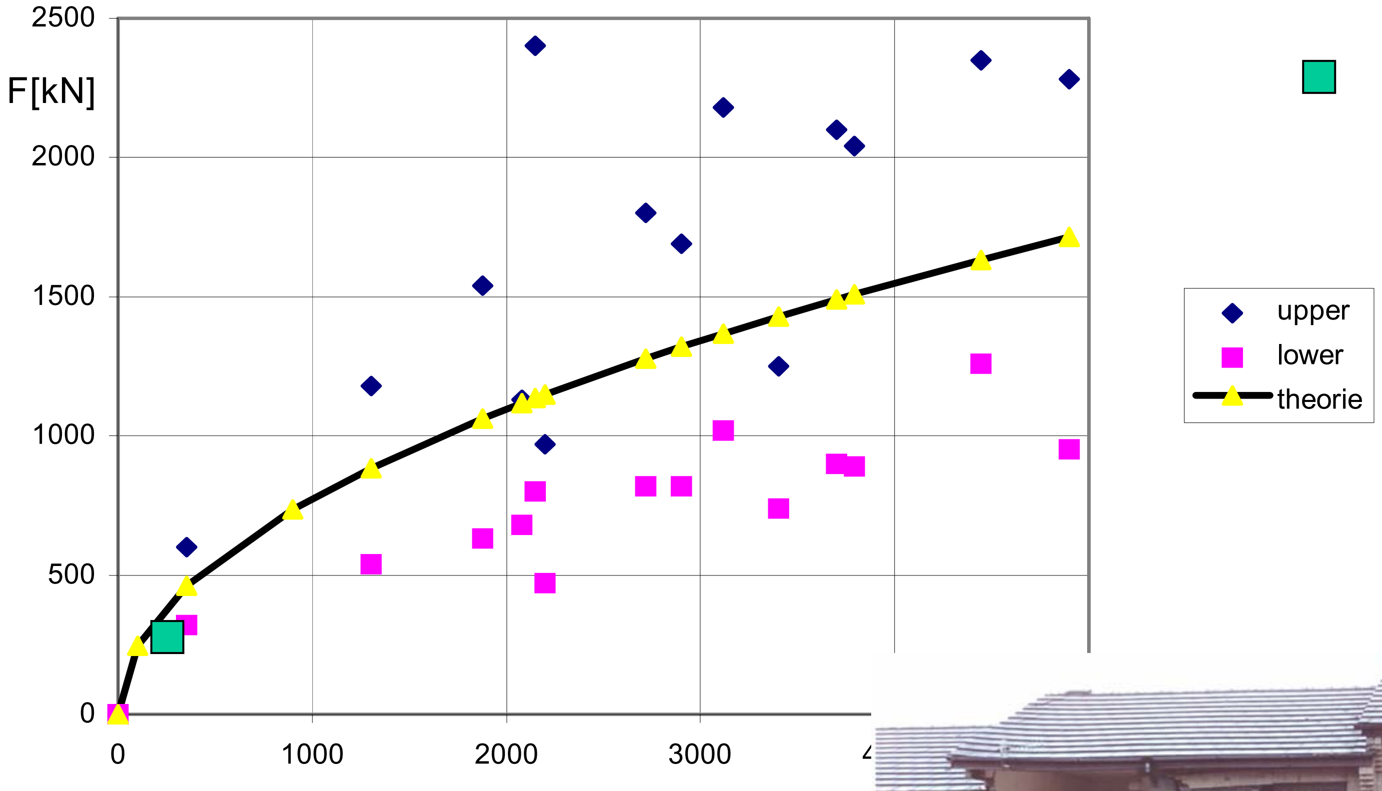
Type of road	Vehicle type	$F_{d,x}$ [kN]
Motorway	Truck	1000
Country roads	Truck	750
Urban area	Truck	500
Parking place	Truck	150
Parking place	Passenger car	50



Annex B: scenario model



Annex C: force model

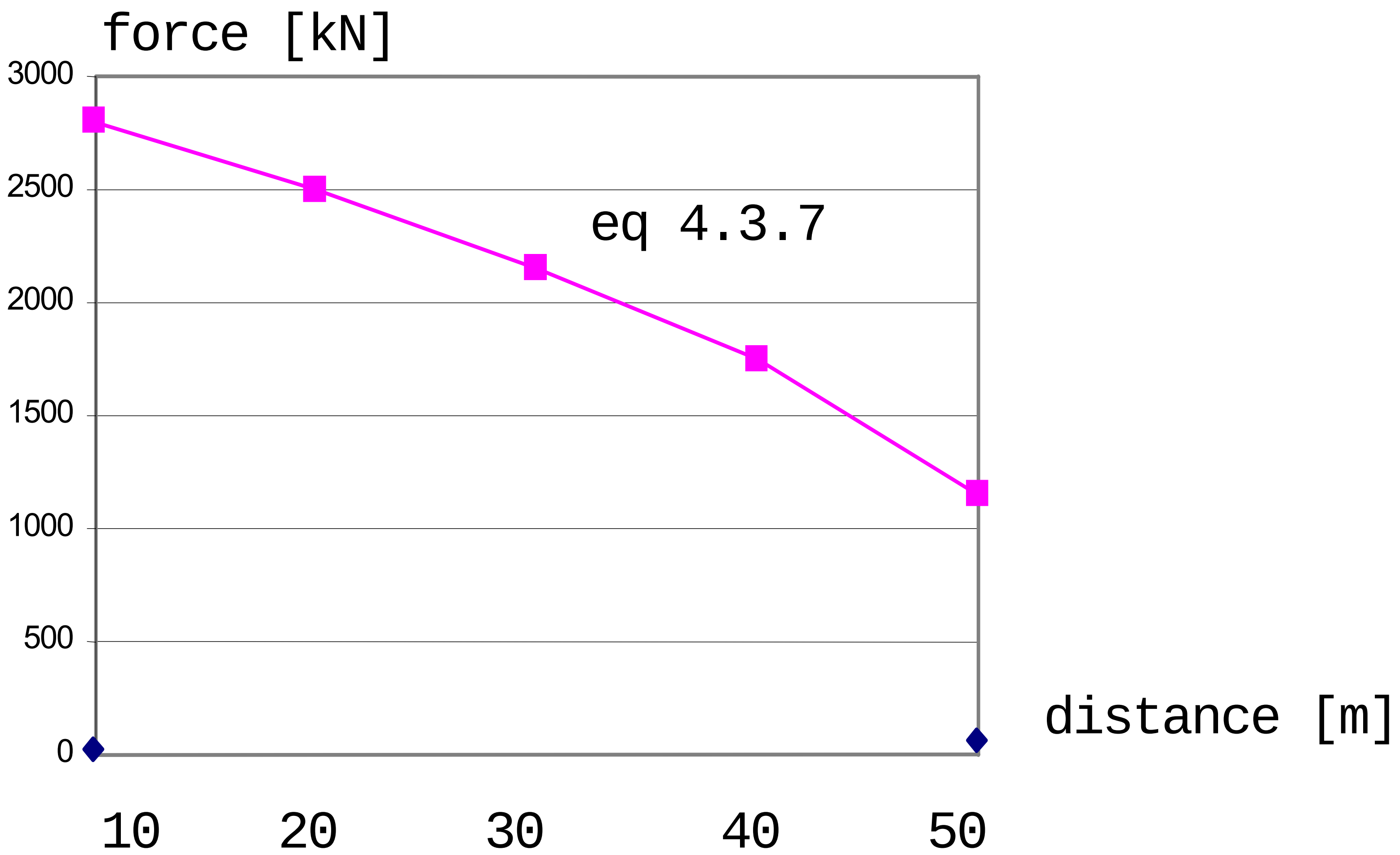


$$F = v\sqrt{(km)}$$

model en experiment

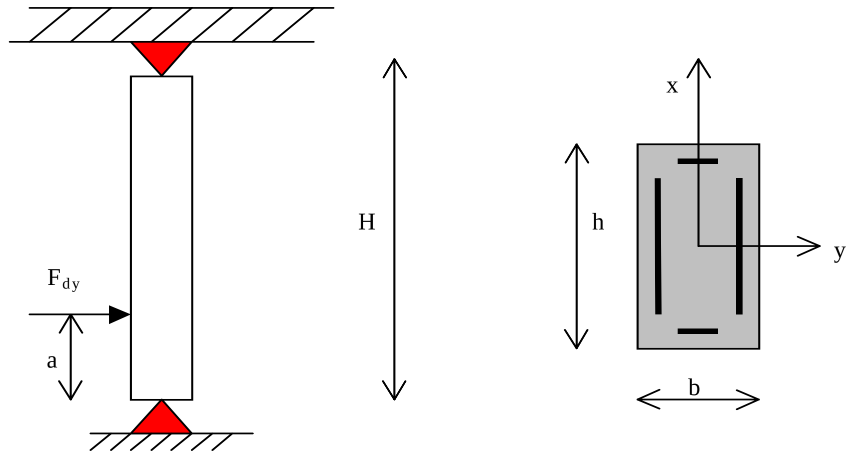
Table 4.2.1: Data for probabilistic collision force calculation

variable	designation	type	mean	stand dev
n	number of lorries/day	deterministic	5000	-
T	reference time	deterministic	100 years	-
λ	accident rate	deterministic	10^{-10} m^{-1}	-
b	width of a vehicle	deterministic	2.50 m	-
α	angle of collision course	rayleigh	10^o	10^o
v	vehicle velocity	lognormal	80 km/hr	10 km/hr
a	deceleration	lognormal	4 m^2/s	1.3 m/s^2
m	vehicle mass	normal	20 ton	12 ton
k	vehicle stiffness	deterministic	300 kN/m	-



Life time exceedence probability: 10^{-3}

Design example: bridge column in motorway



b	**width**	**0.50 m**
h	**thickness**	**1.00 m**
H	**column height**	**5 m**
f_y	**yield stress steel**	**300 MPa**
f_c	**concrete strength**	**50 MPa**
ρ	**reinforcement ratio**	**0.01**

Bending moment:

$$M_{dx} = \frac{a(H-a)}{H} F_{dx} = \frac{1.25\ (5.00-1.25)}{5.00}\ 1000\ = 940\ \text{kNm}$$

Resistance:

$$M_{Rdx} = 0.8\ \omega\, h^2\, b\, f_y$$

$$= 0.8\ \ 0.01\ \ 1.00^2\ \ 0.50\ \ 300\,000$$

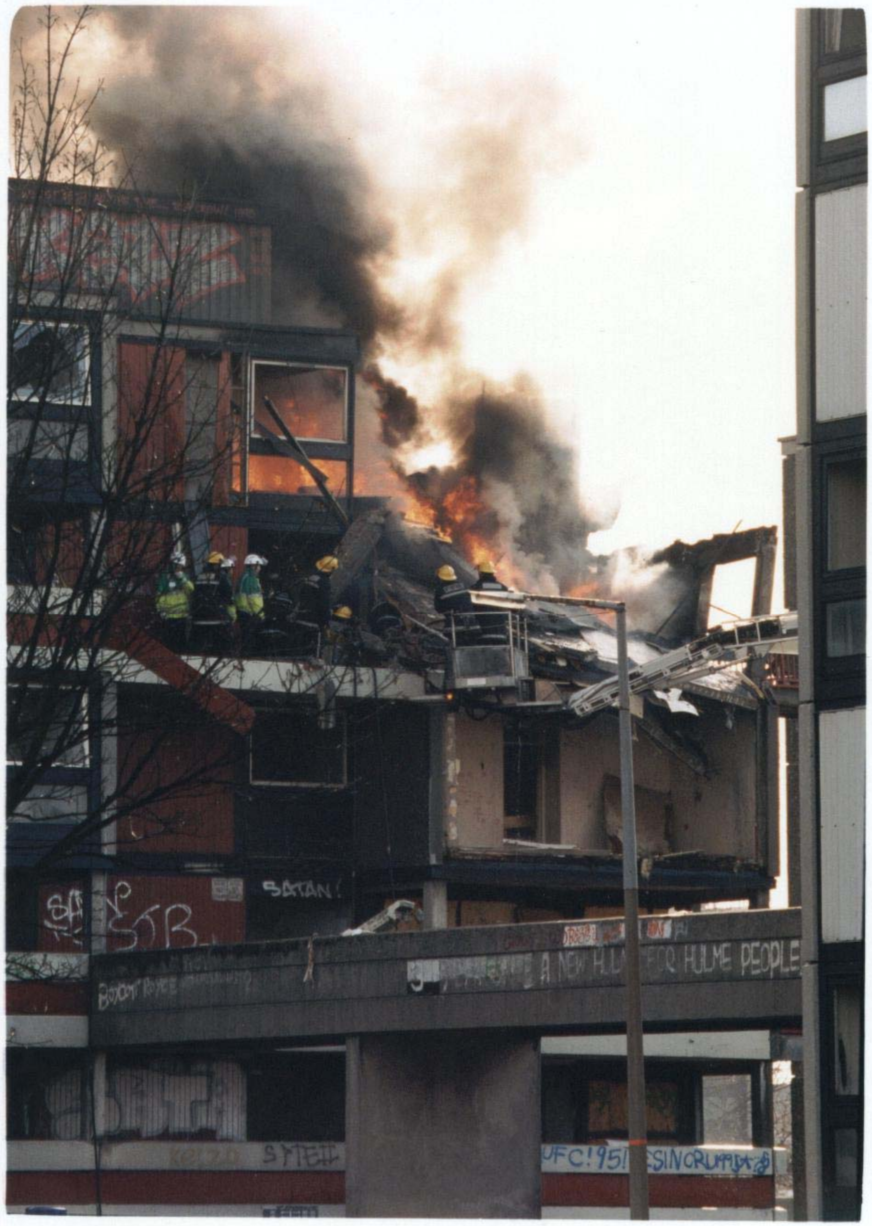
$$= 1200\ \text{kNm} > \mathbf{940\ kNm}$$

5 + Annex D:

gas explosions in buildings

gas explosions in tunnels

dust explosions



INTERNAL NATURAL GAS EXPLOSIONS

The design pressure is the maximum of:

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

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

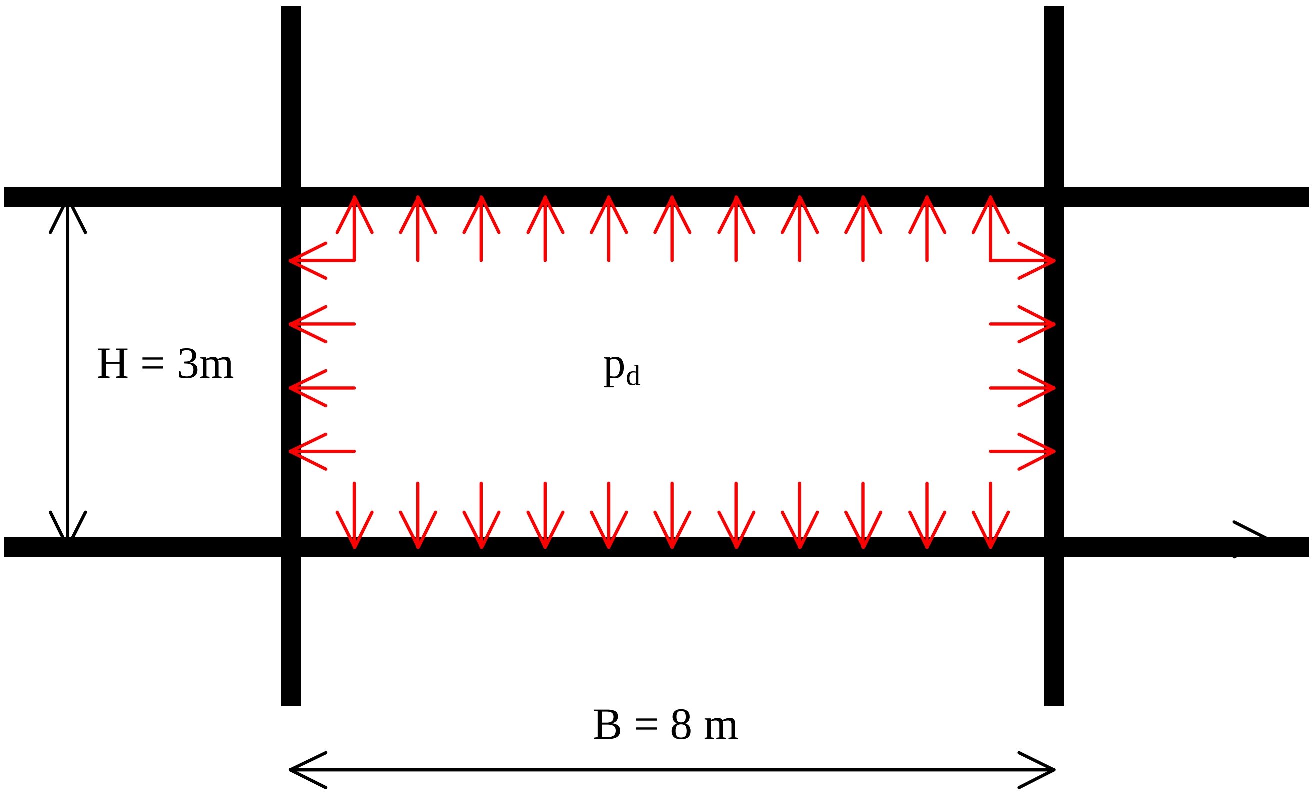
A_v = area of venting components [m^2]

V = volume of room [m^3]

Validity: $V < 1000$ m^3 ; $0{,}05$ m$^{-1} \leq A_v / V \leq 0{,}15$ m^{-1}

Annex B: load duration = 0.2 s

Design Example: Compartment in a multi story building



Compartment: 3 x 8 x 14 m

Two glass walls (p_v =3 kN/m^2) and two concrete walls

explosion pressure:

$$p_{Ed} = 3 + p_v/2 + 0{,}04/(A_v/V)^2$$
$$= 3 + 1.5 + 0.04 / 0.144^2 = 6.5 \text{ kN/m}^2$$

self weight = 3.0 kN/m^2

live load = 2.0 kN/m^2

Design load combination (bottom floor):

$$p_{da} = p_{SW} + p_E + \psi_{1LL} \; p_{LL}$$
$$= 3.00 + 6.50 + 0.5*2.00 = 10.50 \text{ kN/m}^2$$

Dynamic increase in load carrying capacity

$$\varphi_d = 1 + \sqrt{\frac{p_{sw}}{p_{Rd}}}\sqrt{\frac{2u_{max}}{g(\Delta t)^2}}$$

Δt = 0.2 s = load duration

g = 10 m/s^2

u_{max} = 0.20 m = midspan deflection at collapse

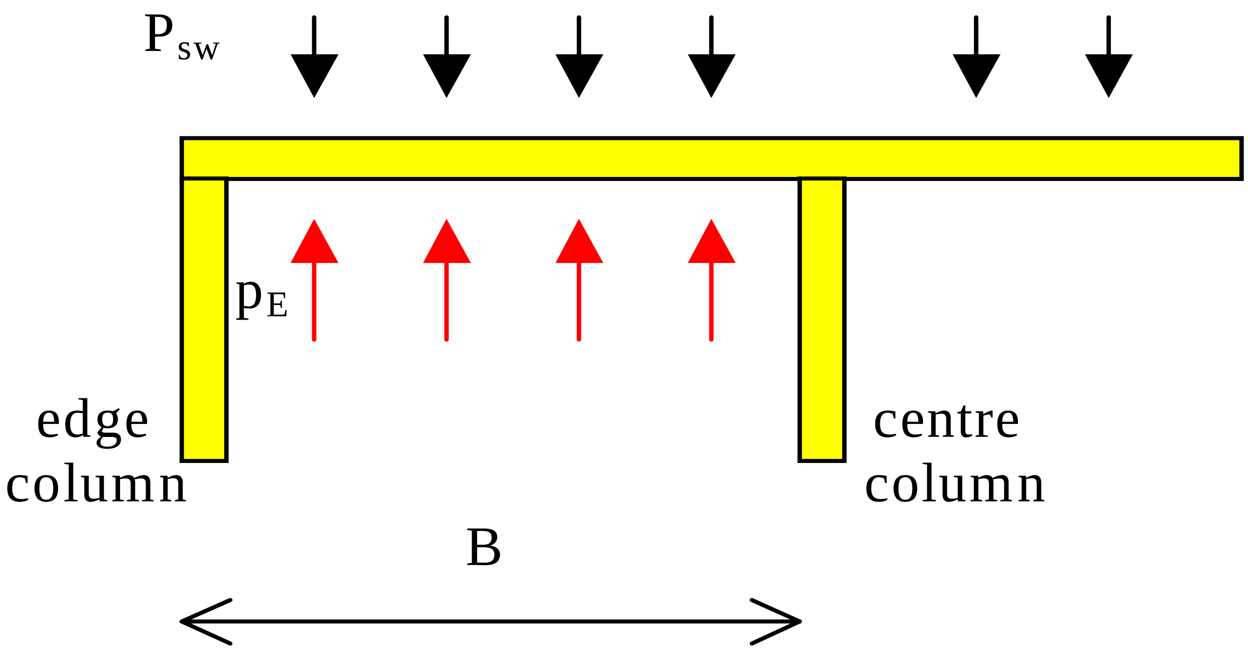
p_{sw} = 3,0 kN/m^2 and p_{Rd} =7.7 kN/m^2

$$\varphi_d = \left[1 + \sqrt{\frac{3}{7.7}}\sqrt{\frac{2*0.20}{10\ (0.2)^2}}\right] = 1.6$$

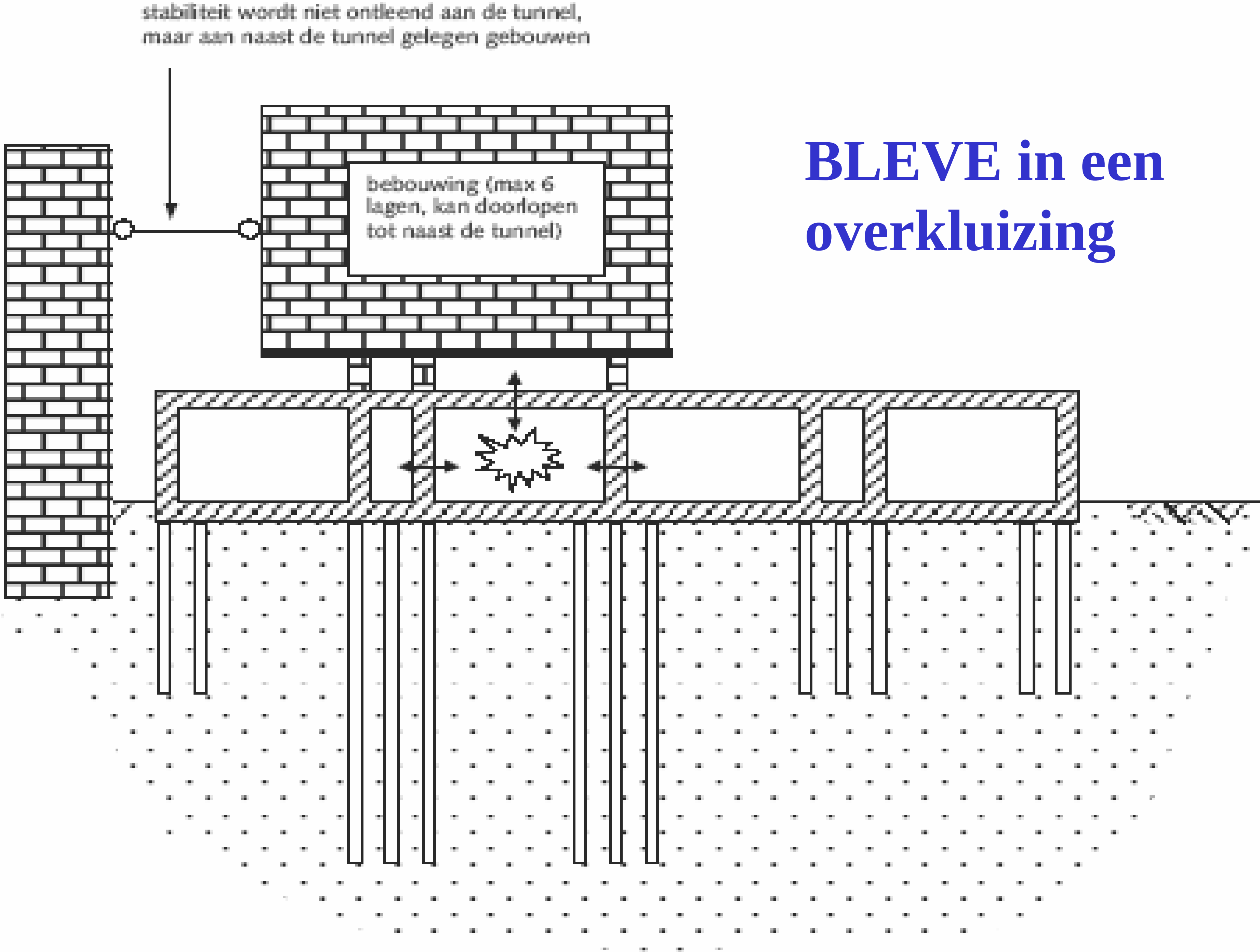
$p_{REd} = \varphi_d\, p_{Rd}$ = **1.6 * 7.7 = 12.5 kN/m^2 > 10.5 kN/m2**

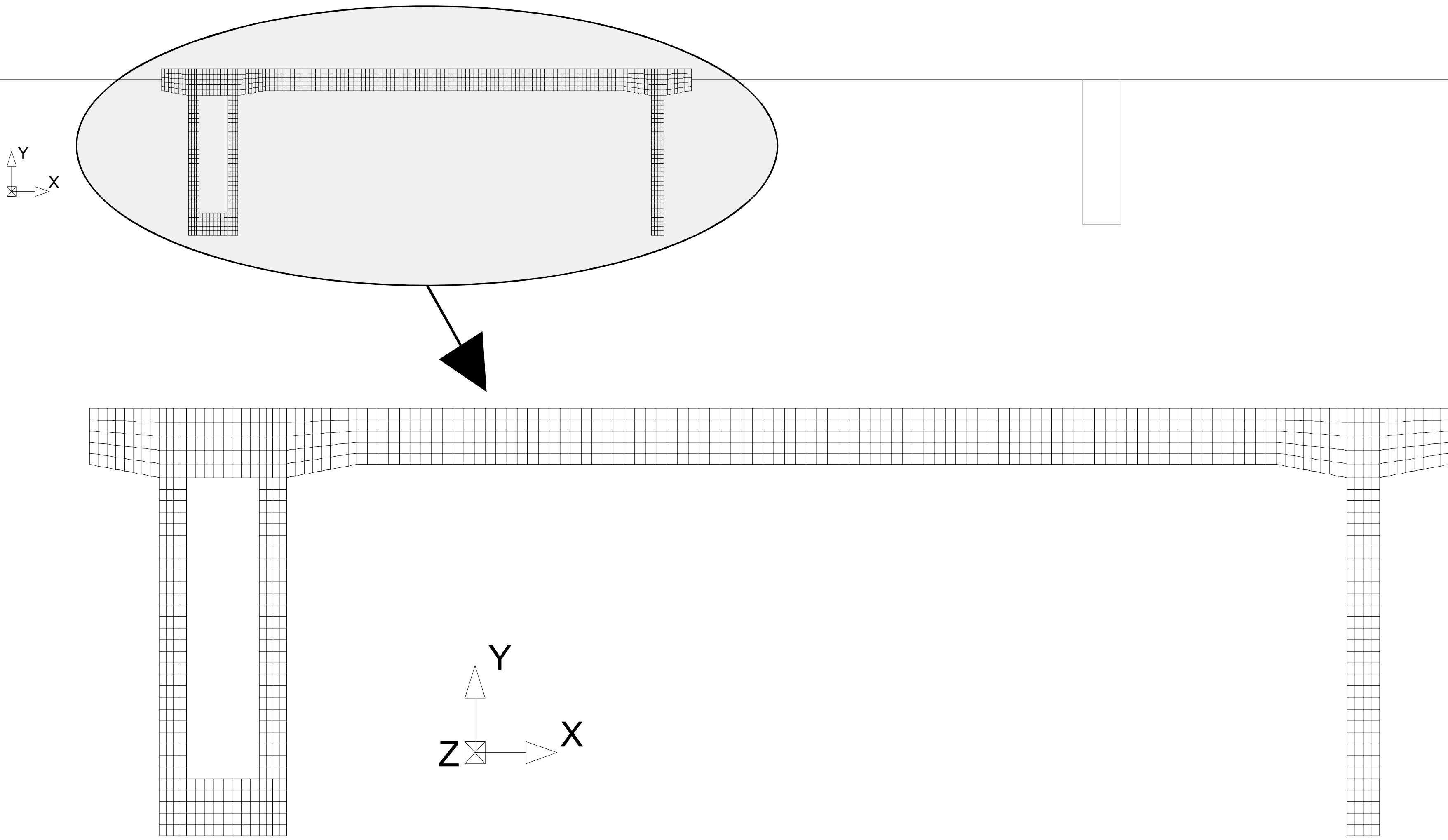
Conclusion: bottom floor system okay

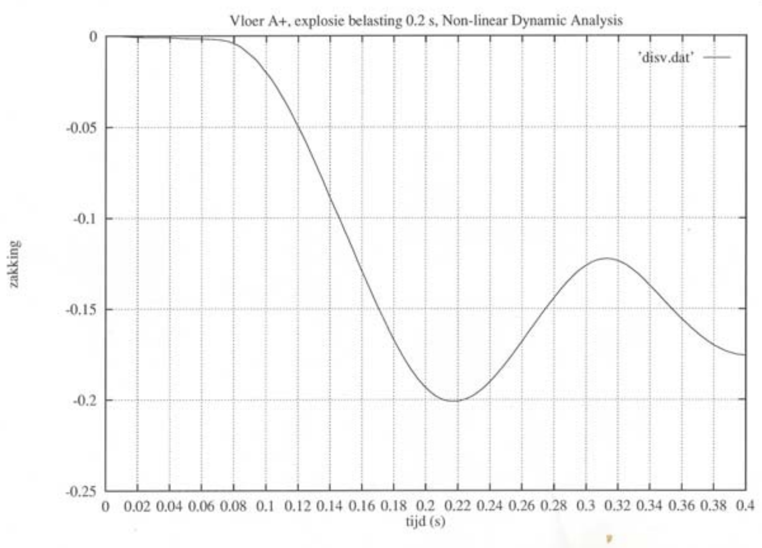
Be careful for upper floors and columns

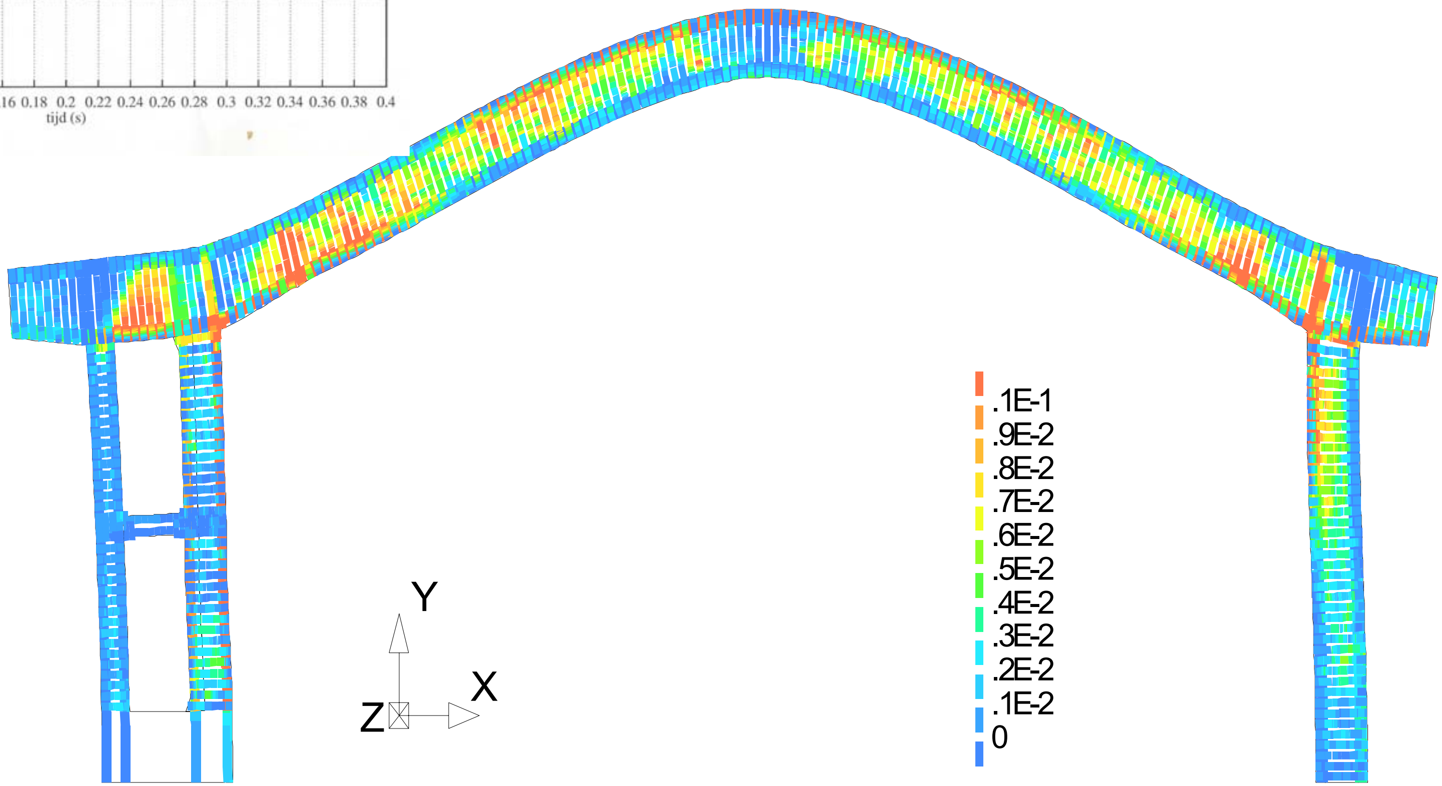


BLEVE in een overkluizing




Y
X
Y
Z
X


Vloer A+, explosie belasting 0.2 s, Non-linear Dynamic Analysis
'disv.dat'
zakking
tijd (s)
0
-0.05
-0.1
-0.15
-0.2
-0.25
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2 0.22 0.24 0.26 0.28 0.3 0.32 0.34 0.36 0.38 0.4


.1E-1
.9E-2
.8E-2
.7E-2
.6E-2
.5E-2
.4E-2
.3E-2
.2E-2
.1E-2
0
Y
X
Z

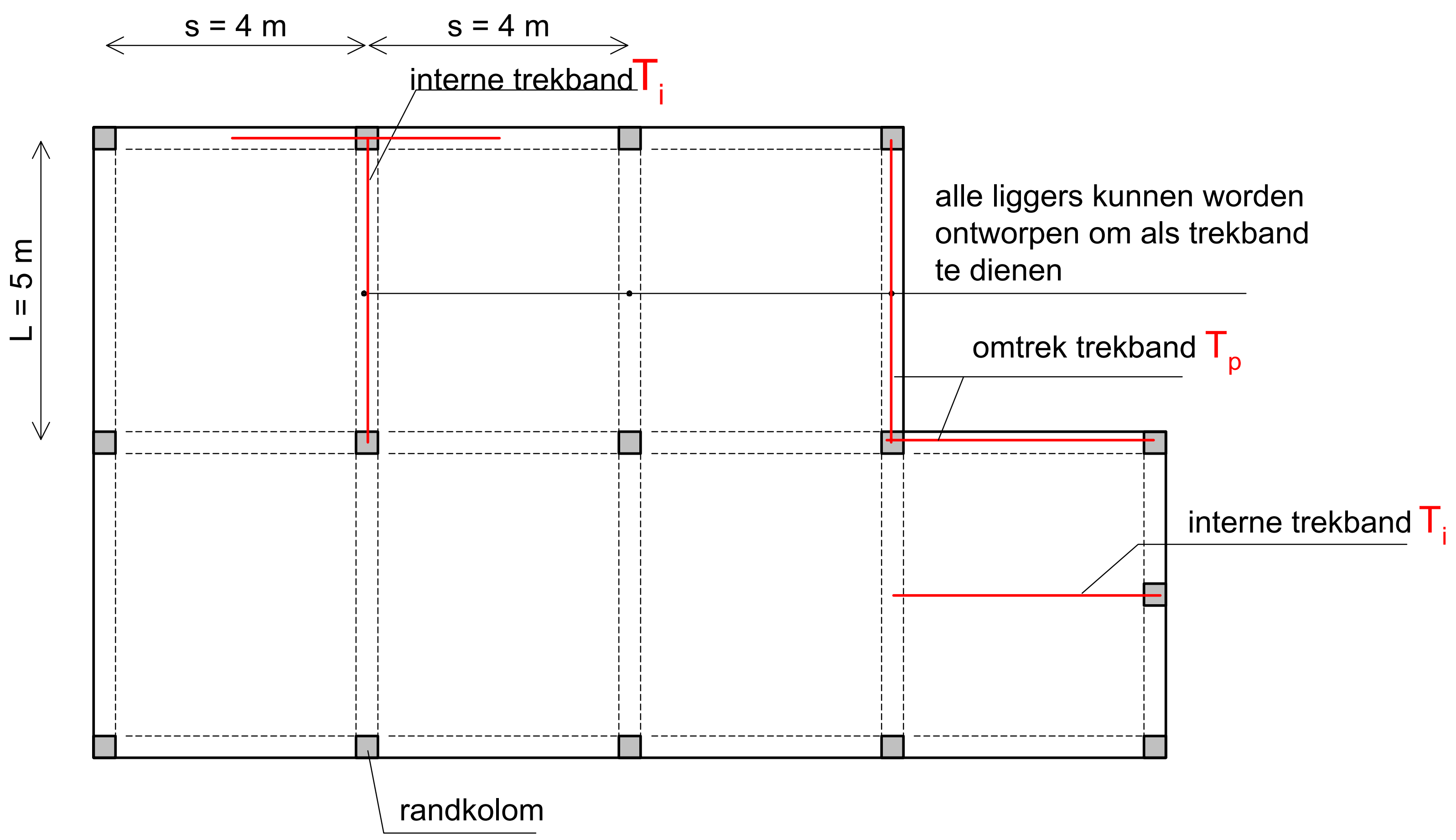
Annex A: Classification of buildings

Consequences class	Example structures
class 1	low rise buildings where only few people are present
class 2, lower group	most buildings up to 4 stories
class 2, upper group	most buildings up to 15 stories
class 3	high rise building, grand stands etc.

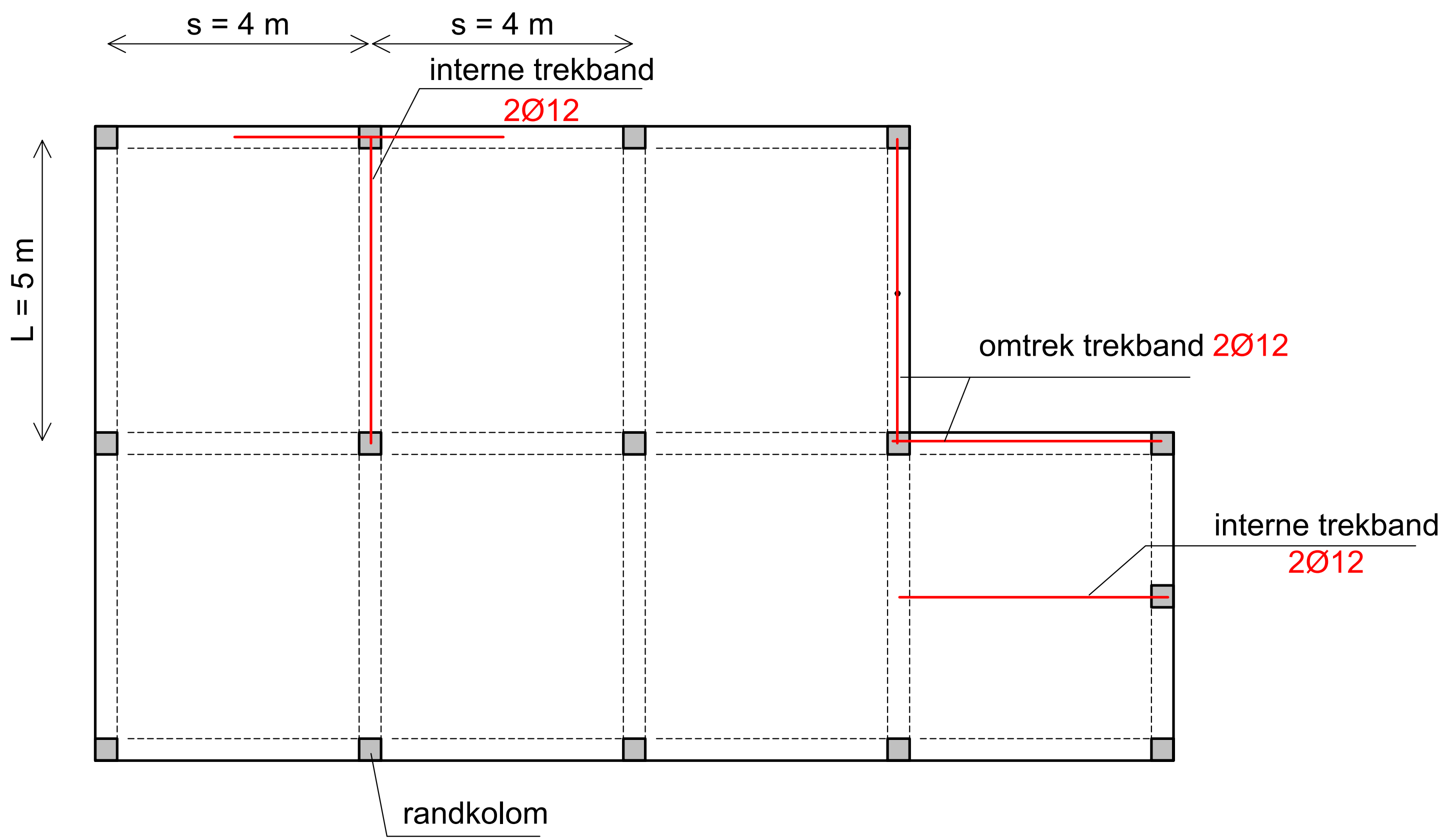
Annex A: What to do

Class 1	No special considerations
Class 2, Lower Group Frames	Horizontal ties in floors
Class 2, Lower group Wall structures	Full cellular shapes Floor to wall anchoring.
Class 2, Upper Group	Horizontal ties and effective vertical ties OR limited damage on notional removal OR special design of key elements
Class 3	Risk analysis and/or advanced mechanical analysis recommended

Class 2a (lower group)



Class 2a (lower group)



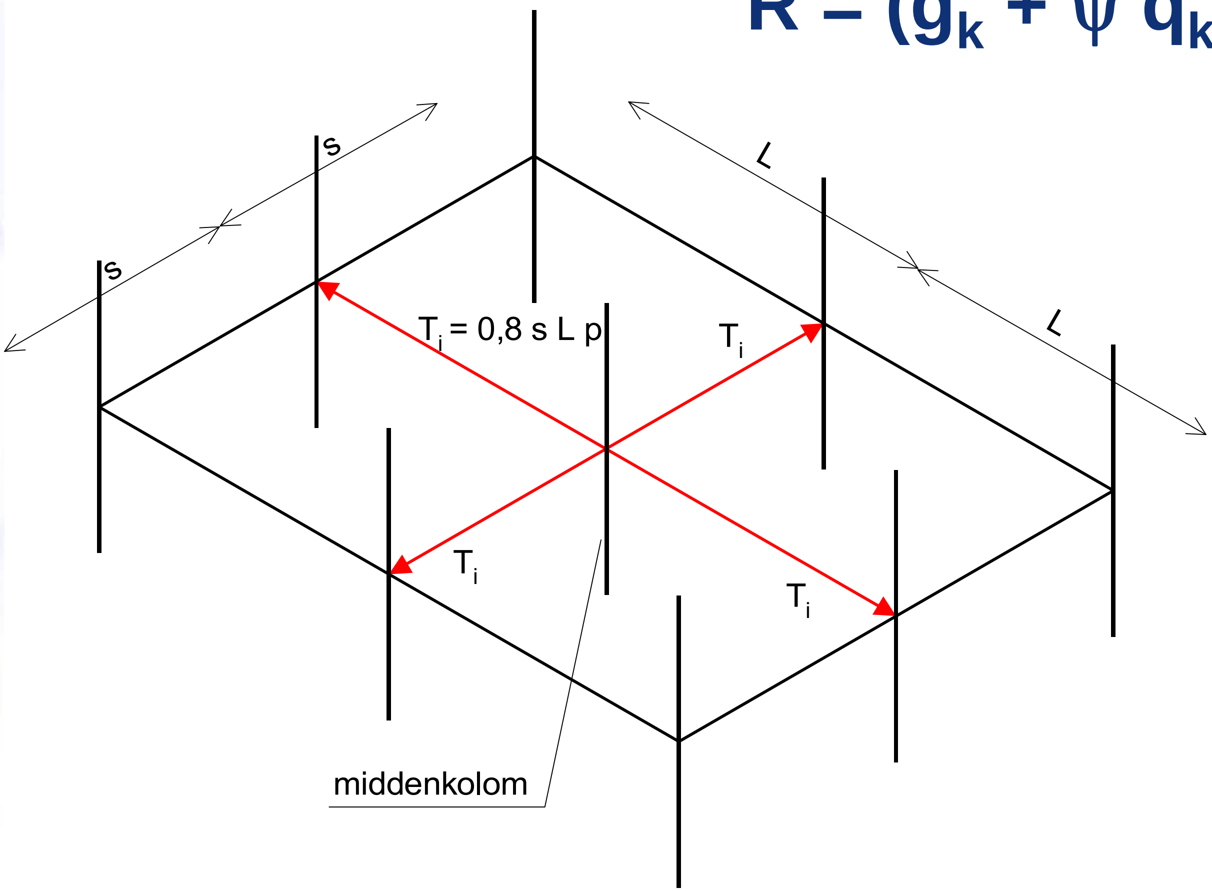
$$T_i = 0.8\ (g_k + \Psi q_k) sL = 0.8\{3+0.5*3\}x4x5=88\ kN>75\ kN$$

FeB 500: $A = 202\ mm^2$ *or* *2 Ø12mm*

Background horizontal typings

total load on center column

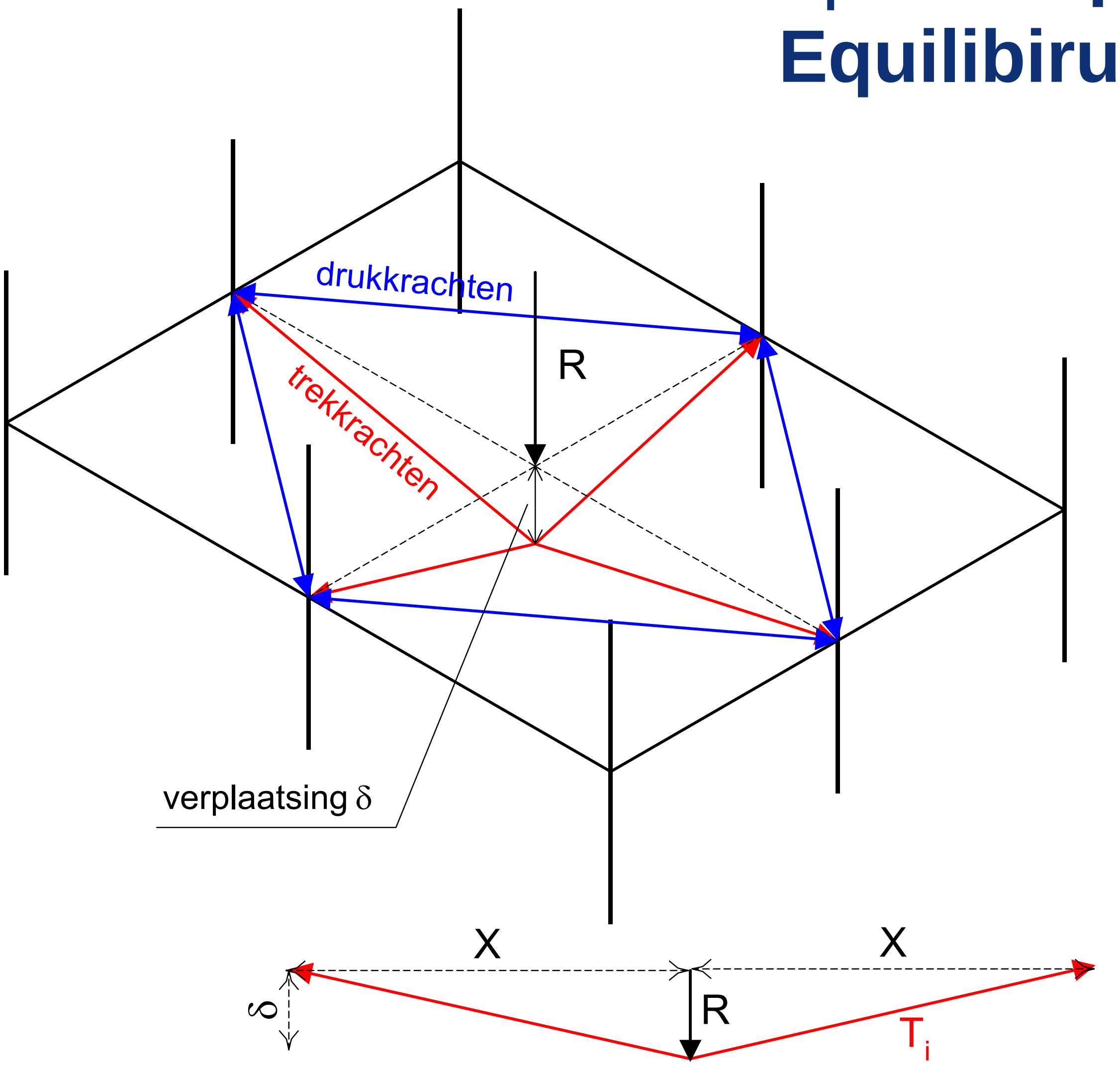
$R = (g_k + \psi\, q_k)\, L\, s = p\, L\, s$

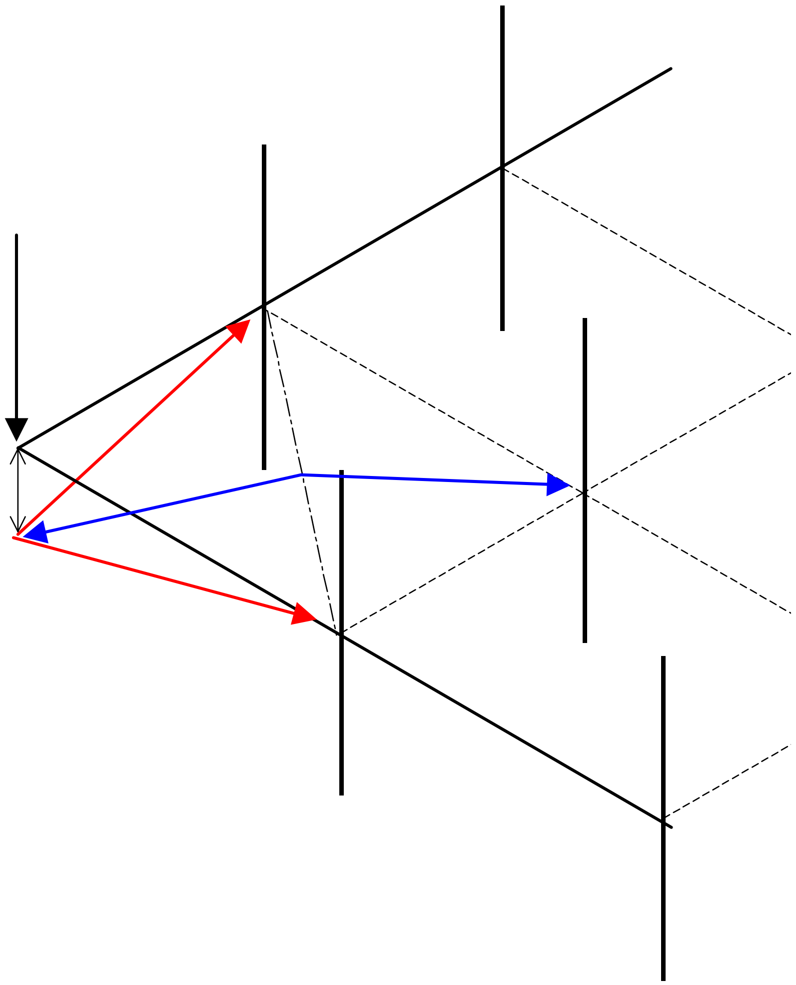


Background typing forces

$T_i = 0.75 \, p \, s \, L$

Equilibirum for $\delta = (s+L)/6$



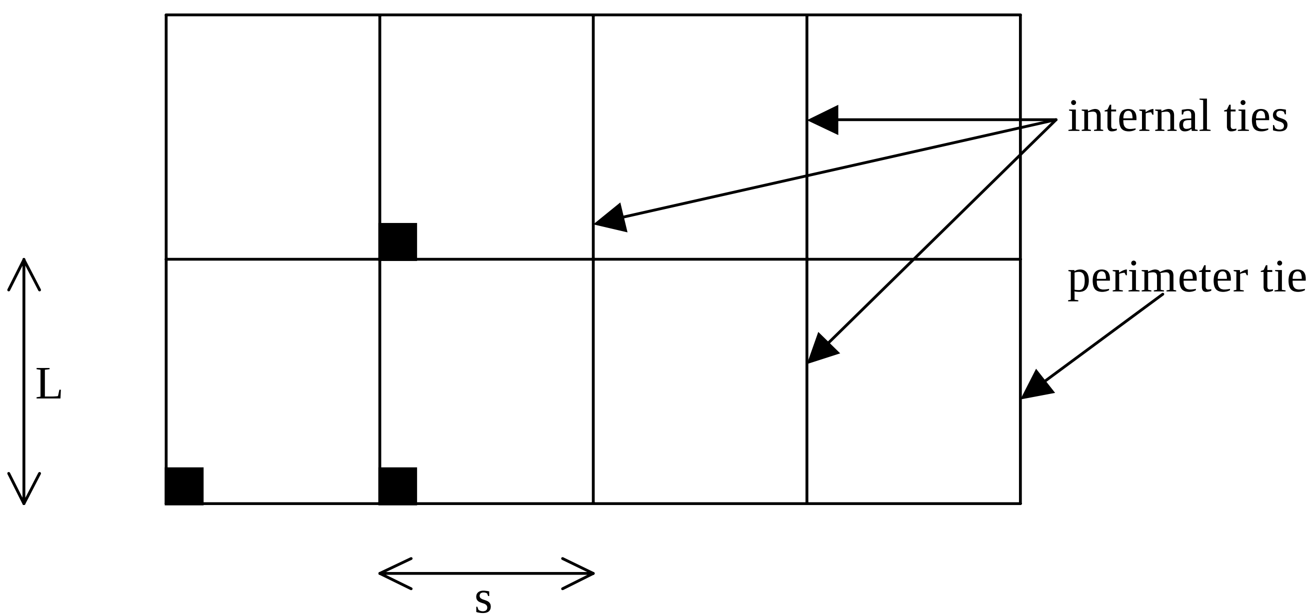


Suggestion:

design corner column as a key element.

Example structure, Class 2, Upper Group, Framed

L =7.2 m, s =6 m, $q_k = g_k$ =4 kN/m^2, Ψ=1.0



Example structure

Internal horizontal tie force

$T_i = 0.8\,(g_k + \Psi q_k)\; s\,L = 0.8\,\{4+4\}\,(6 \times 7.2) = 276$ kN

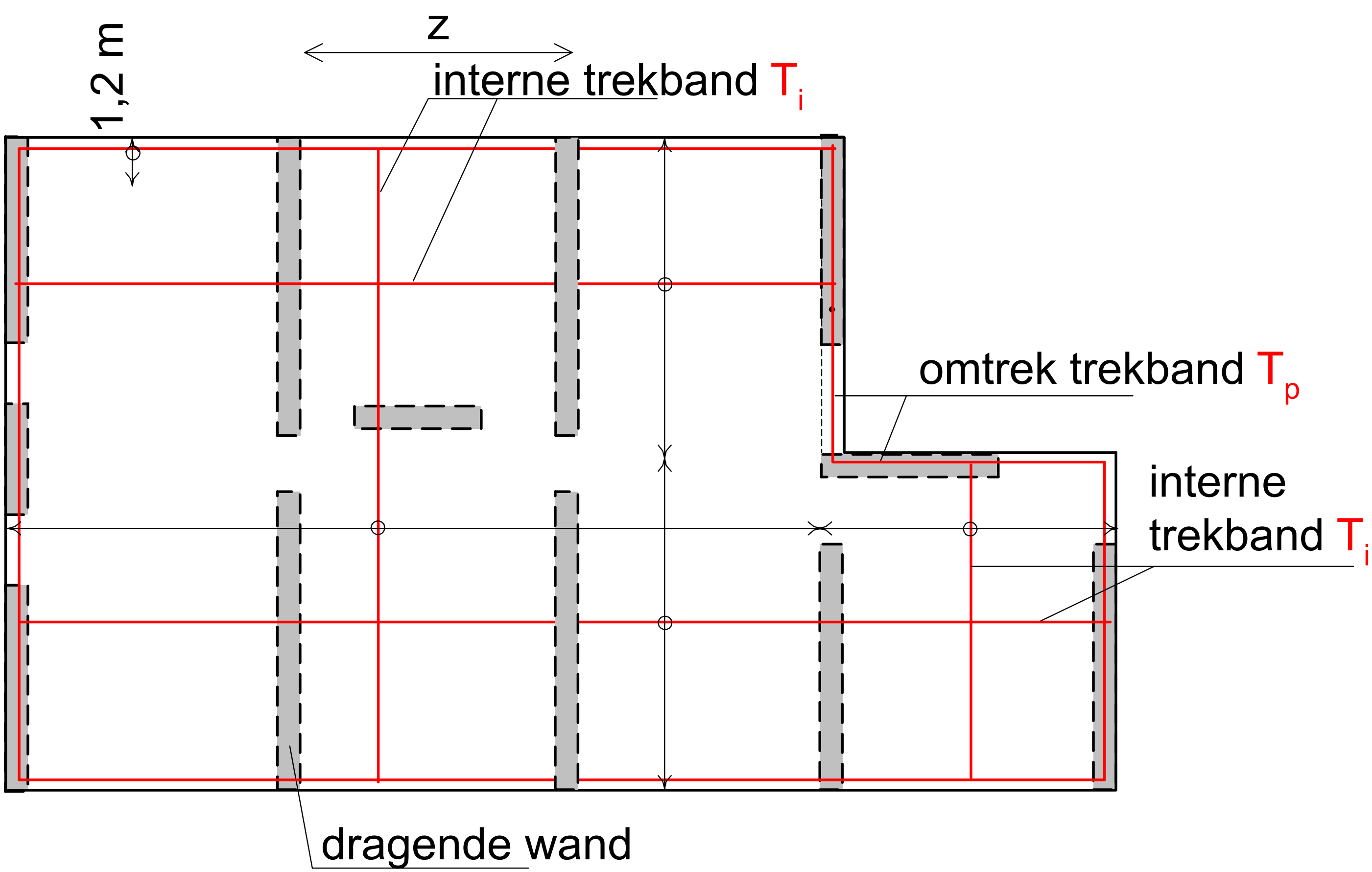
FeB 500: A = 550 mm^2 *or* *2 ø18 mm*.

Vertical tying force:

$T_i = (g_k + \Psi q_k)\; s\,L = \{4+4\}\,(6 \times 7.2) = 350$ kN

FeB 500: A = 700 mm^2 or *3 ø18 mm*.

Class 2 higher class – walls



Class 2 higher class – walls

Tyings

Horizontal: $T_i = F_t (g_k + \psi q_k) /7{,}5 \times z/5$ kN/m > F_t

Periphery: $T_p = F_t$

Vertical: $T = 34\ A / 8000 \times (H/t)^2$ in N > 100 kN/m

$F_t = 20 + 4n_s$ kN/m < 60 kN/m

n_s = number of storeys

z = span

A = horizontal cross section of wall [mm²]

H = free storey height

t = wall thickness

Class 2 higher class – walls

Design Example:

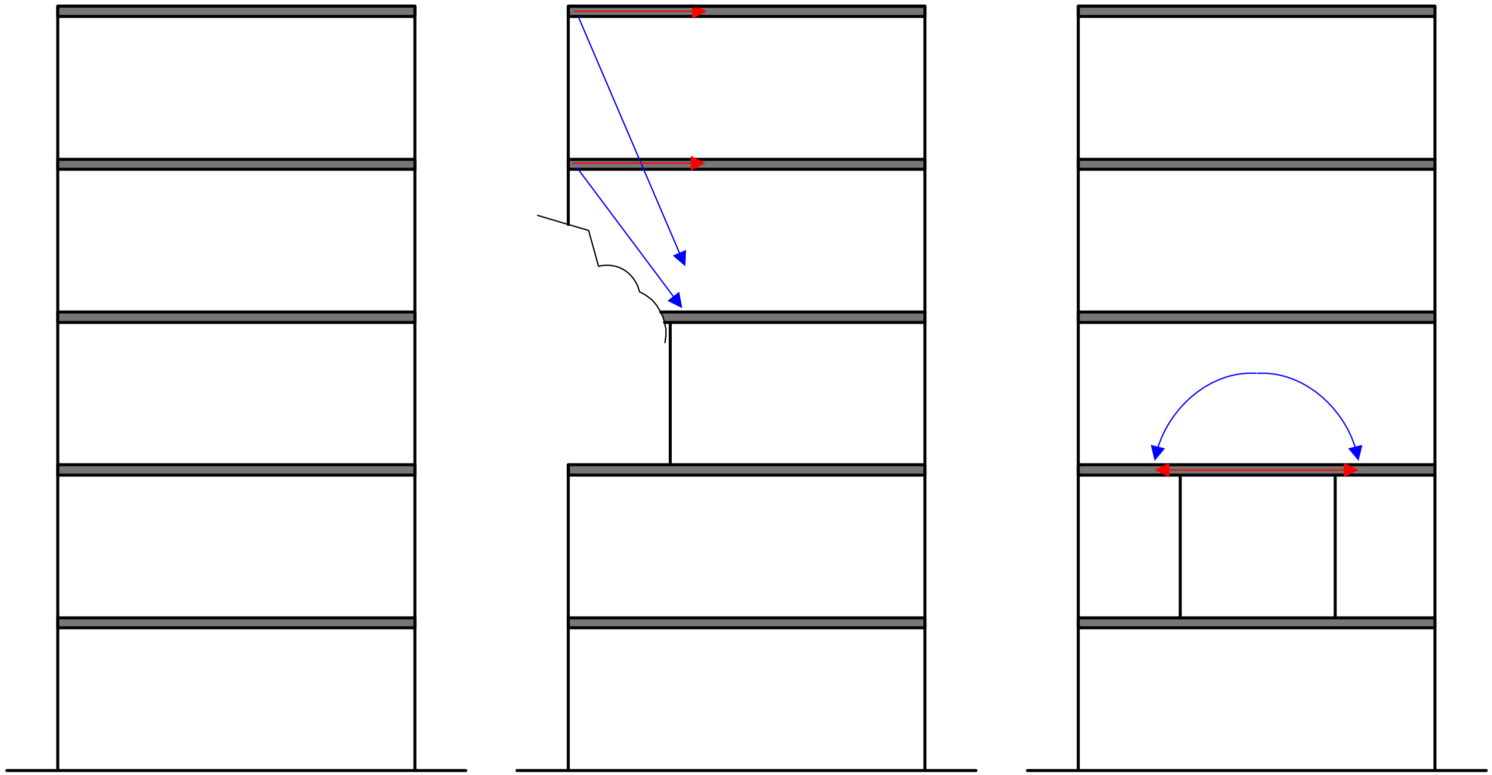
L = 7,2 m, H = 2,8 m en t = 250 mm

$$T = 34 \times 7200 \times 250/8000 \times (2800/250)^2 =$$
$$= 960 \times 10^3 \text{ N} = 960 \text{ kN} > 720 \text{ kN}$$

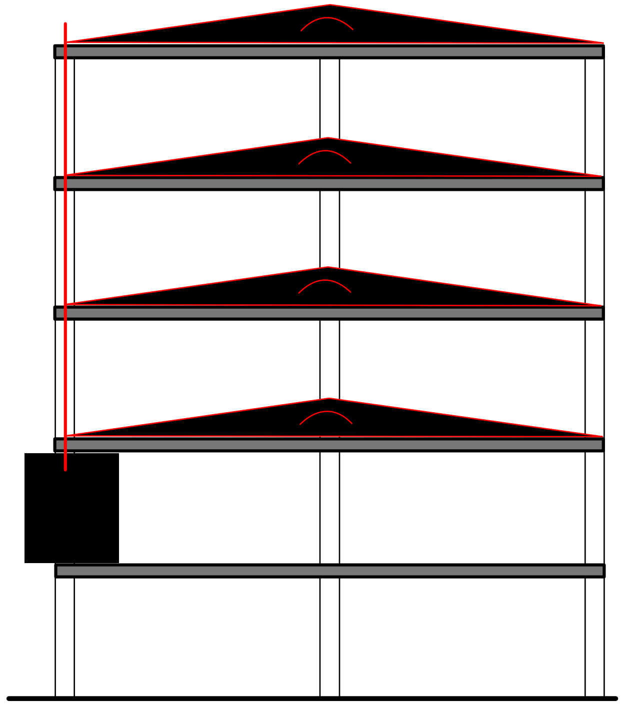
maximal distance 5 m
maximal distance from edge: 2.5 m

Result: 2 tyings of 480 kN

Effect of tyings in walls

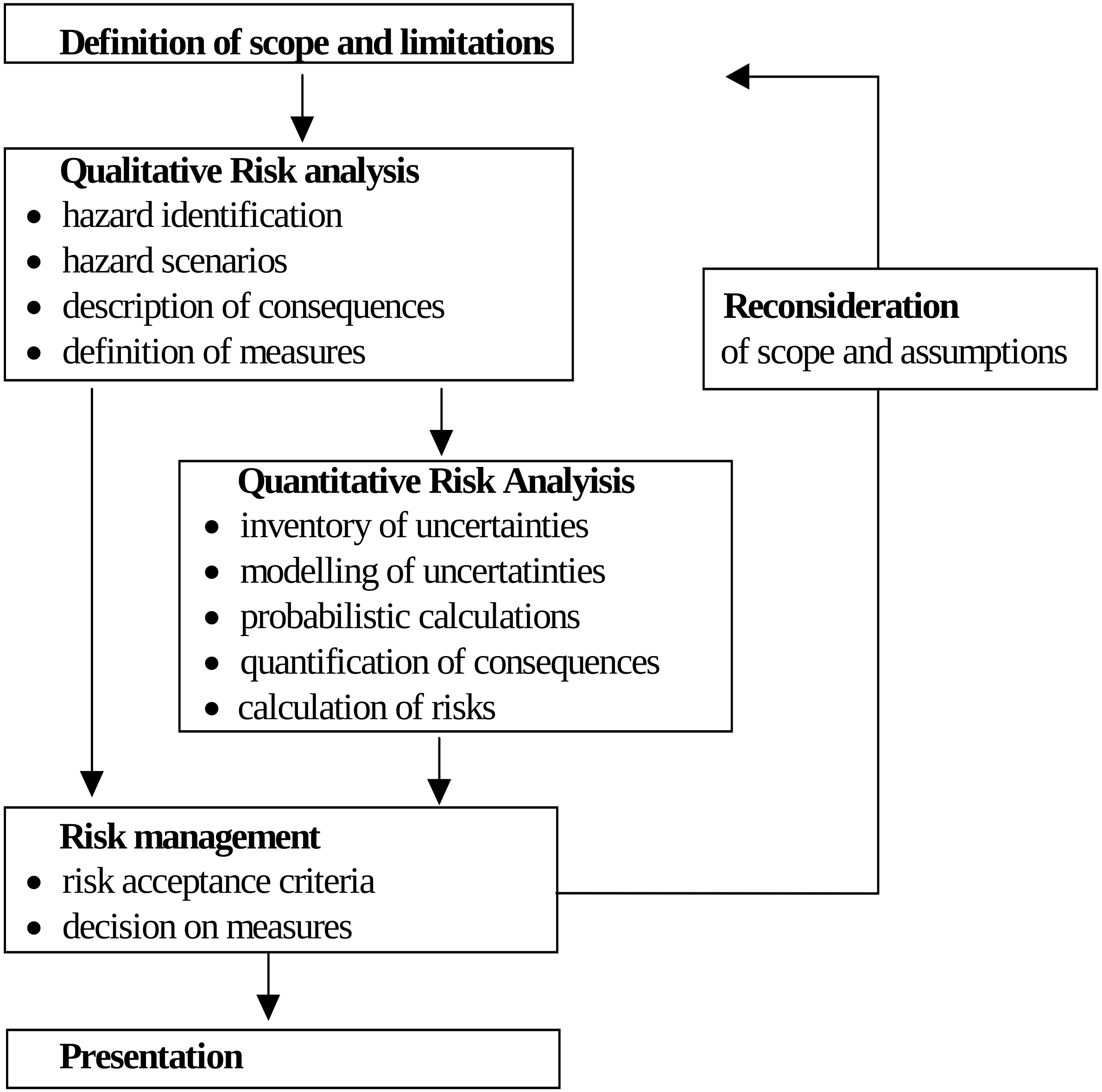


Effect of vertical tyings

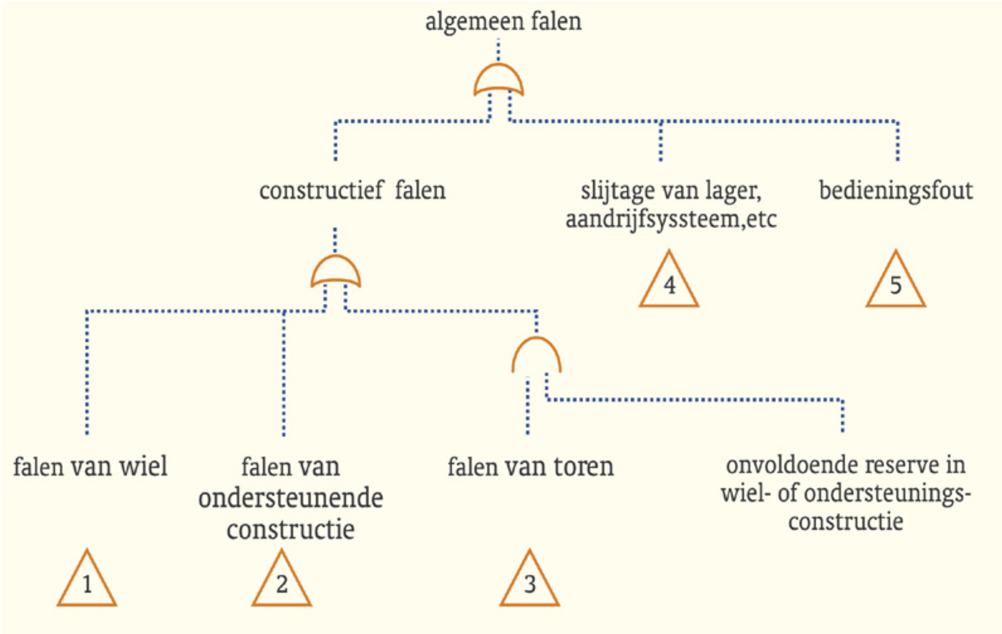


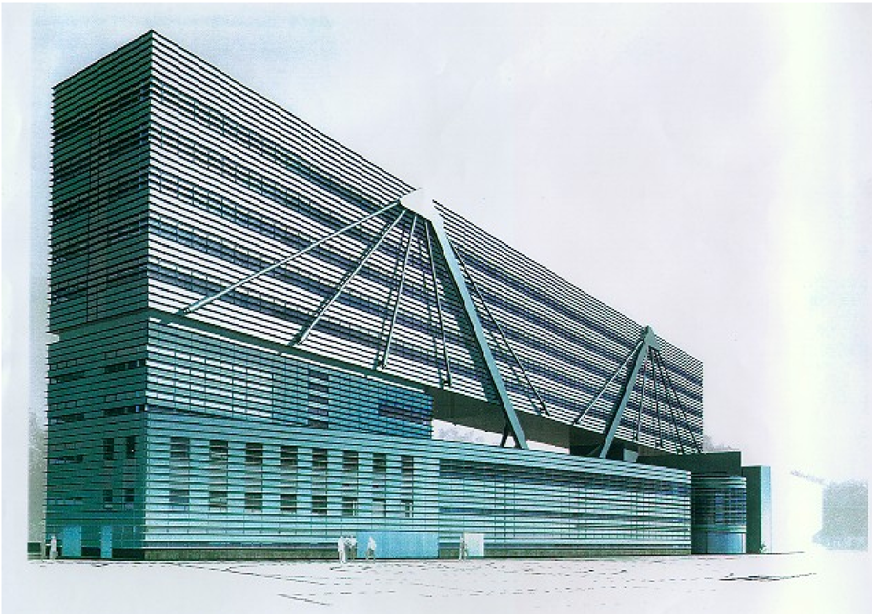
class 3: Risk analysis

Guidance can be found in Annex B:



Risk Analysis Eastern Scheldt Storm Surge Barrier (1980)





Office building Zwolle (The Netherlands)

London Eye

Points of attention in risk analysis

- list of hazards
- irregular structural shapes new
- construction types or materials
- number of potential casualties
- strategic role (lifelines)

hazards

Earthquake

Landslide

Tornado

Avalanche

Rock fall

High groundwater

Flood

Volcano eruption

Internal explosion

External explosion

Internal fire

External fire

Impact by vehicle etc

Mining subsidence

Environmental attack

Vandalism

Demonstrations

Terrorist attack

Design error

Material error

Construction error

User error

Lack of maintenance

Step 1

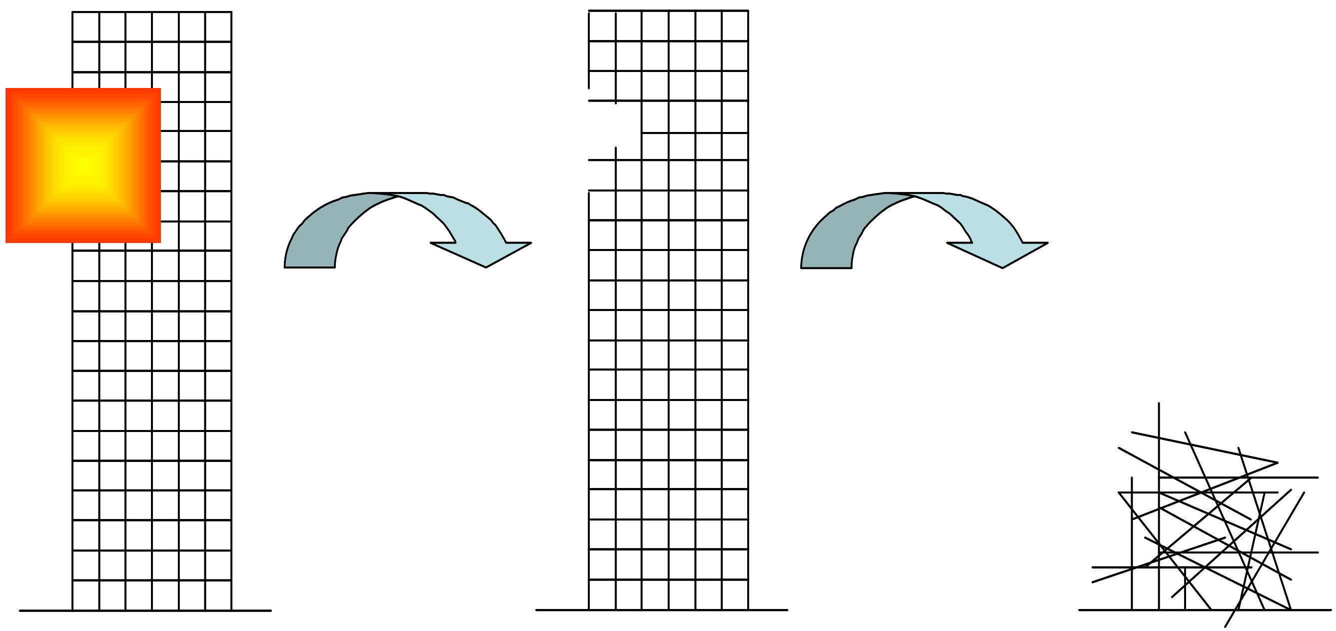
Identifical and modelling of relevant accidental hazards

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 calculation:

Step 1: identification of hazard H_i

Step 2: damage D_j at given hazard

Step 3: structural behaviour S_k and cpmsequences C(S_k)

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

Take sum over all hazards and damage types

Conclusions

EN 1991-1-7: valuable document,

but not a masterpiece of European harmonisation

Reasons:

- **large prior differences**
- **member state autonomy in safety matters**
- **legal status different in every country**

It will be interesting to see the National Annexes and NDP's .

Relevant Background Documents

ISO-documents

COST actions C28 and TU0601

Background document for the ENV-version of EC1 Part 2-7 (TNO, The Netherlands, 1999)

Leonardo da Vinci Project CZ/02/B/F/PP-134007 Handbooks Implementtion of Eurocodes (2005)