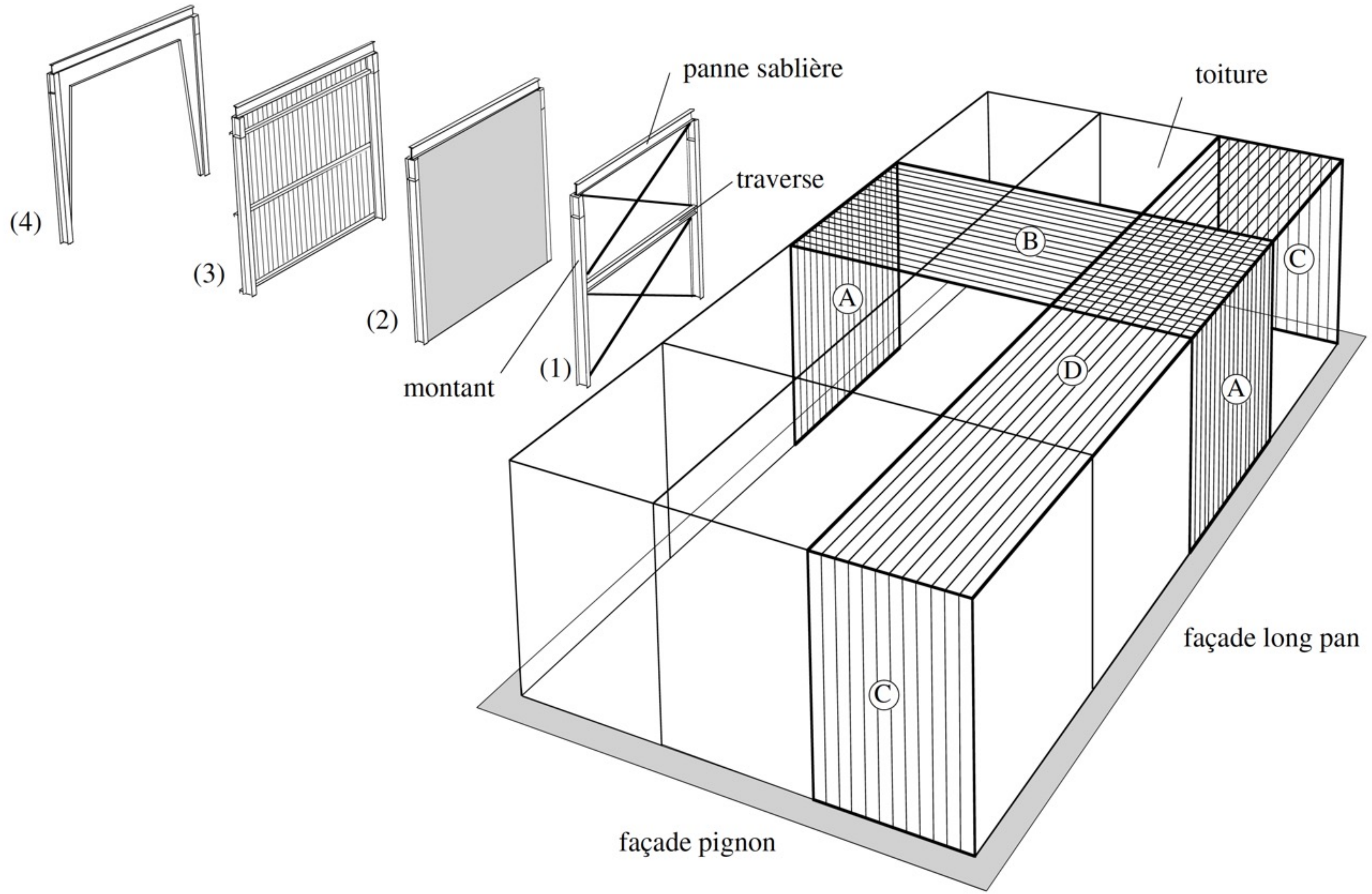
CIVIL-526: Steel structures, selected chapters

Design of load-bearing systems for halls and buildings

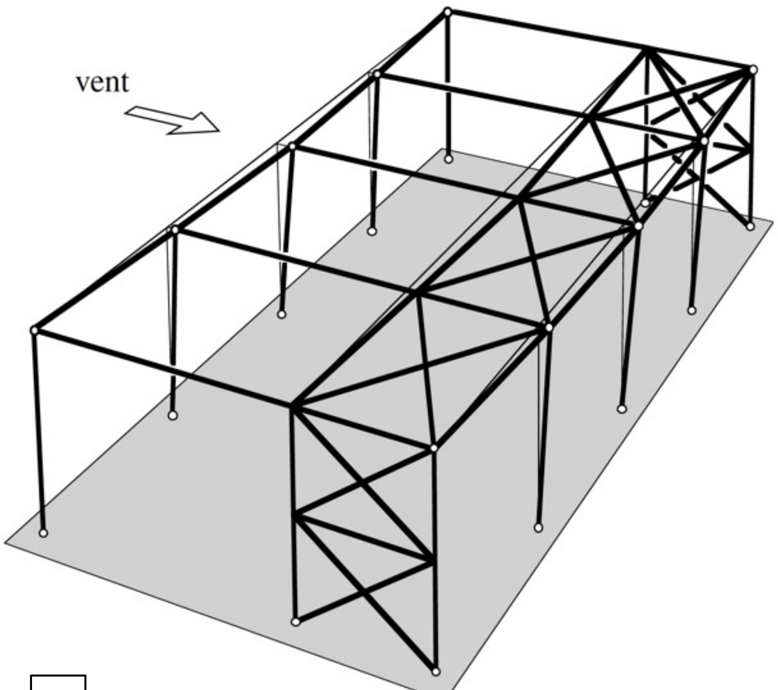
Topics

- Design of indust. halls and buildings — TGC 11, chap. 1-5
  - Stabilisation, design of load-bearing systems, beams — Chaps. 3&4
  - Load path to foundations — Chaps. 6&13
- Building components in composite steel and concrete
  - composite beams, composite slabs, shear connection (total, partial) — Chap. 10
  - Joints: beam-column, frame joints, column bases — Chap. 12
  - Composite columns — Chap. 13

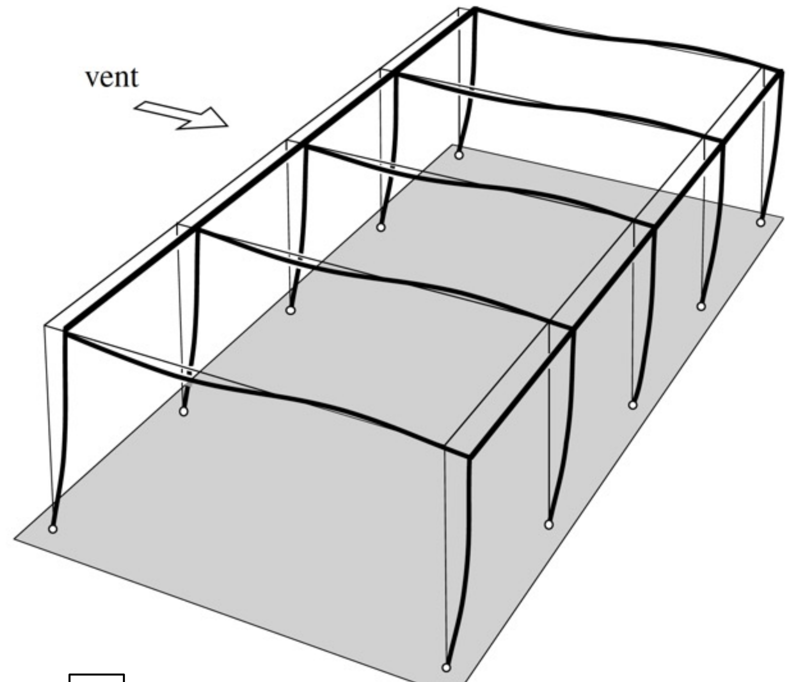
Reminder: bracing panels/walls (TGC 11, fig. 3.18)



Reminder: stabilisation of hinged VS rigid frames (Fig 3.22)



a Frames with 4 hinges
(bracings for stability)



b Rigid frames
(stability thru frame effect)

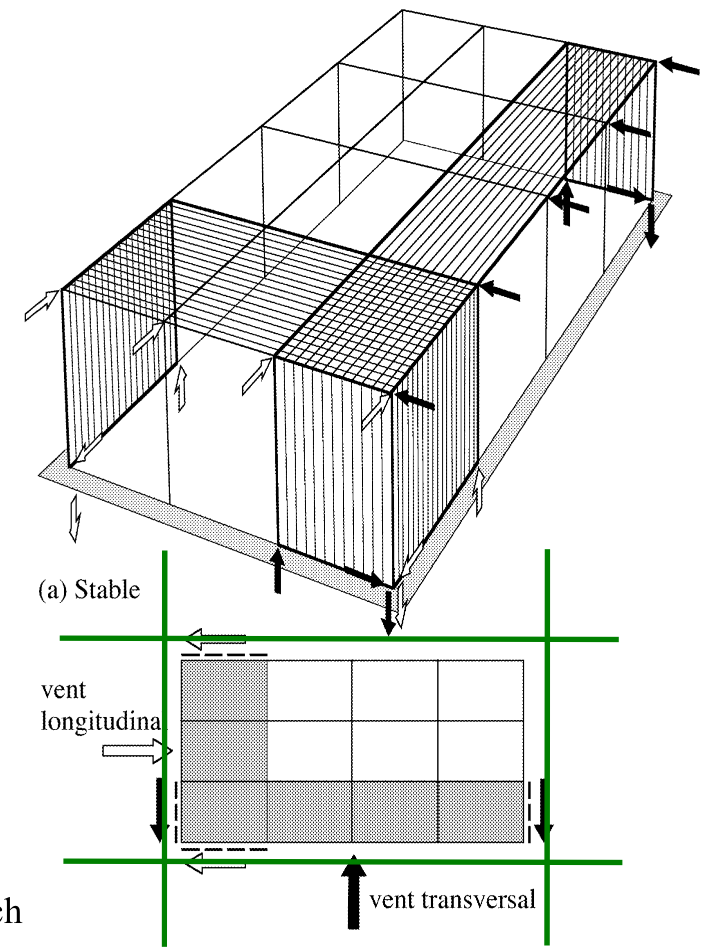
1) Under wind loads, which statements are correct when comparing these 2 systems?

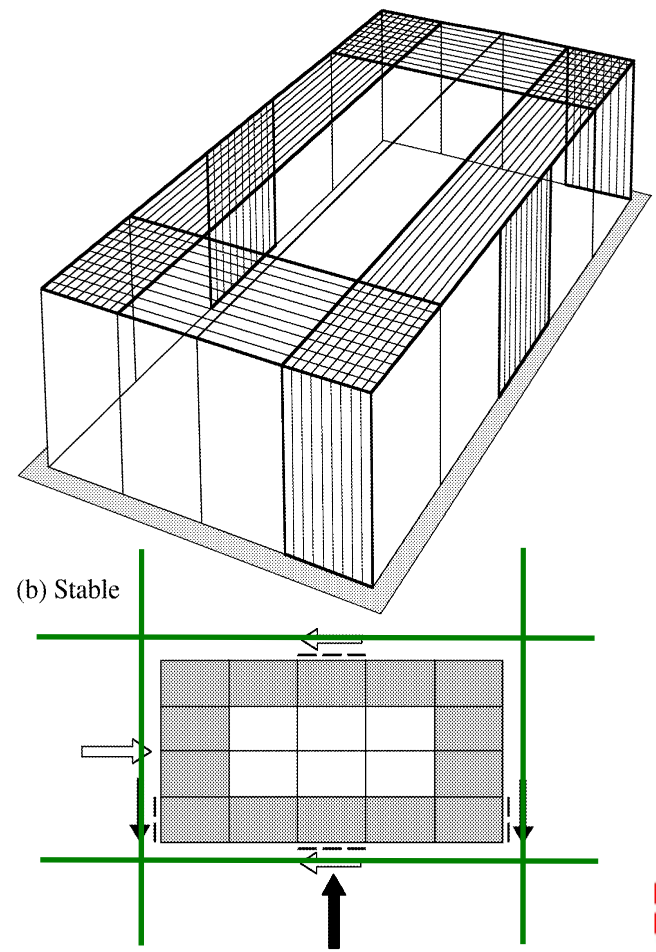
A. System **a** is more rigid than system **b**
B. System **b** is lighter and more economical
C. In the case of a very long hall, system **b** is advantageous
D. The system **a** makes it easier to extend the length of the hall

Reminder: bracing layout (TGC 11, fig. 3.19)

To balance a force acting in any direction :

1. you need at least 3 lines of force,
2. the lines of action of the forces must not intersect at a point,
3. the lines of action of the forces must not be all parallel.





Reminder: bracing layout (TGC 11, fig. 3.19)

Bracing has 3 functions:

1. Transmit horizontal forces,
2. Limit distortion,
3. Help stabilise elements (beams to prevent tipping, LTB, columns to prevent buckling)

} Global stability (functions 1 and 2)

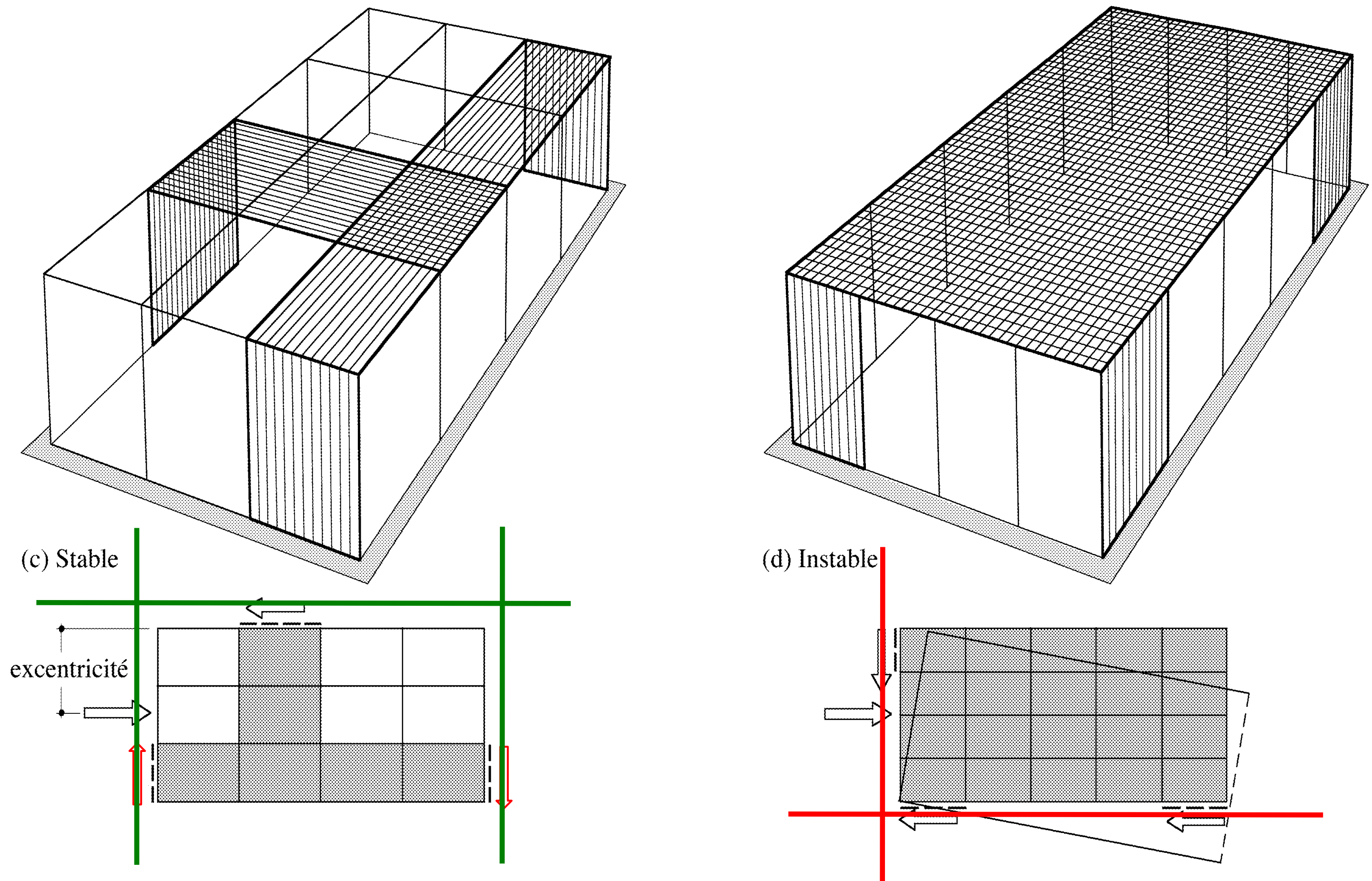
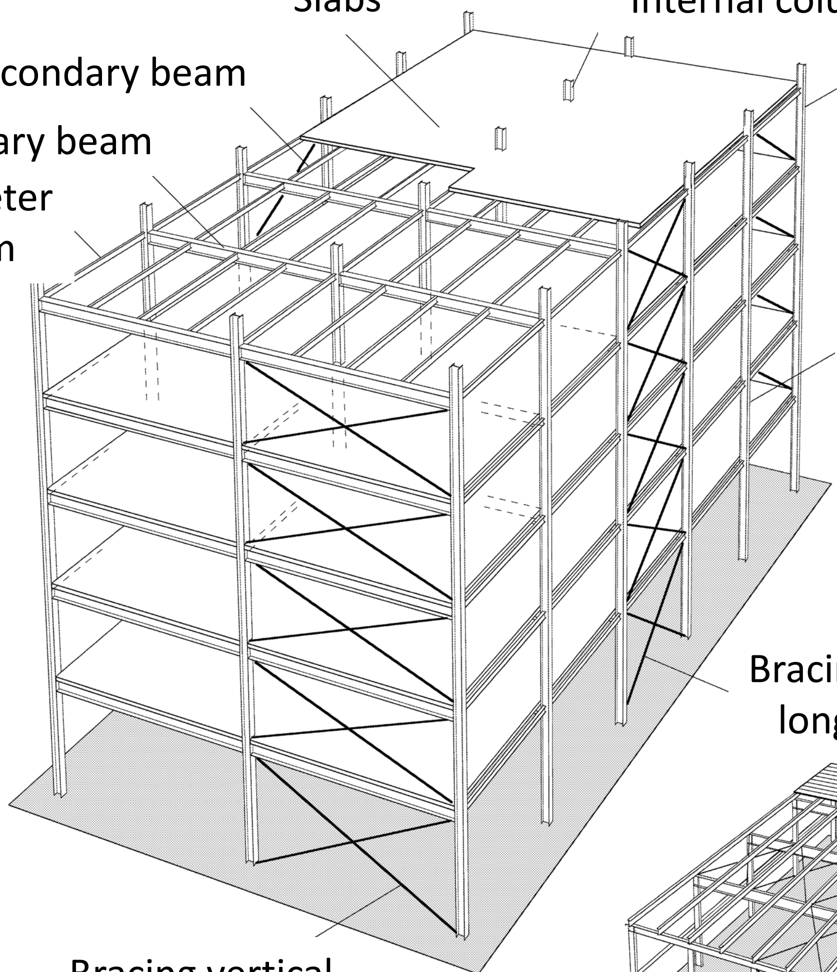
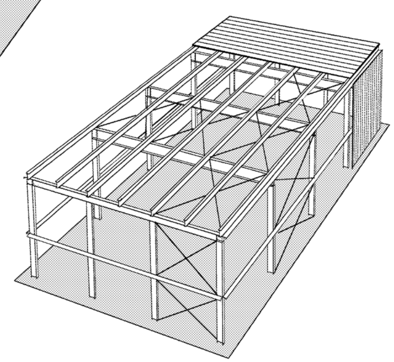


Fig. 4.1: Frame of multi-storey building



Vocabulary:
Primary beam – Sommier
Secondary beam – Solive
Purlin – Panne
Lattice girder – Poutre treillis
Slab – Dalle
Bracing – Contreventement (CV)



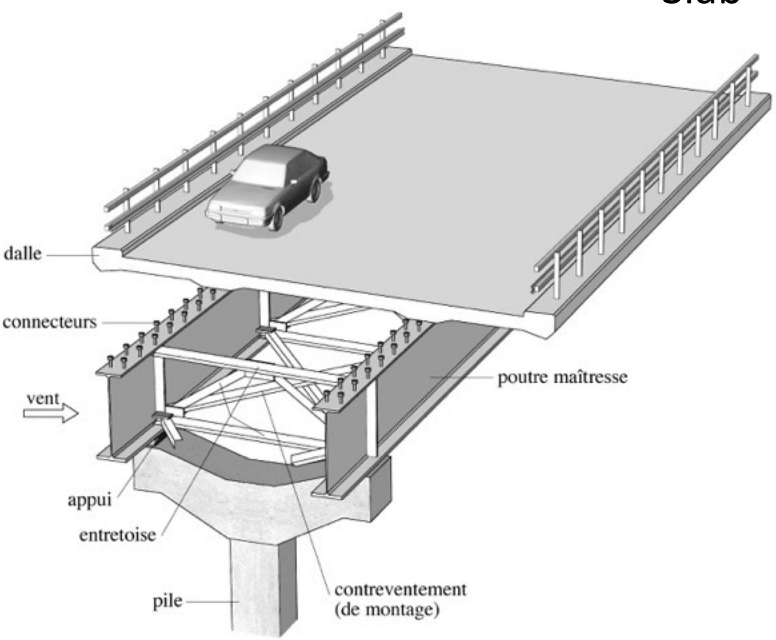
Differences with indust. buildings

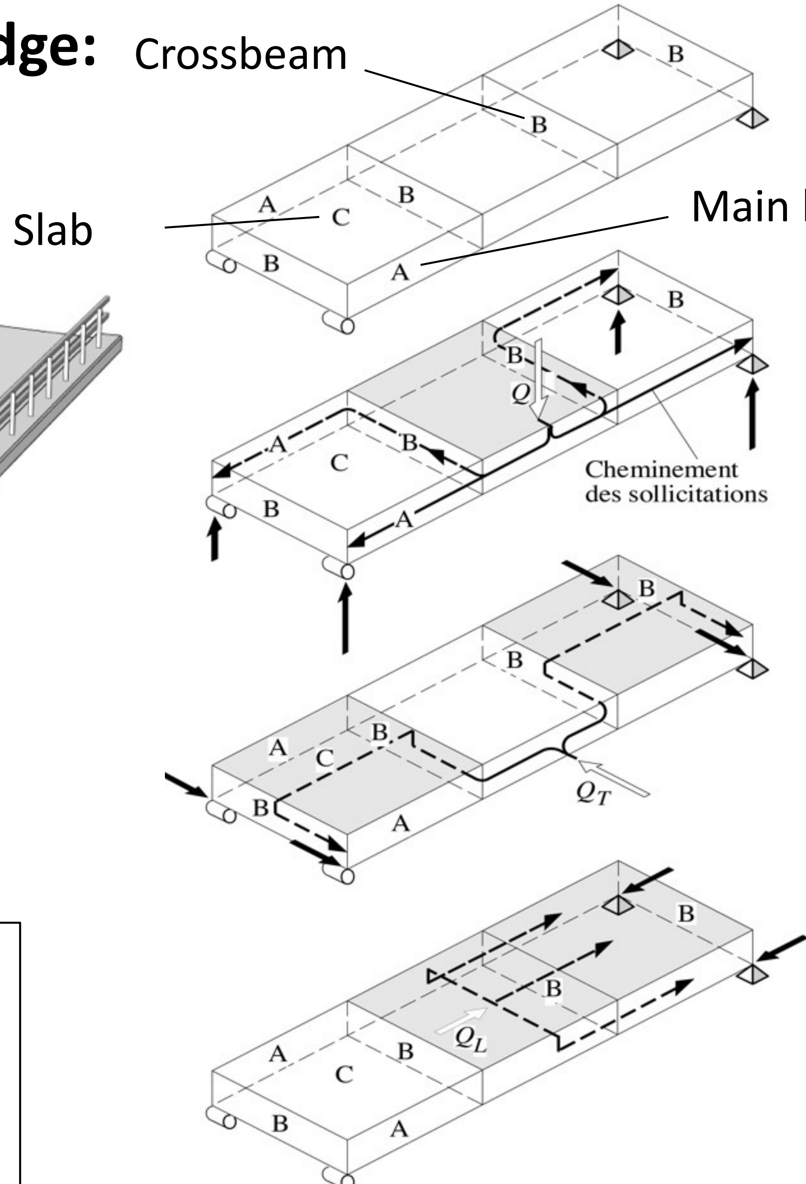
- Several transverse bays
- Horizontal CV = Slabs

Breakdown into planes in 3 directions

Bridge: breakdown of structure into planes, loads paths

Example composite bridge:
(TGC 12 Fig. 5.3)





(a) Structure composed of planes

(b) Vertical load path

(c) Path of an horizontal transverse load

(d) Path of an horizontal longitudinal load

Vocabulary:
Main beam – Poutre maîtresse
Crossbeam – Entretoise
Bearing – Appui
Pier – Pile

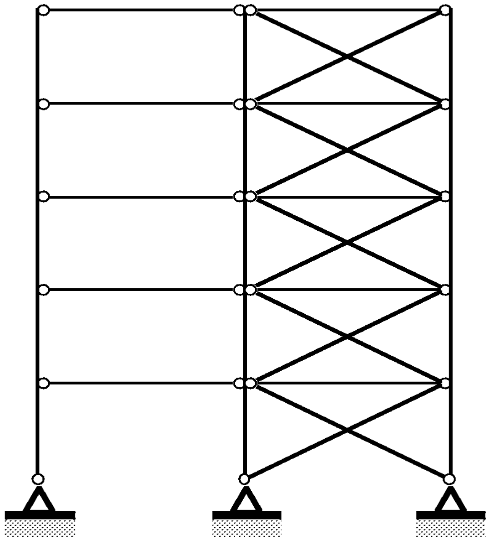
The most common solution:

- two systems to resist the different load types applied to the structural system
- a semi-rigid or articulated framing system, which only resists vertical actions
- steel bracing or concrete walls/cores to resist horizontal actions.

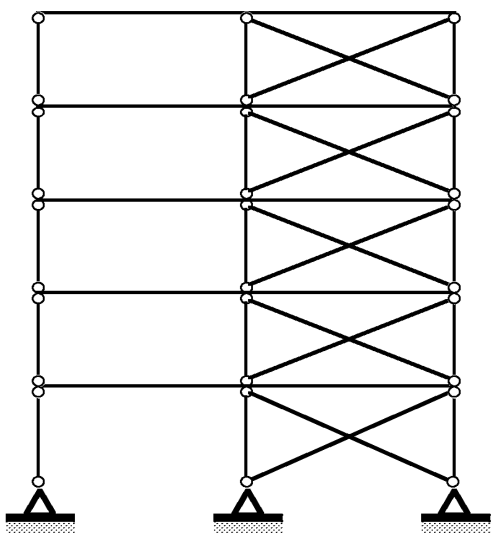
Standard building main load-bearing systems

- **Articulated frames** figs. 4.1 - 4.2
- **Frames with central core** figs. 4.3 - 4.4
- **Structures with rigid storeys (stiffening belt or roof with suspended floors)** figs. 4.5 - 4.7
- **Rigid frame structures** figs. 4.8 - 4.10
- Cost summaries, pre-sizing
- **Tall buildings. High-rise buildings, outer tube** figs. 4.12 - 4.13

Fig. 4.2: Articulated (and braced) frames



(b) Poteaux continus



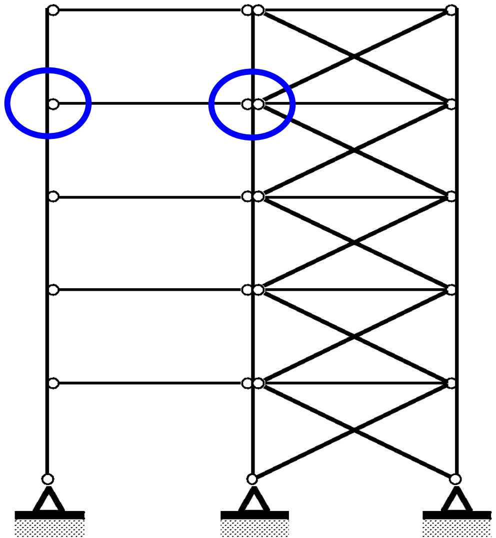
(c) Sommiers continus

- ✓ Simple design and execution
- ✓ Quick assembly (to be stabilised at each floor)
- ✓ System not very sensitive to tolerances
- ✓ Continuous columns. N

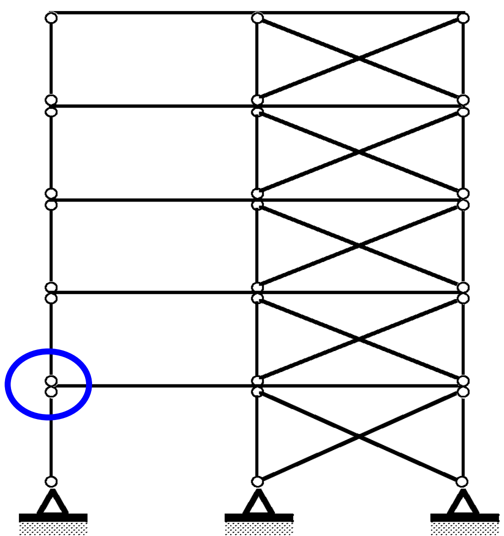
- x High and heavy beams
- x In case of interrupted columns, what about transfer of significant vertical forces?
- x Not very robust
- x CV strong presence

Joints ? Figs. 4.41, 4.43 and 4.44

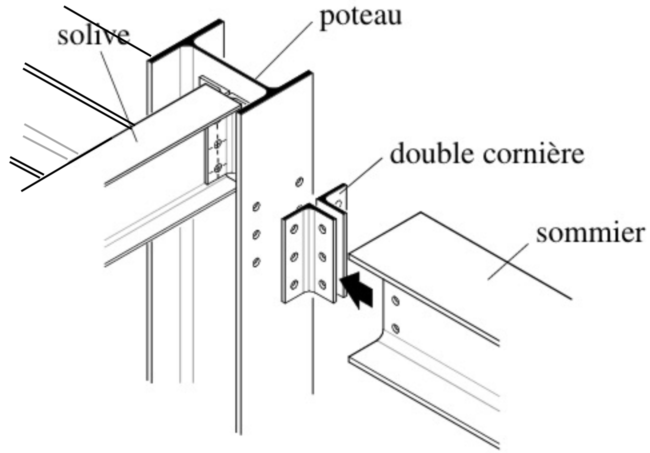
Fig. 4.2: Articulated (and braced) frames. Ex. of joints



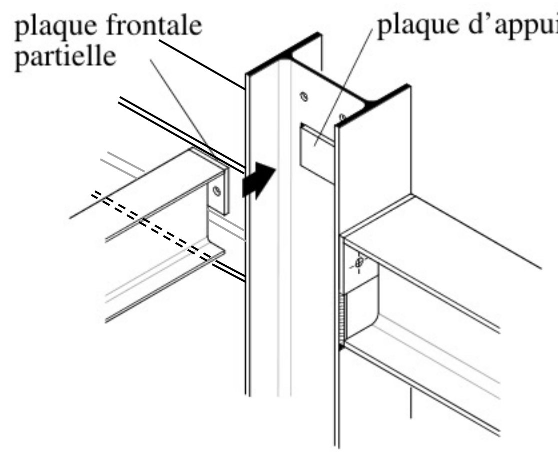
(b) Poteaux continus



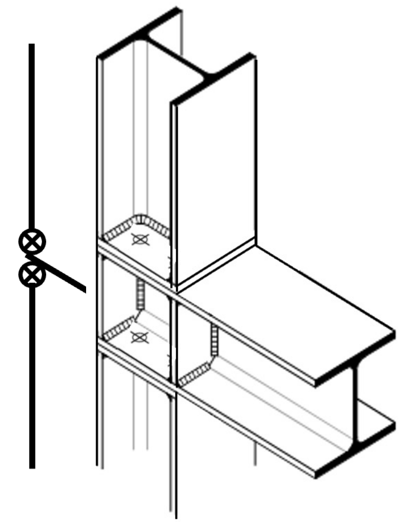
(c) Sommiers continus



Vocabulary:
Double angle – Double cornière
Endplate – Plaque frontale
Seat plate – Plaque d'appui

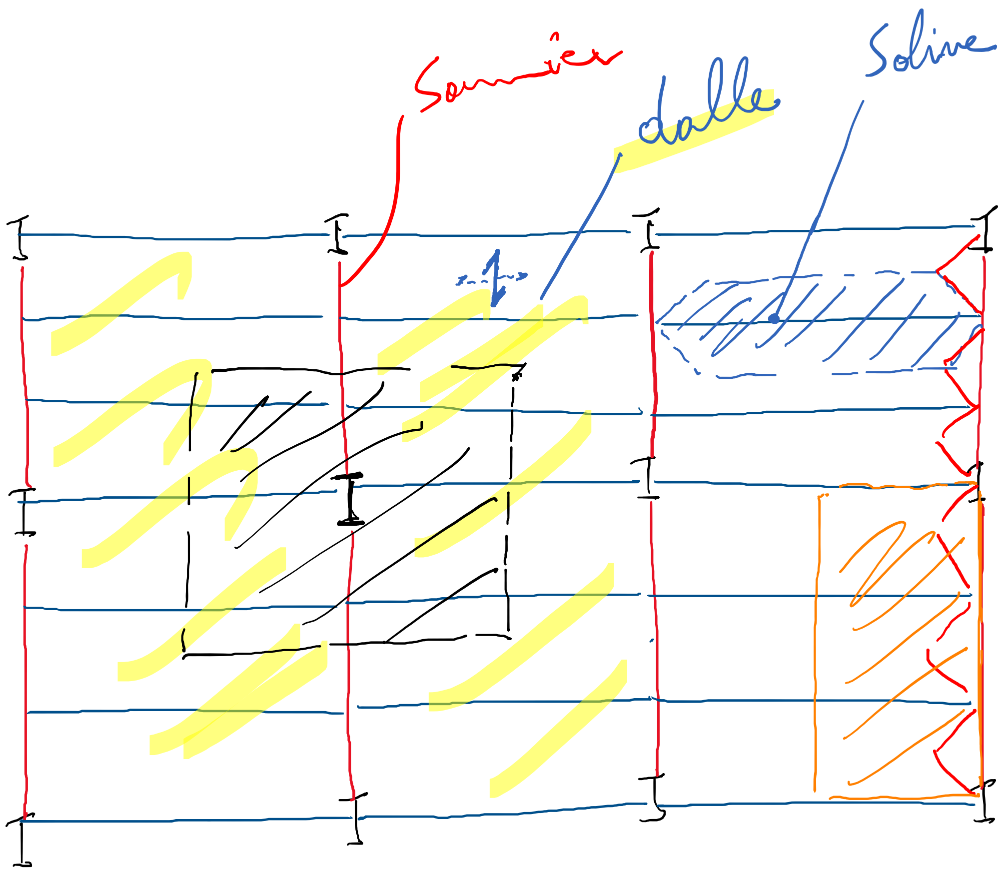


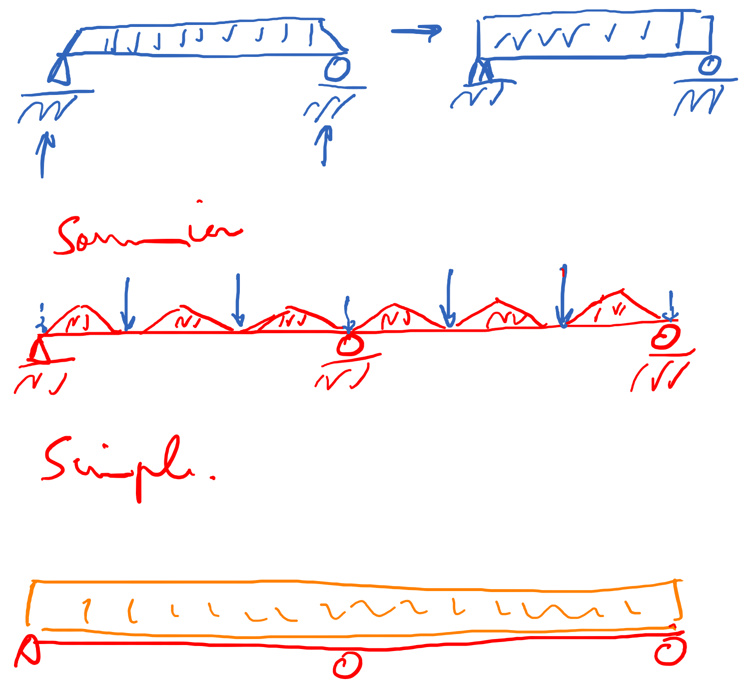
O Hinges to
⊗ semi-rigid joints



Flooring, distribution for vertical load path to fundation (influence surfaces)

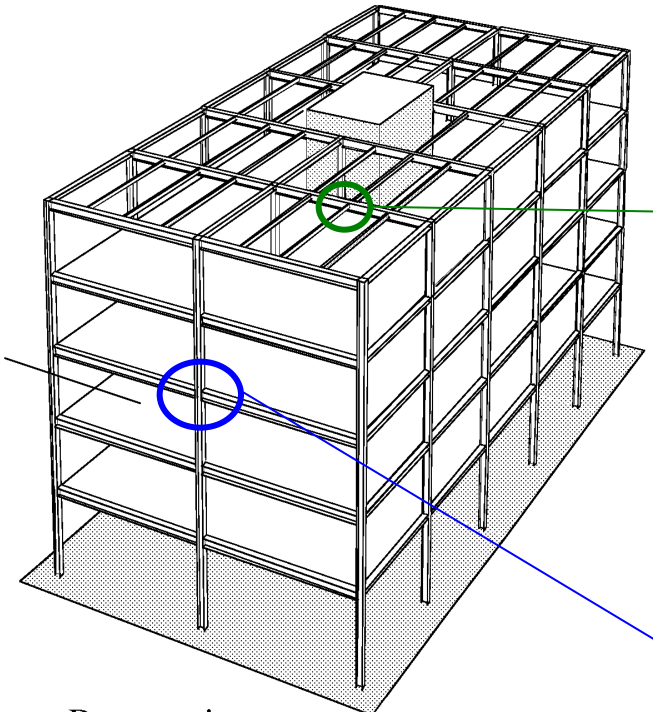
Plan view of a floor:



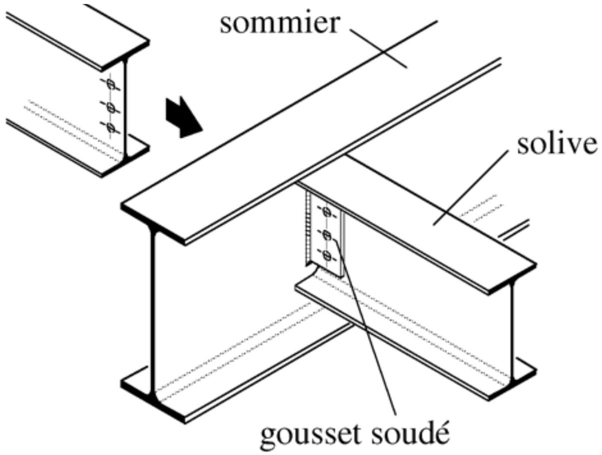


ex. 6.9.3 TGC 11

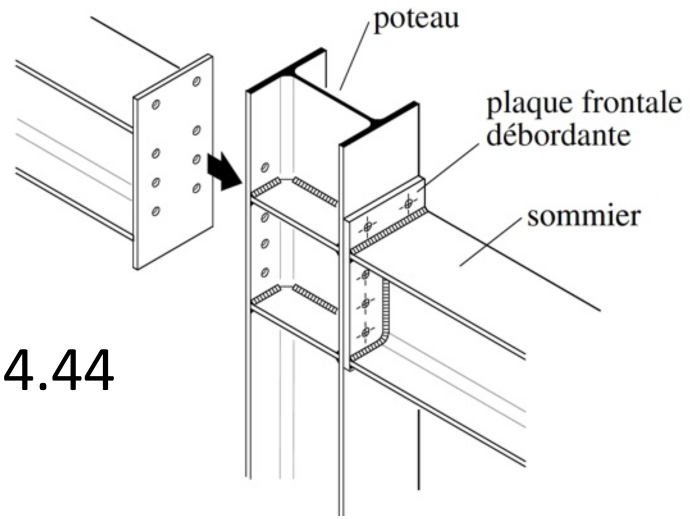
Other examples of joints between elements



Articulated secondary beams (with bolted fins)



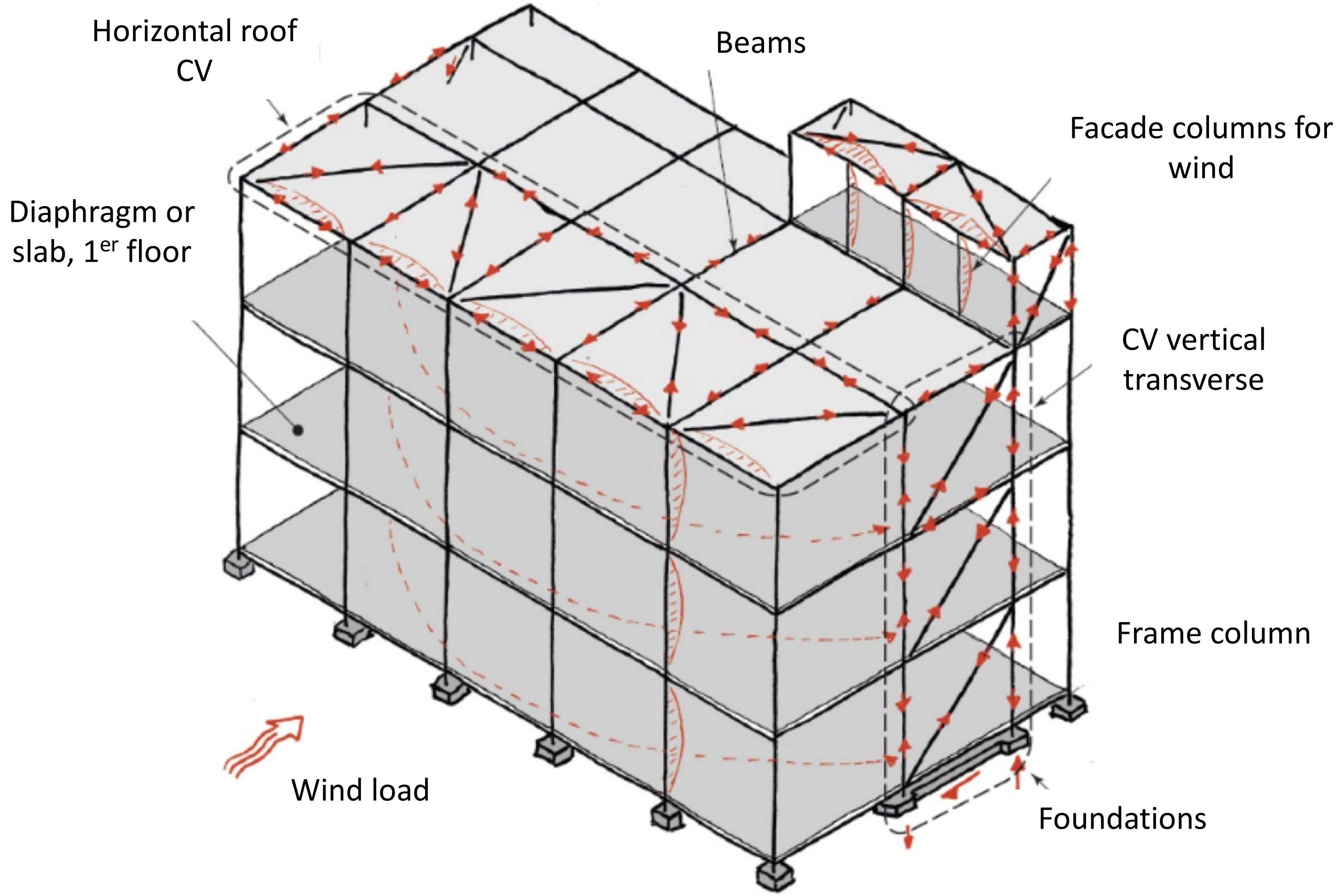
Rigid column-beam joint (second. beam not shown)



Joints ?

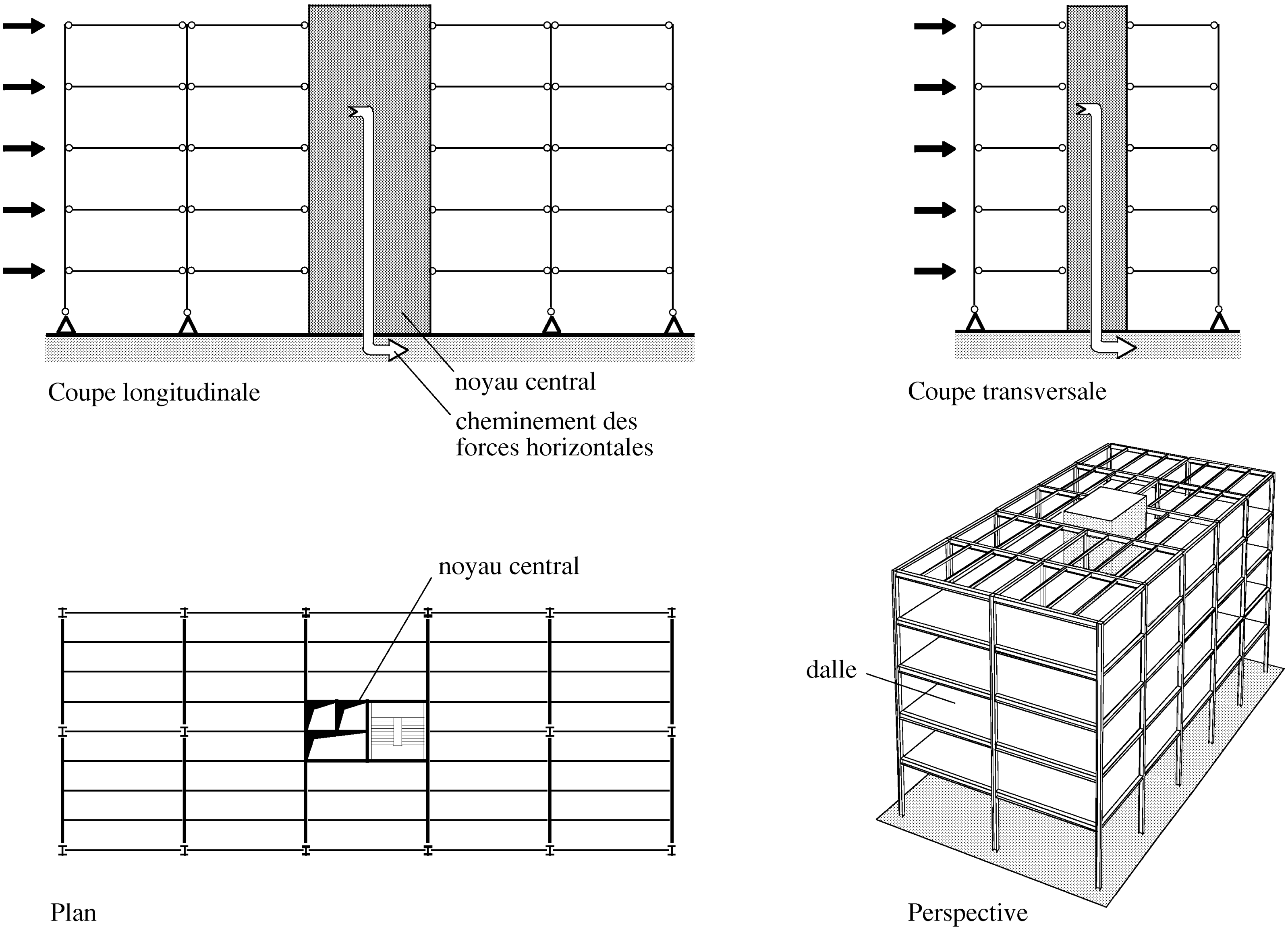
Hinged, figs 4.41, 4.43 and 4.44
Rigid, figs. 4.42 and 4.45

Building: transmission of horizontal forces from façade to foundation



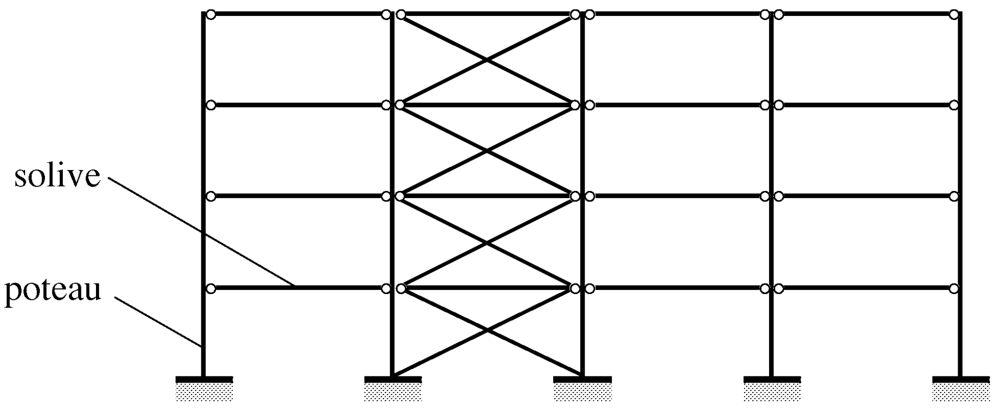
Source: IStructE guidance, www.istructe.org/

2) Fig. 4.3: (Articulated) frames with central core

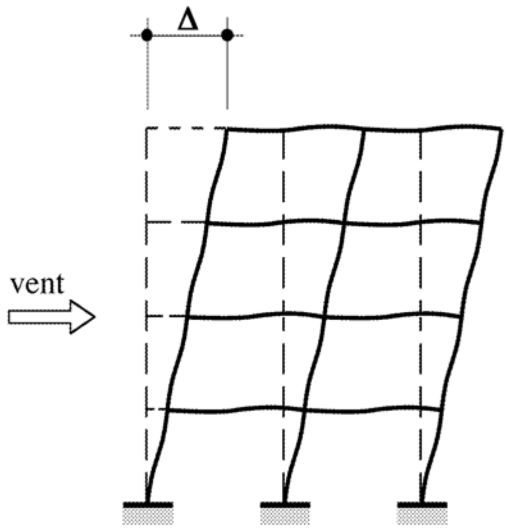


Joints between steel & concrete core ? Figs. 4.48 to 4.52

Fig. 4.8: Rigid (or combined) frame construction



Coupe longitudinale

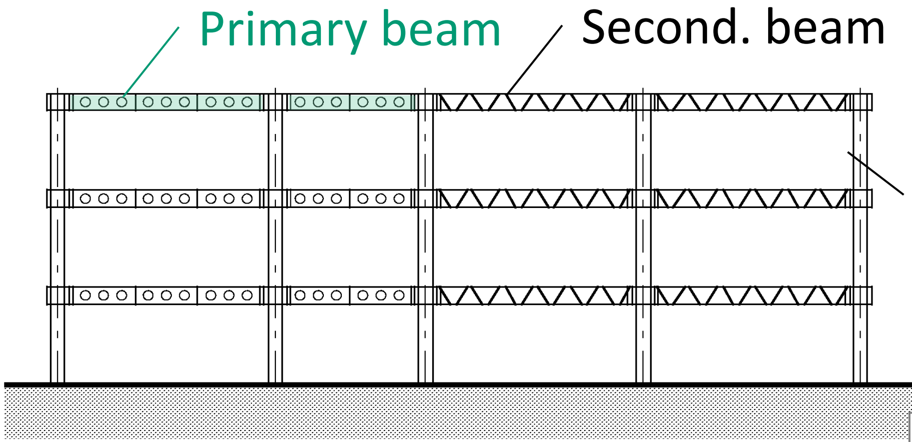


Coupe transversale

- ✓ Statically indeterminate, reduced element dim., robust system
- ✓ Larger usable area and flexibility (no core anymore)

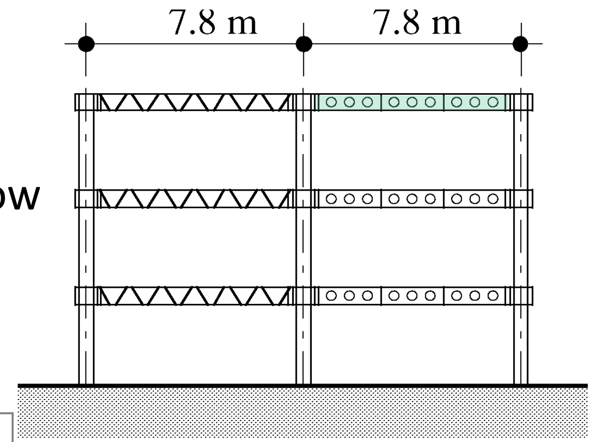
- x Larger horizontal displacements (ok for buildings ≤ 5 storeys)
- x Complicated rigid joints
- x More sensitive to manufacturing tolerances
- x Columns more sensitive to 2ème order, more bending
- x Generally more expensive $$, especially if fully rigid

Fig 4.9: Rigid frame structures, CROCS building example

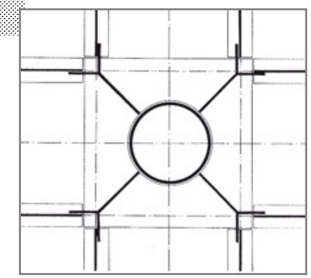


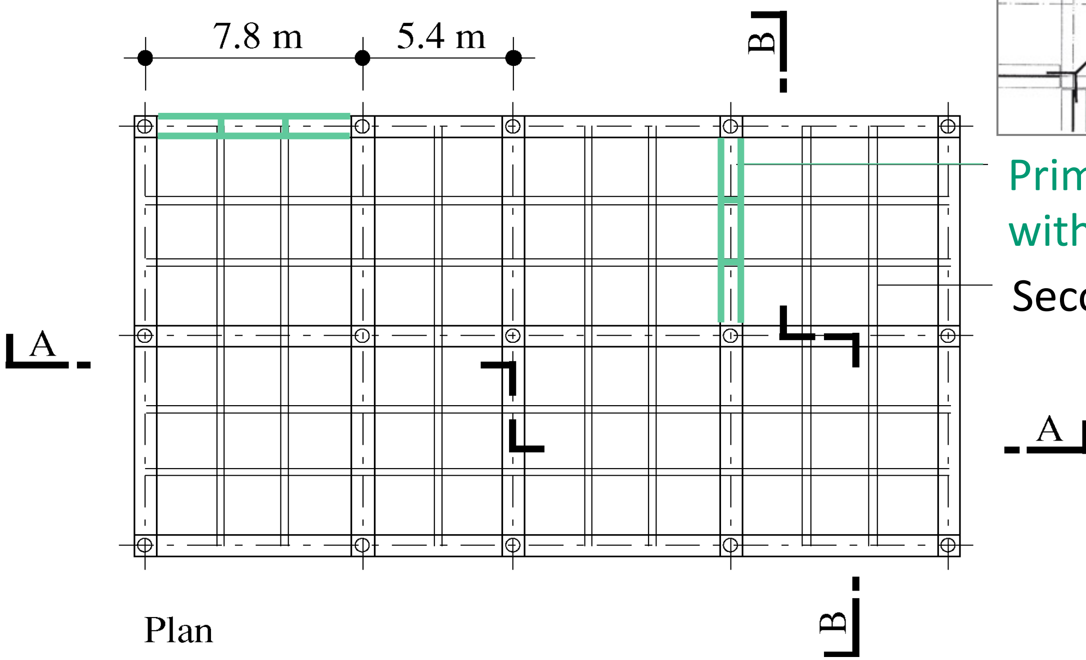
Coupe longitudinale A-A

Continous columns (circular hollow tubes), with mushrooms



Coupe transversale B-B





Plan

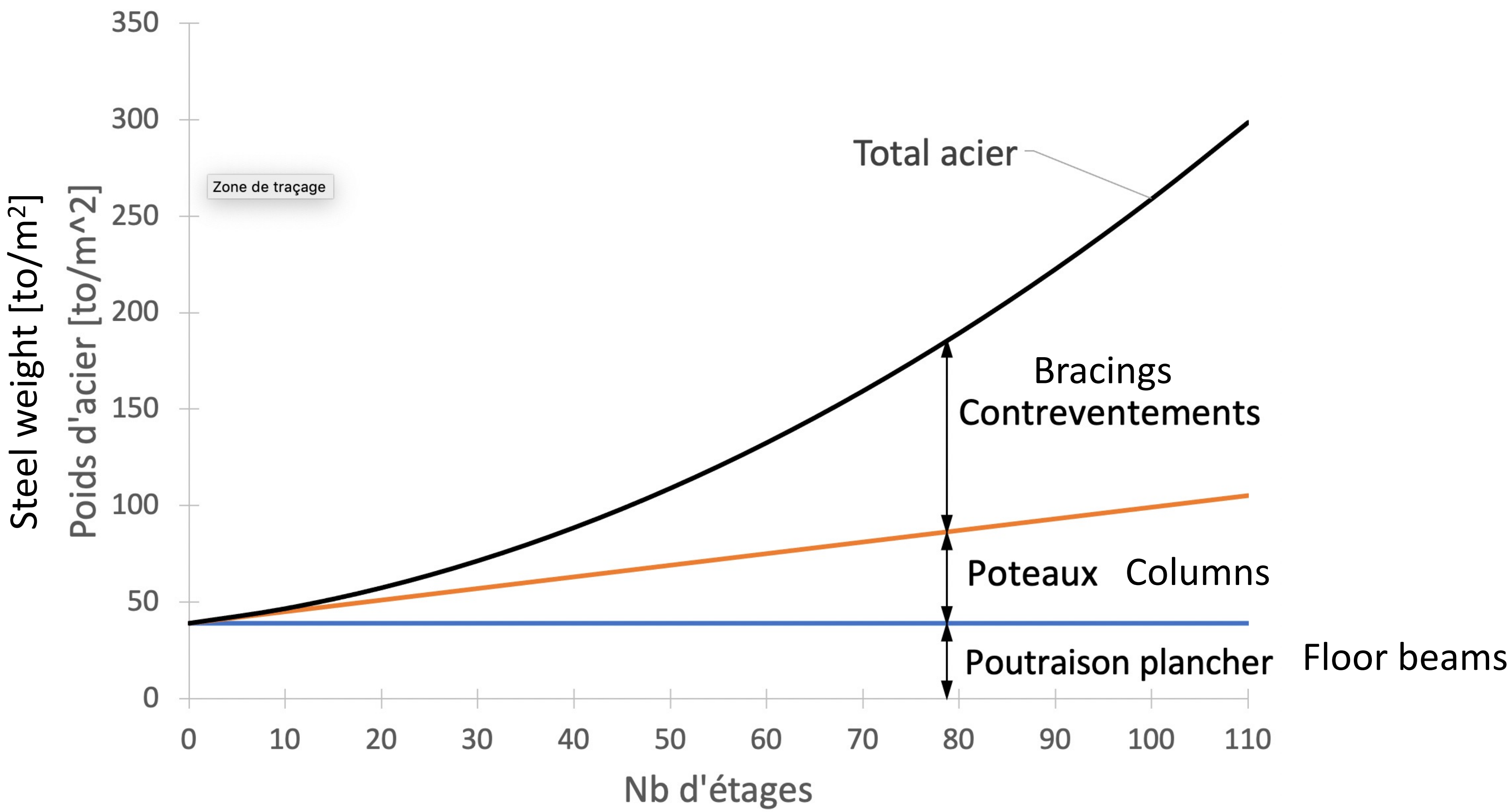
Primary beam combine 2 castellated I-beams with links where 2nd beams connect

Secondary beam, lattice girder

CROCS: centre de rationalisation et d'organisation scolaires. Number of schools built in the 1970s.

+ Speed of execution, many configurations
- In the end, flexibility yes, but expensive transformations
- Waterproofing and insulation problems

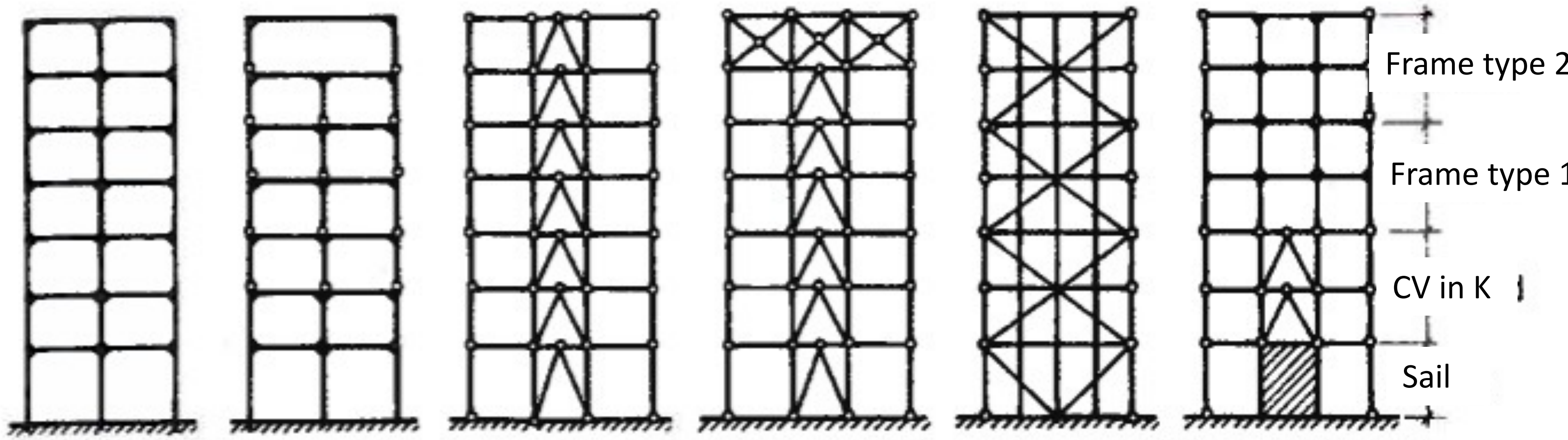
The challenge of high-rise buildings



- ✓ Wind loads are becoming increasingly important
- ✓ Involve all elements in horizontal force recovery

Summary of load-bearing systems for multi-storey buildings

Nb floors: ≤ 30 | ≤ 35 | ≤ 45 | up to 85 (100 or more, multitube)

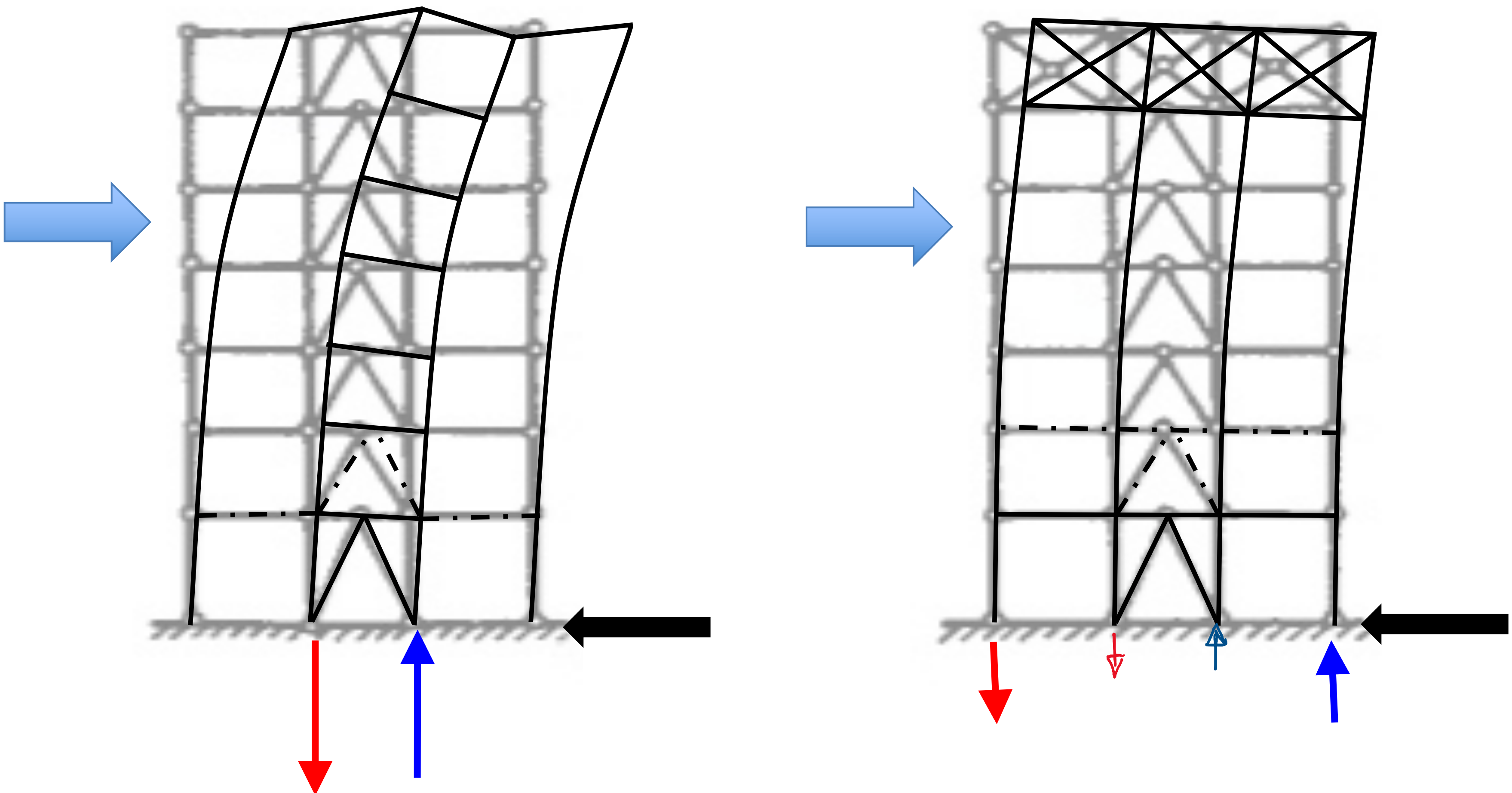


Regular, frames rigid	Varies according to floors: - Rigid frames - Articulated - Top floor	With central steel core (and hinged frames)	Plus a stiffening roof floor (cap)	Peripherical Tube (shown with X-bracings)	Combination of systems

Source: Extract from the book Industriestahlbauwerke

+ Particular, hybrid systems: some examples in TGC 11 § 4.5

Taller buildings: e.g. add a cap or stiffening belts



- ✓ Limiting horizontal movements
- ✓ Participation of external columns to horizontal loads transfert
- ✓ Service/mechanical floor(s) (also an inconvenient, add height)

Breakdown of costs for a typical multi-storey office building

- Foundations 5 to 15%
- Superstructure and floors 10 to 12%
- Façades and roof 15 to 25%
- Services (mechanical, electrical, lifts) 20-25%
- CVSE (water and sanitation) 5 to 8%
- finishing work, partitions and adjustments 10 to 20%
- Site management (preparation, excavations) 12 to 18%

Source: www.steelconstruction.info

Pre-sizing of elements (buildings)

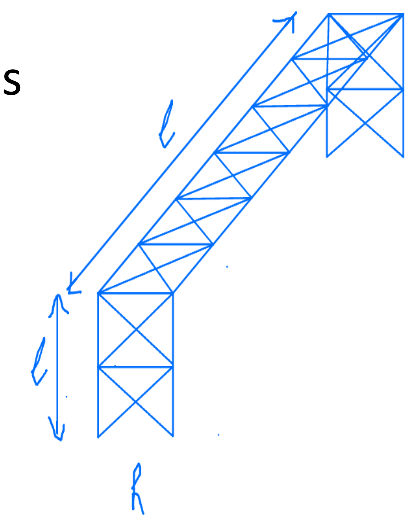
From experience, from TGC 11 § 3.2.3, § 5.3.3 and Appendix chap. 6: rules of thumb for pre-sizing elements

Spans and spacings:

- Compromise between adaptability (large spans) and economy (small spans)
- Frame spans: typically between 6 and 15 m (standard hot-rolled sections), but possible up to 30 m
- Main beam spacing (= 2nd beam spans): typically between 6 and 9 m, but possible up to 12 to 15 m (lattice girders)
- 2nd beam/purlin spans: typically between 6 and 9 m
- Purlin spacing: from 1 m (fibre cement corrugated roofing sheets without substructure) to 4 m (profiled steel sheets or decking).

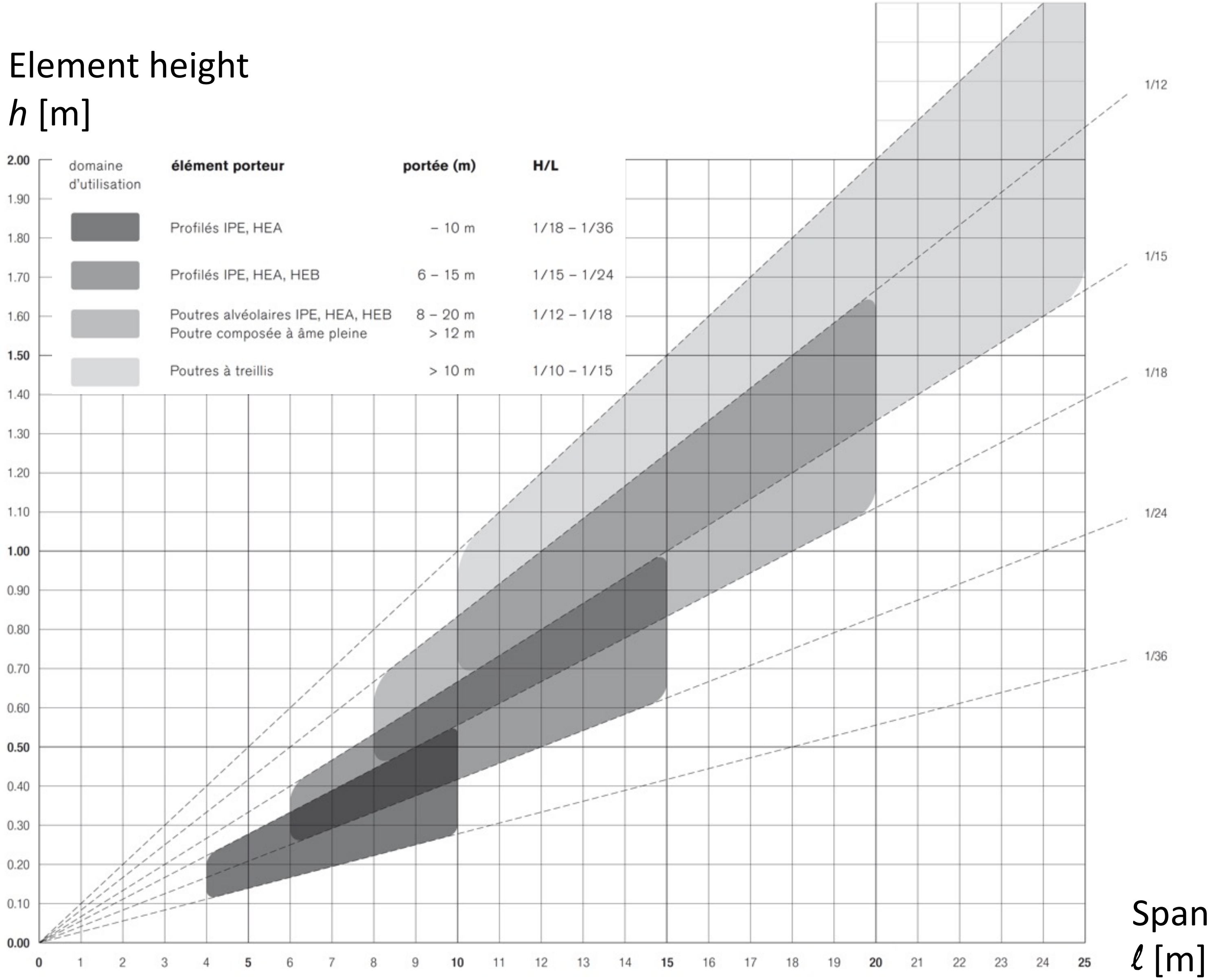
Slenderness:

- Composite slab with profiled steel decking: $d \cong \ell/32$ (d: static height)
- Hot-rolled purlin: $h \cong \ell/30$ (h: static height)
- Hot-rolled main beam: $h \cong l/20$ to $l/25$
- Hot-rolled section column: HE section with slenderness $\lambda_k \leq 50$
- Bracing, equiv. to lattice with low slenderness, if possible: $h \cong \ell/5$ to $h \cong l/8$



EPFL

Pre-dimensioning of steel beams



(Source: M. Dietrich: Ecole d'ingénieurs Burgdorf, 1990)

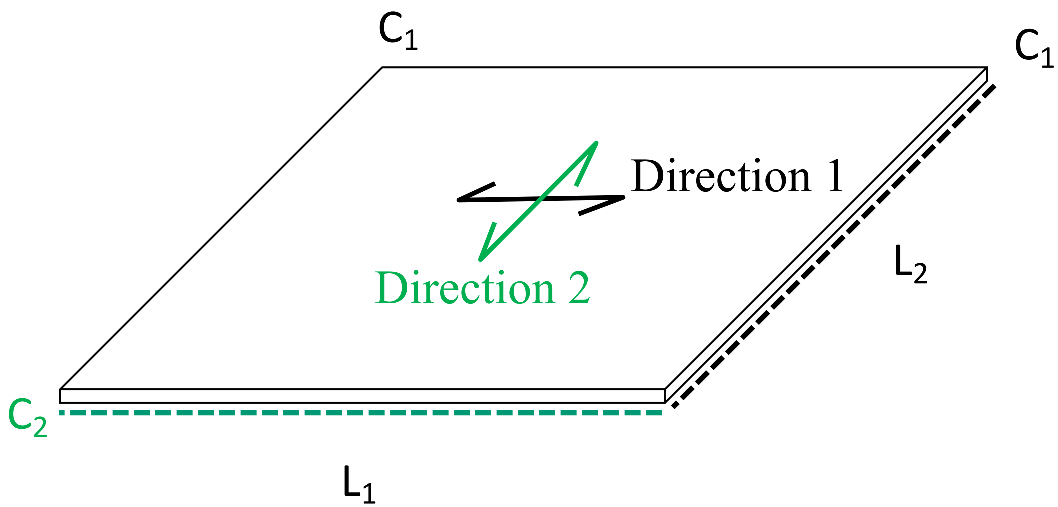
EPFL

Slabs: Summary of the strip method

L/L_{12}	C/C_{21}				
	0,2	0,4	**1,0**	2,5	5,0
1,0	0,17	0,29	**0,5**	0,71	0,83
1,2	0,29	0,45	**0,67**	0,84	0,91
1,5	0,5	0,67	**0,84**	0,93	0,96
2,0	0,76	0,86	**0,94**	0,98	0,99

Same supp. conditions, the shorter (dir. 2) takes 84%

C_1 , C_2 : stiffness factors for support lines (e.g. 1/384 simple support, 5/384 rigidely fixed)

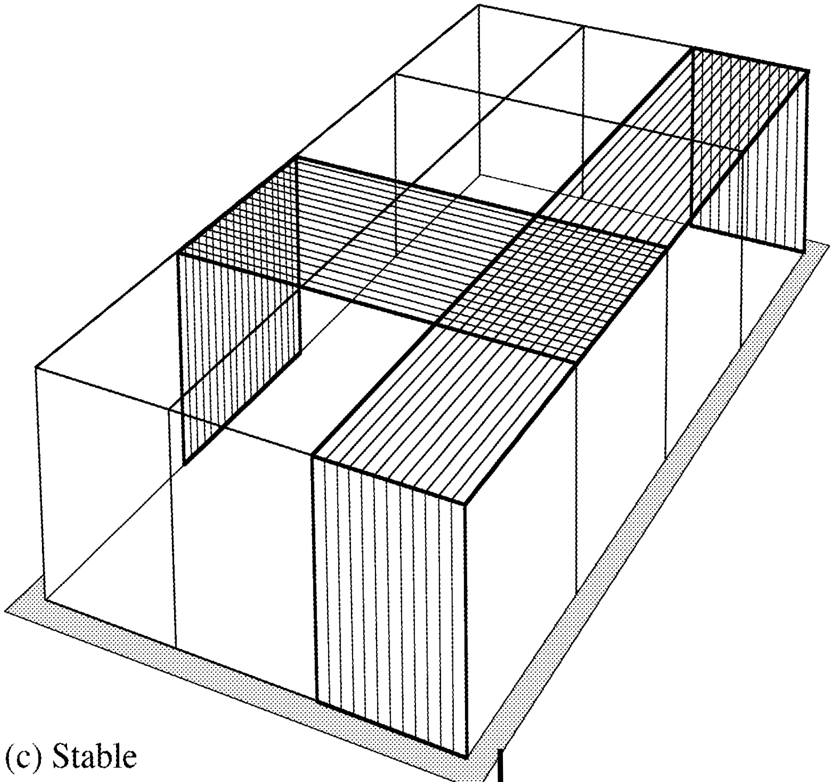


APPENDICES

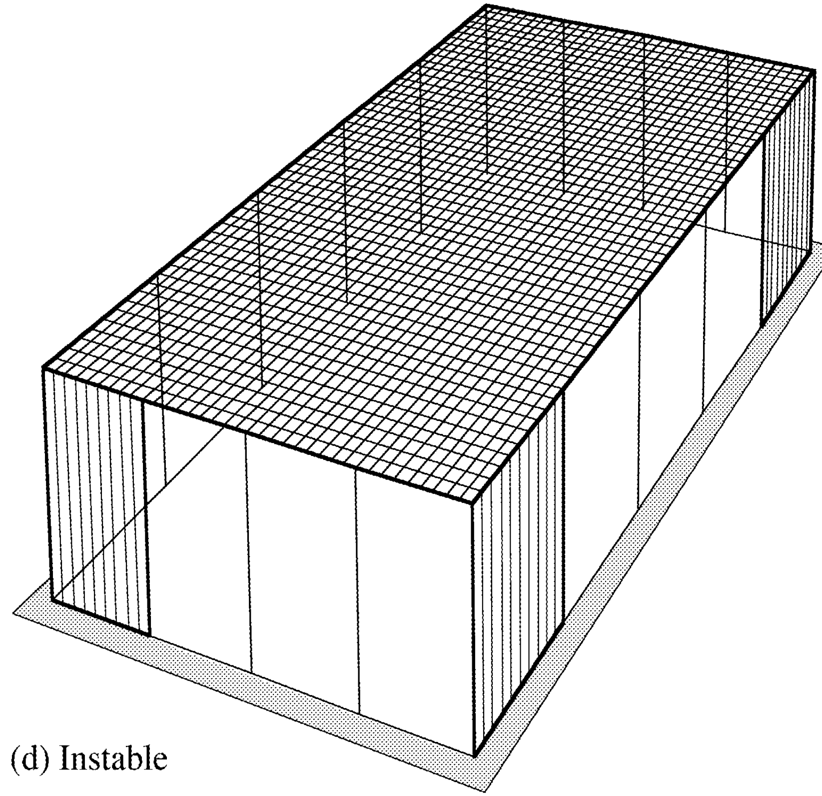
Recall of stabilization

Examples of buildings and towers with tube structures

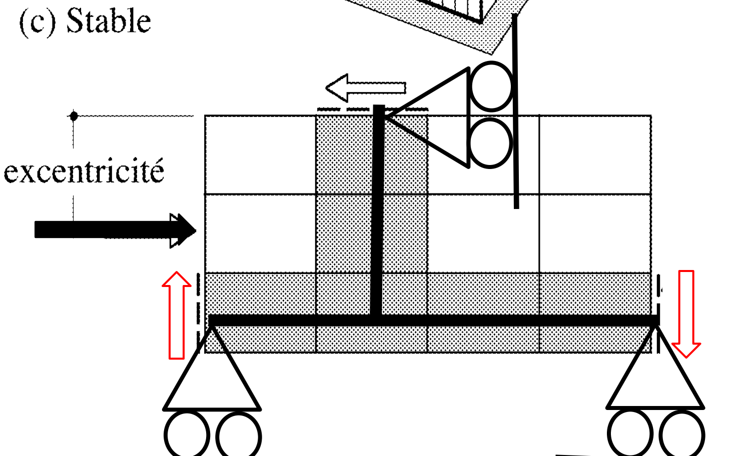
Reminder: bracing arrangement (TGC 11, fig. 3.19)

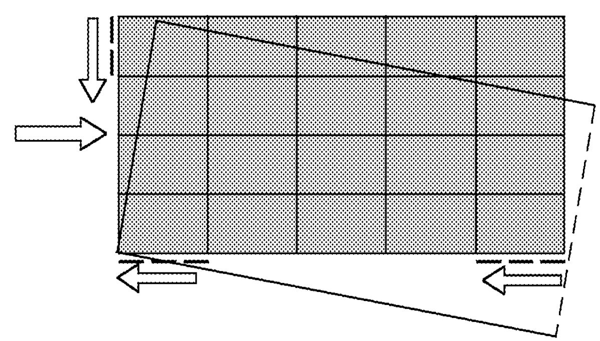


(c) Stable

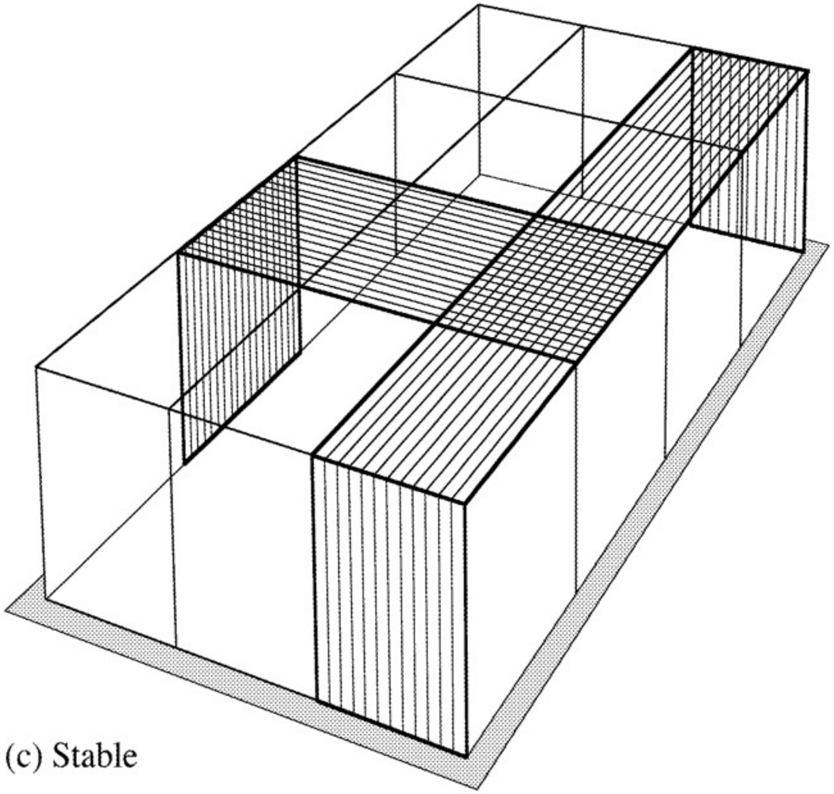


(d) Instable

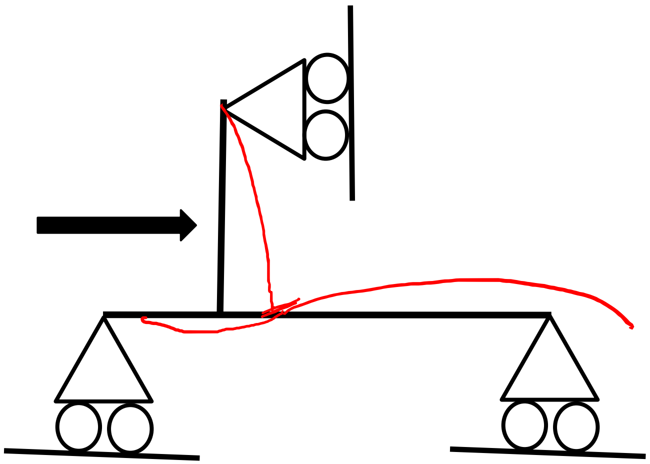




Reminder: bracing layout (TGC 11, fig. 3.19)

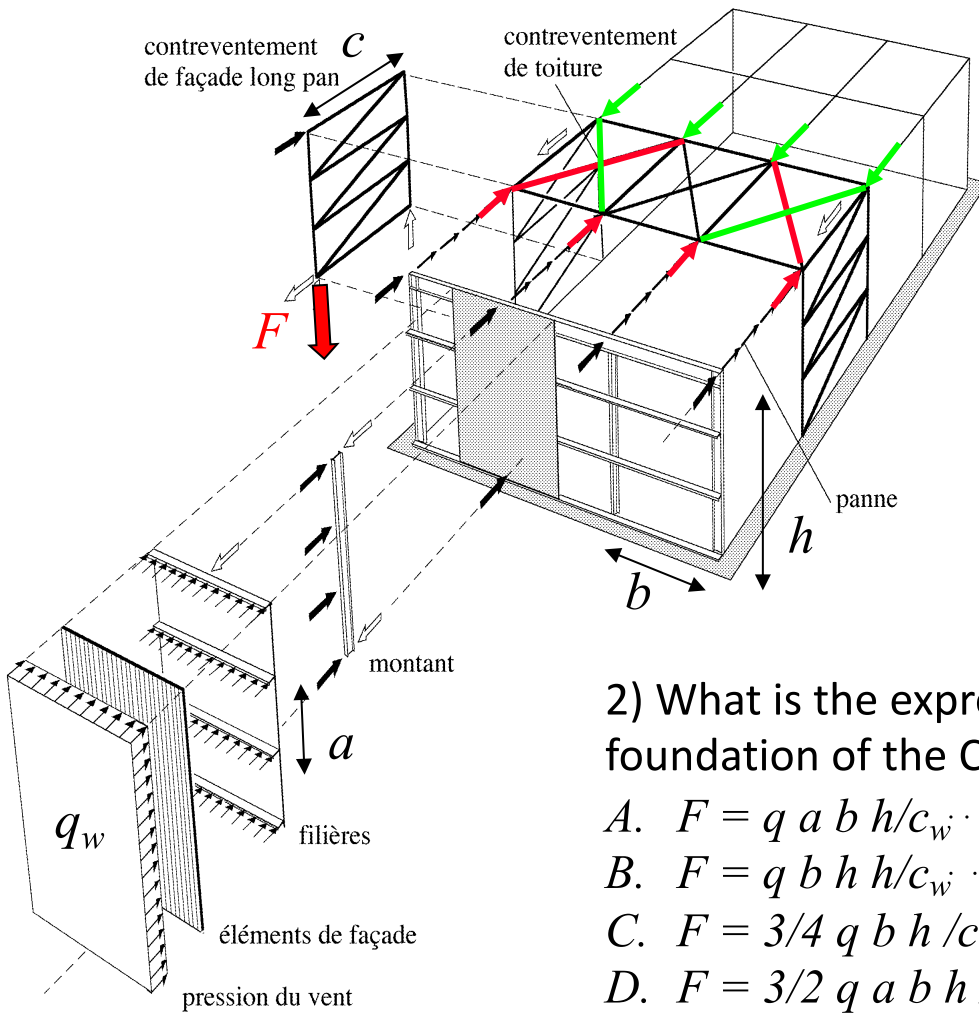


(c) Stable



Reminder: horizontal force path (TGC 11, fig. 3.20)

Only consider bars in tension

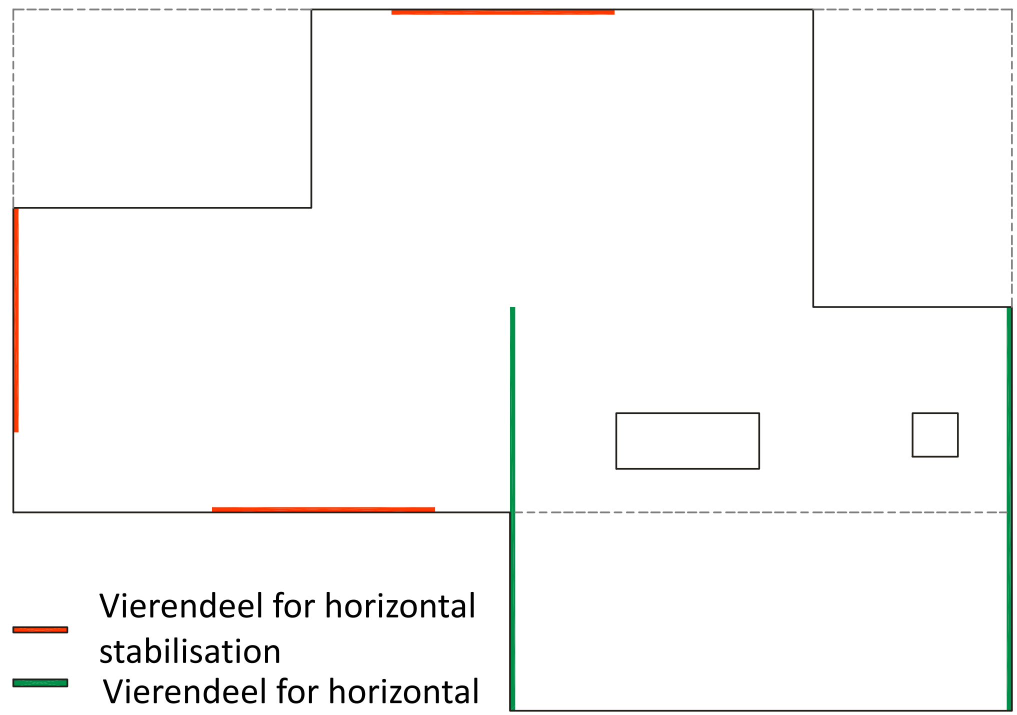


2) What is the expression of force in the foundation of the CV?

A. $F = q\ a\ b\ h/c_w$ ..
B. $F = q\ b\ h\ h/c_w$ ..
C. $F = 3/4\ q\ b\ h\ /c_w$ .2
D. $F = 3/2\ q\ a\ b\ h\ /c_w$ . .2

Rigid frame structures, example Maladière school, Ne

Horizontal stability of the structure, plan view

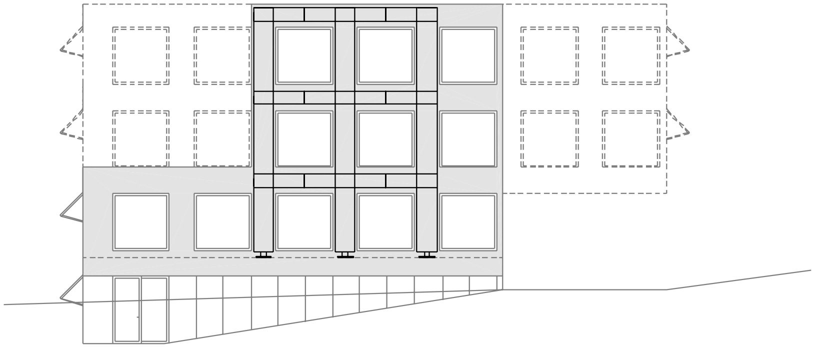


Vierendeel for horizontal stabilisation

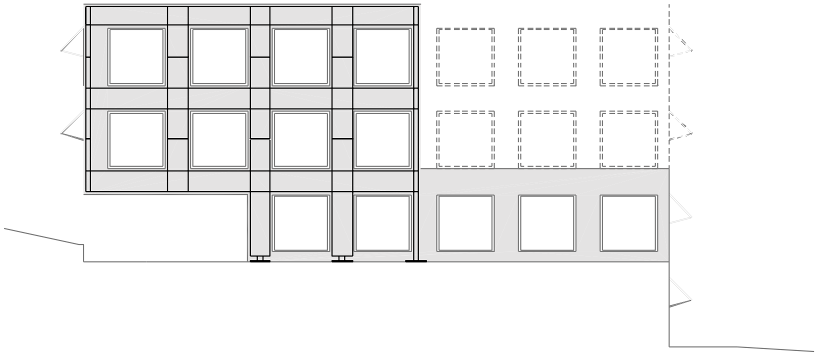
Vierendeel for horizontal stabilisation and overhang recovery

Sources: arch. Andrea Bassi / ing. Guscetti & Tournier, 2006

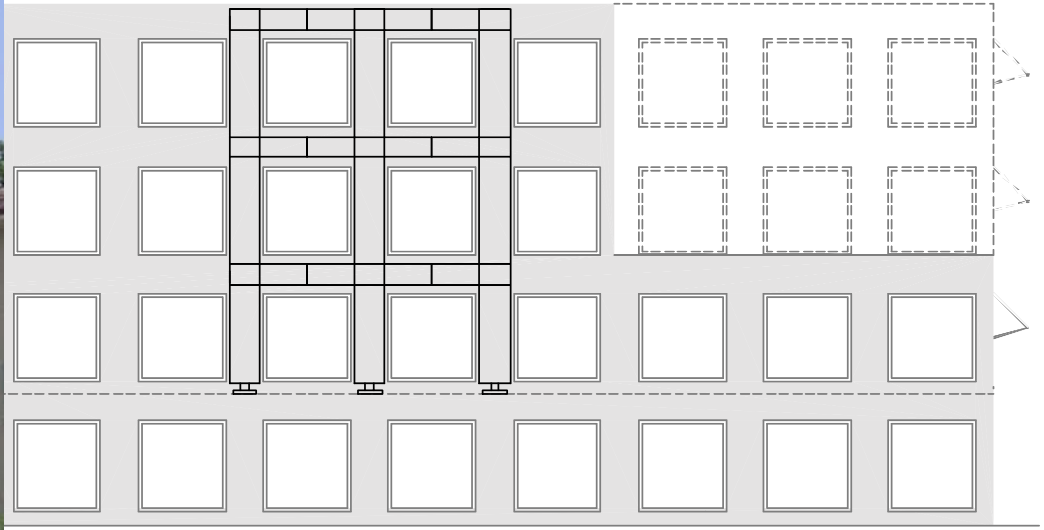
Rigid frame structures, example Maladière school, Ne



South façade

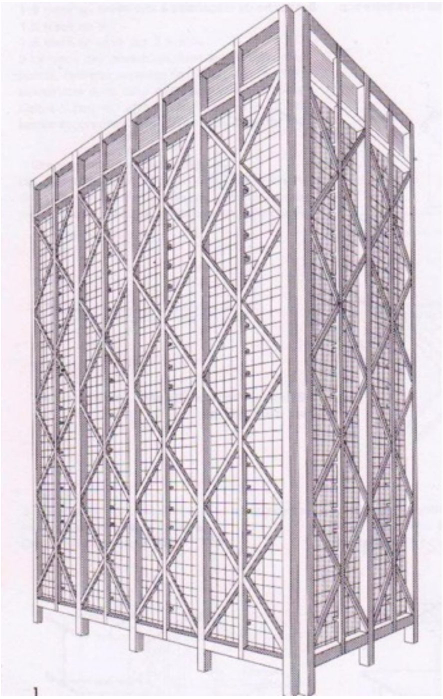


North facade



West façade

5) Tall buildings. Tubular structures with reinforced caissons



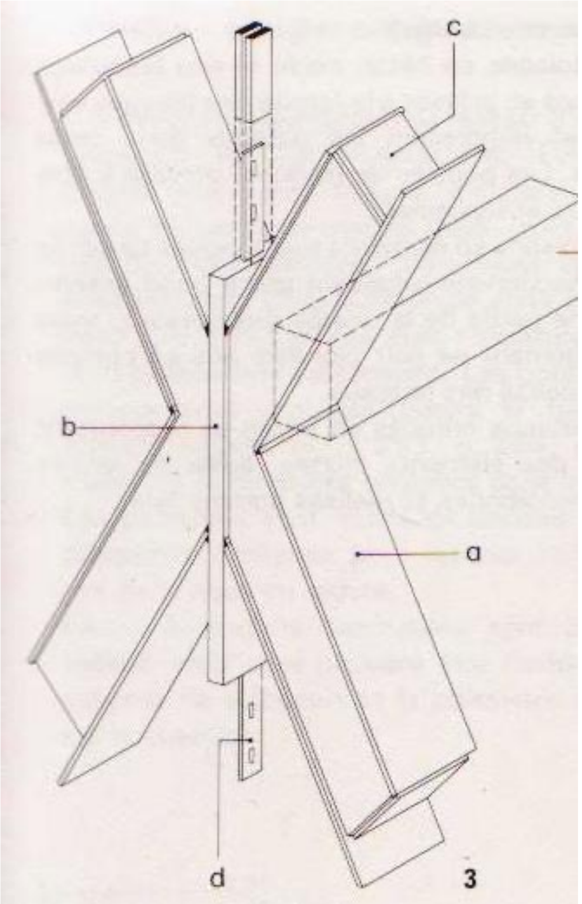
Alcoa administration building, San Francisco

- Heavy lattice structure: helps support vertical loads
- Also known as DIAGRID
- Diagonals are made of welded boxes interrupted at location of vertical gusset and butt-jointed further away
- Hangers are used to take the loads of the intermediate floors.

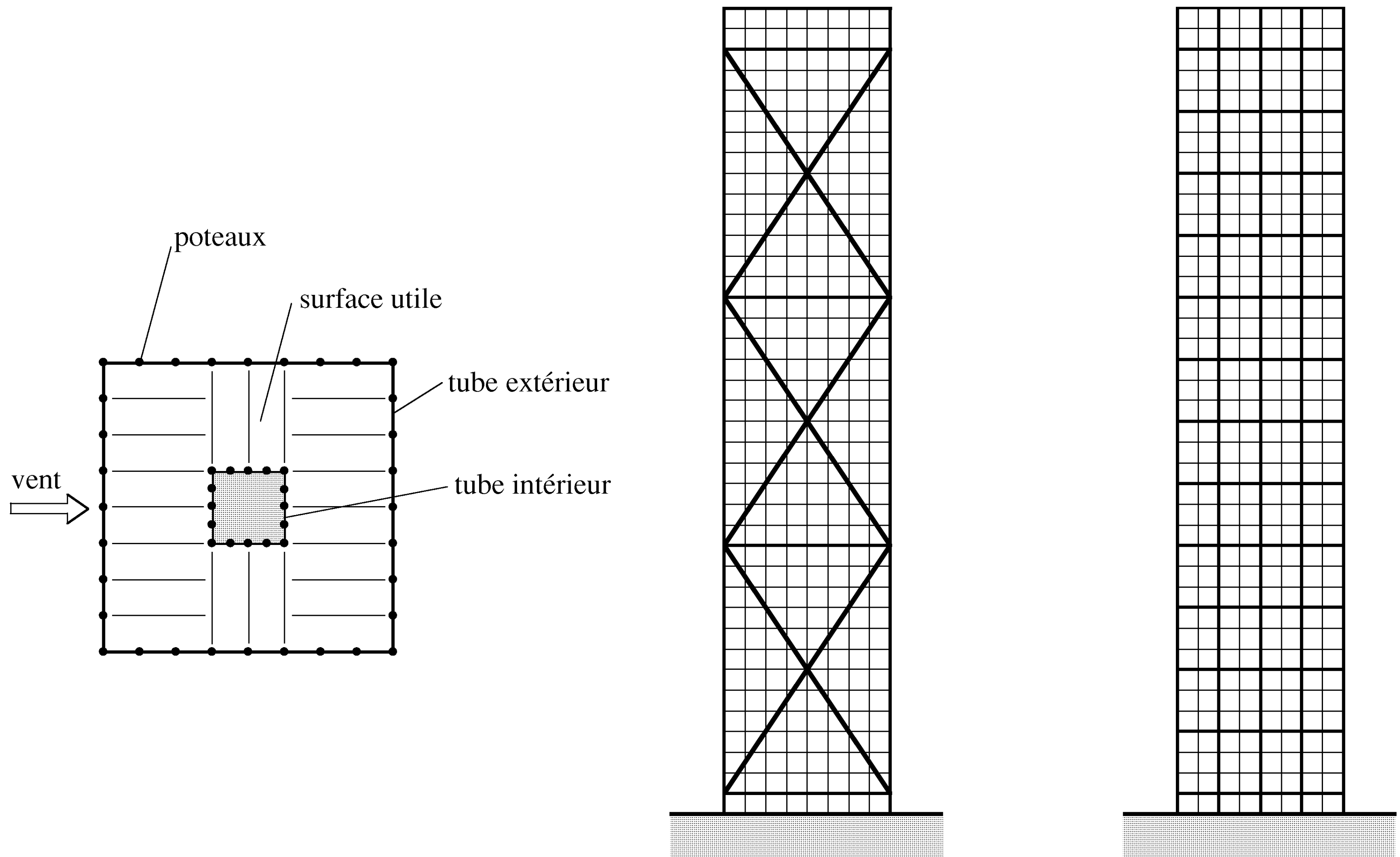
5) Tubular structures with reinforced caissons

Diagonals in welded boxes help to support vertical loads in addition to stiffening the building outer tube

The hanger *d* supports loads of intermediate floors



5) Tube structures ⇔ high-rise buildings (figs TGC 11)



(a) Plan de l'immeuble

(b) Façades avec contreventement en treillis

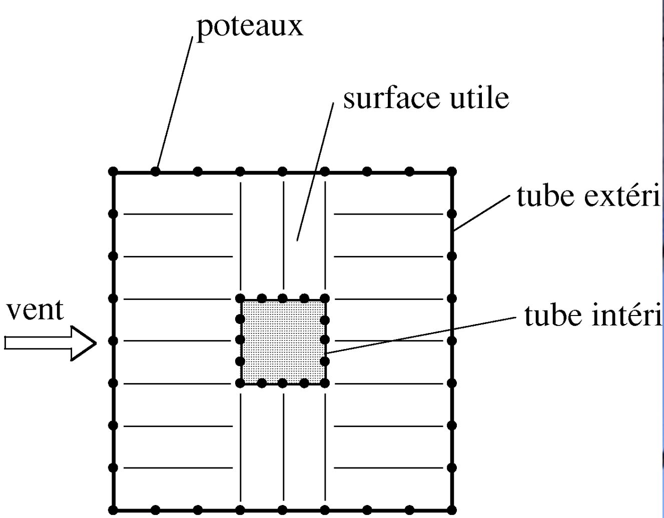
(c) Façades en cadres rigides

Fig. 4.12

John Hancock tower
arch. B. Graham, ing. F. Khan

World Trade center towers
M. Yamasaki, J. Skilling & R. Robertson

5) Tube structures ⇔ high-rise buildings

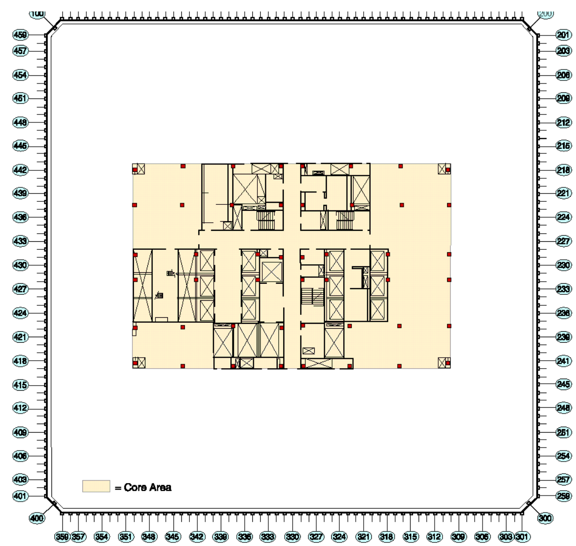


(a) Plan de l'immeuble

(b) Façades avec contreventement en treillis

(c) Façades en cadres rigides

5) Tube structures ⇔ high-rise buildings



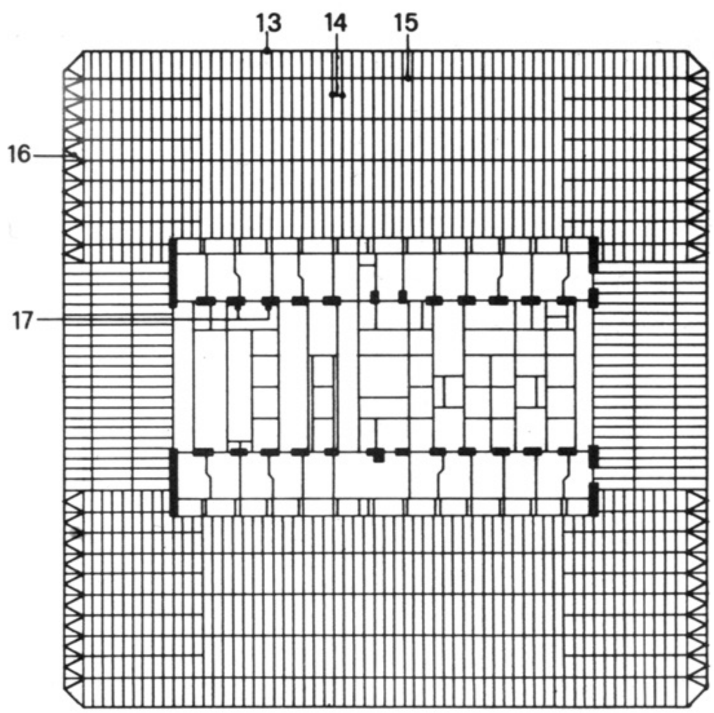
WTC:

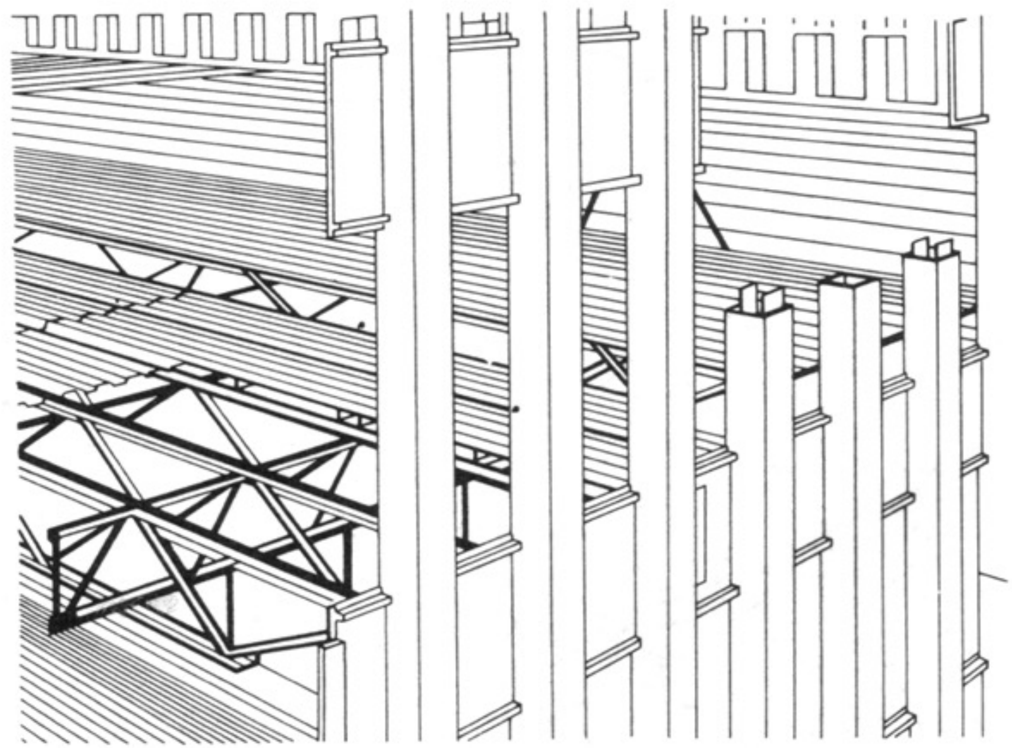
Facade (40% of vertical loads)

Core (60% of vertical loads)

Horizontal loads on the outer tube

5) Tube structures ⇔ high-rise buildings



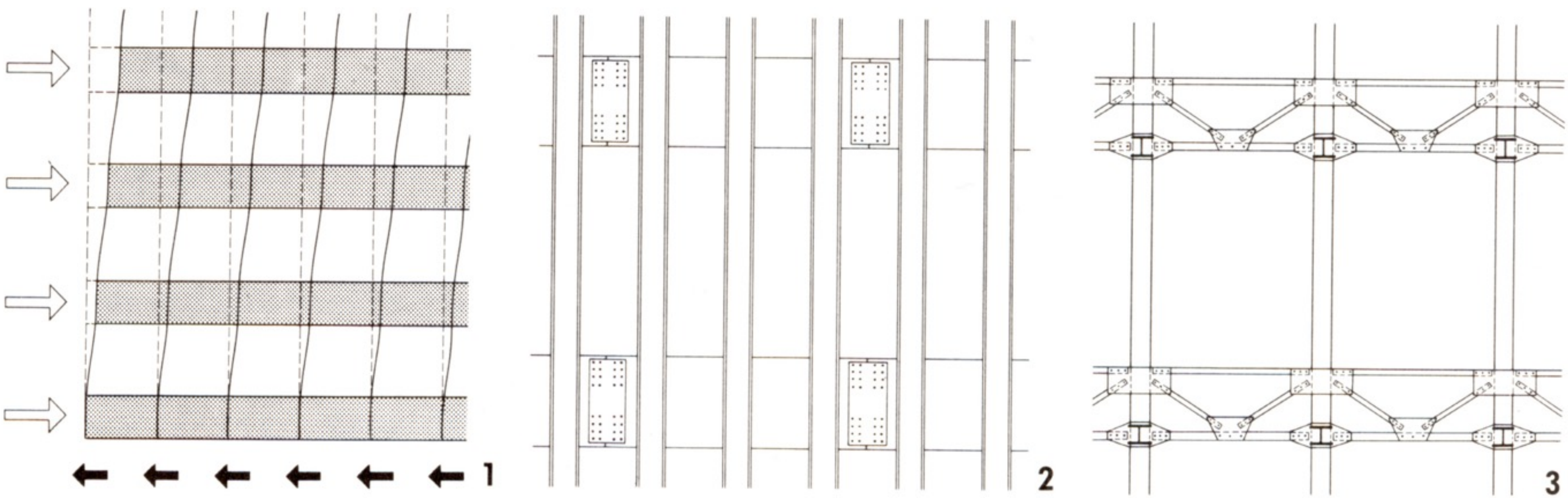


World Trade Center, New York

arch. M. Yamasaki & co., eng. J. Skilling & R. Robertson & co, 1973

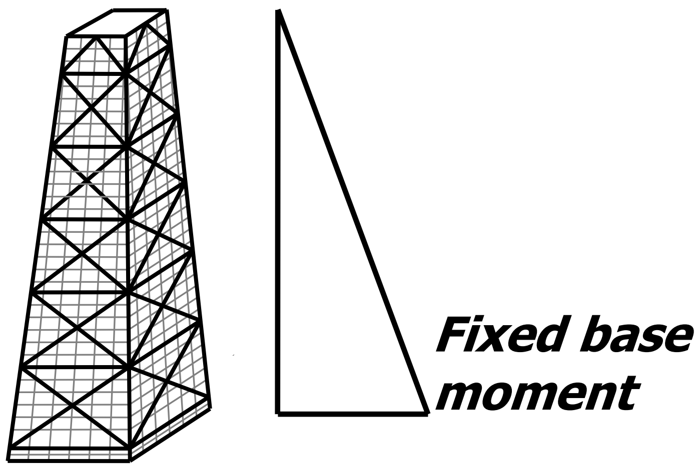
Facade system (or multiple Vierendeel)

Behind the façade parapets (sprandels) are rigid beams which, together with the external facade columns, form a multiframe in the plane of the façade.

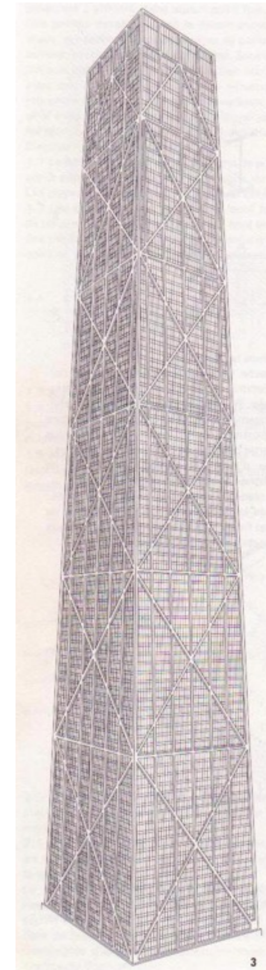


1. The façade beams (the same height as the parapet) are very rigid compared with the columns
2. Plated spandrel beams
3. Truss spandrel beams.

5) Tube structures ⇔ high-rise buildings



Equivalent to a variable inertia beam
→ Larger cross-section at fixed base

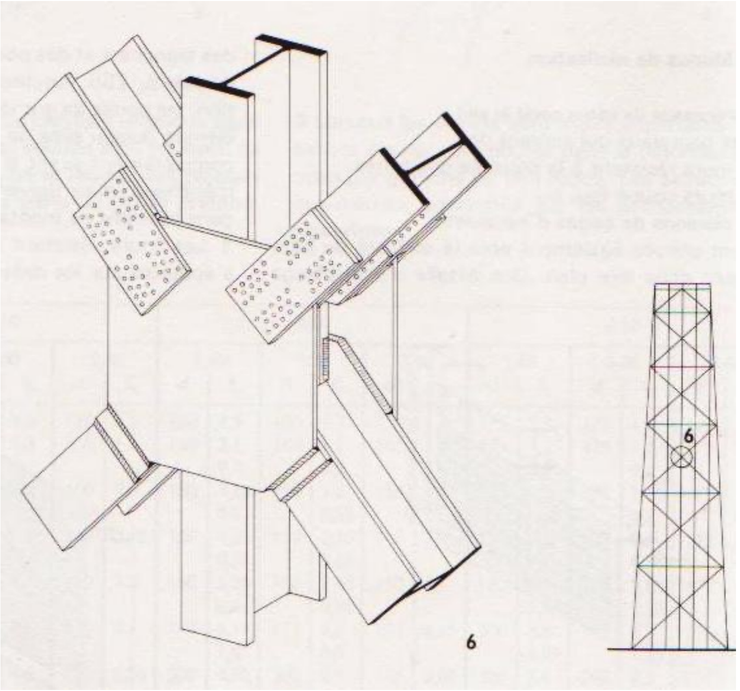


5) Tube structures ⇔ high-rise buildings

- John Hancock Center, Chicago
- Typical construction assembly

Heavy gussets (one storey high)

Reconstituted welded sections (huge beams and columns)

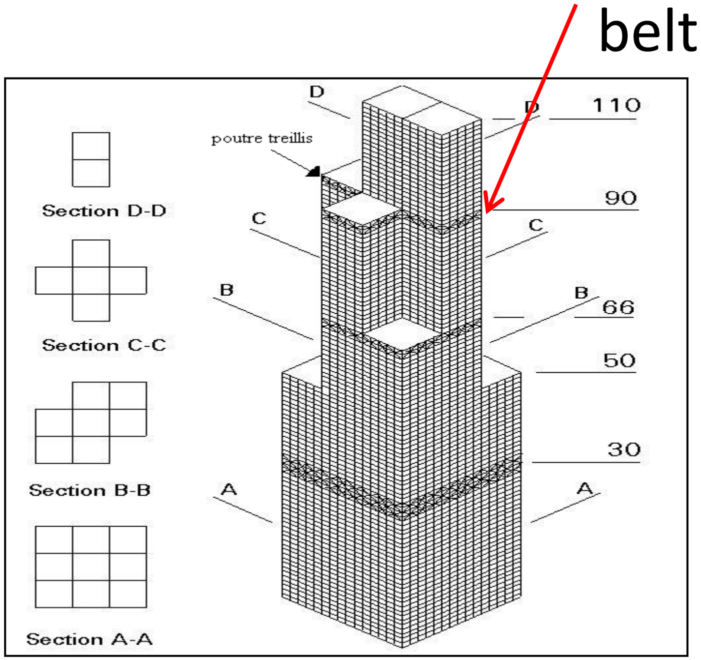


EPFL

5) Tube structures ⇔ high-rise buildings

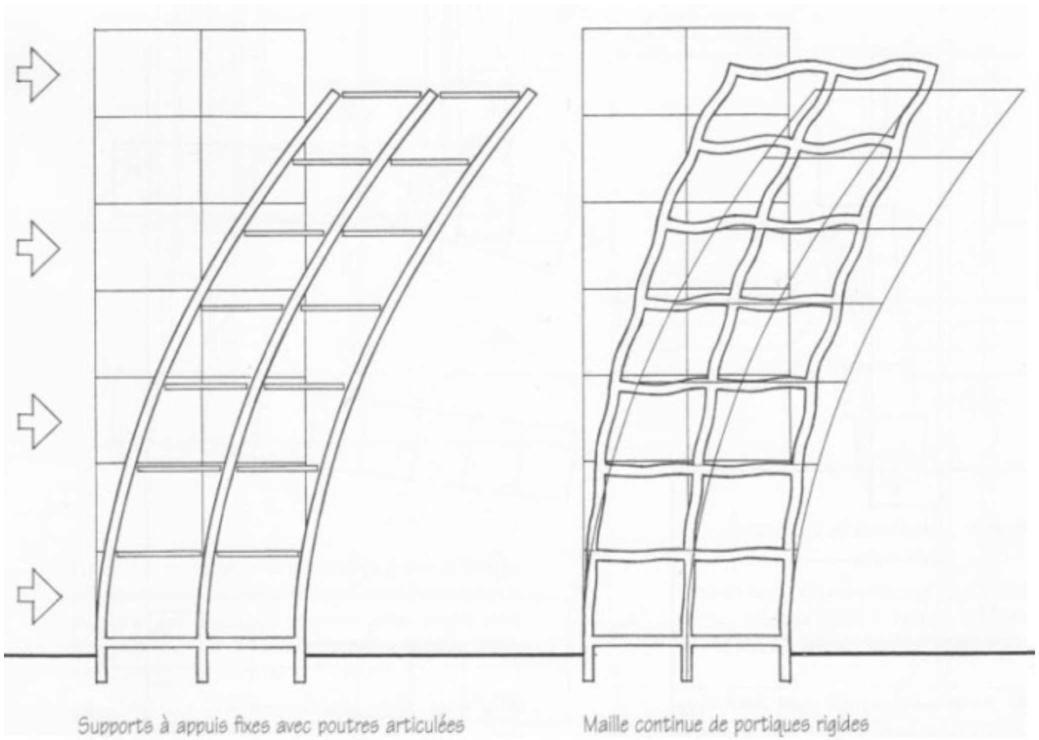
- John Caisson structures: tube bundles
- The Willis tower, Chicago

Stiffening belt



Floor belts

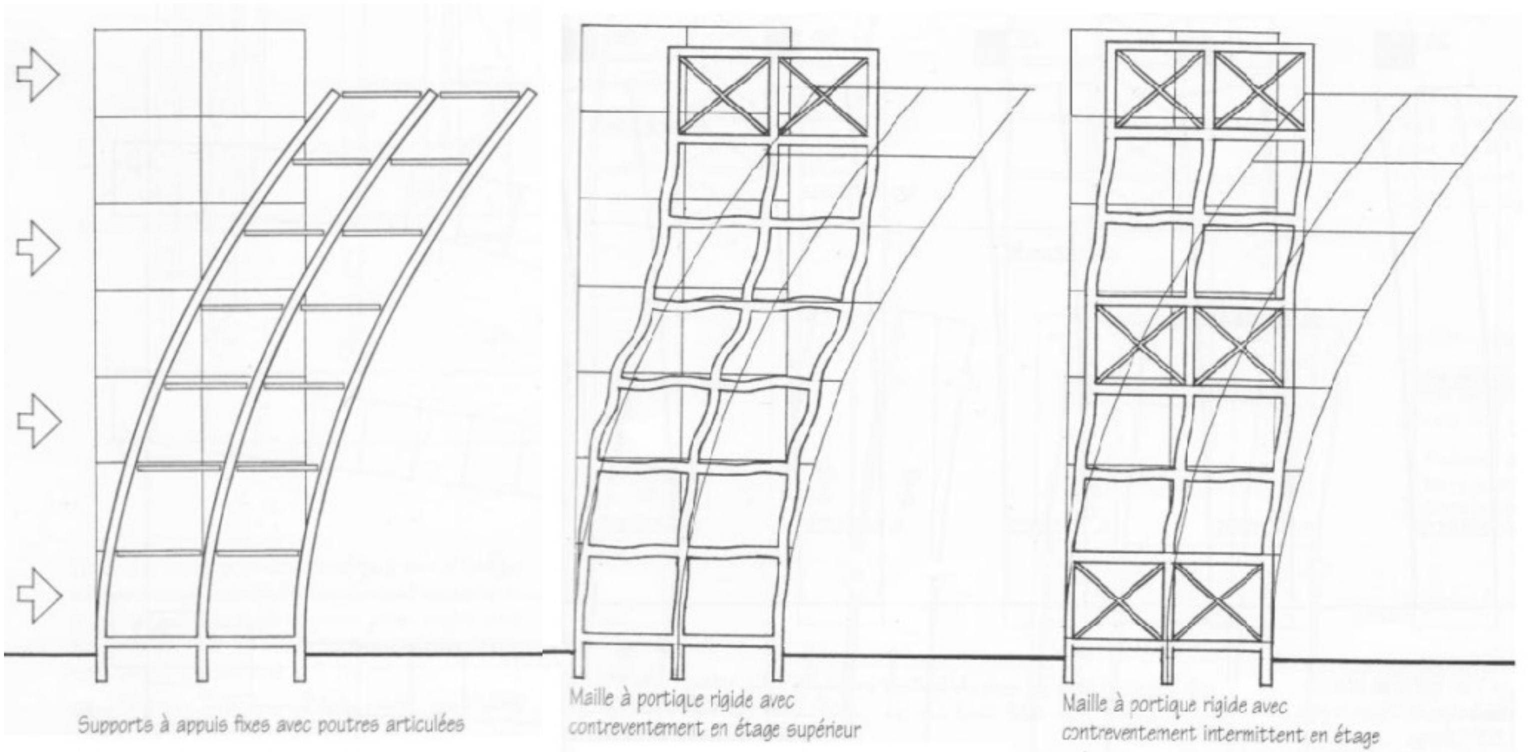
- Limit horizontal displacement of tall buildings



With articulated beams Rigid mesh

Ceintures d'étages

- Limit horizontal displacement of tall buildings

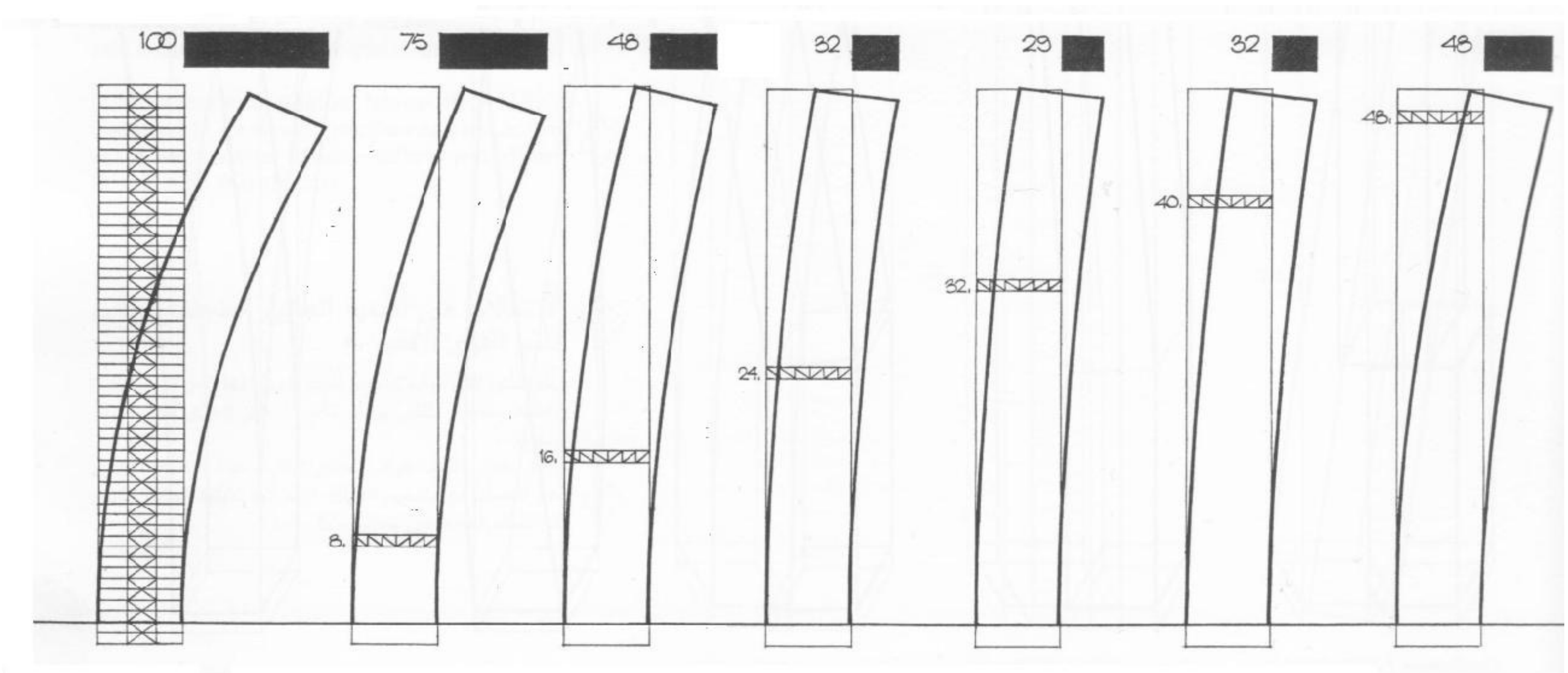


With articulated beams | Rigid mesh + 1 stiff. | Rigid mesh + 3 stiffening floors

=> the console « beam » has become more rigid

Floor belts

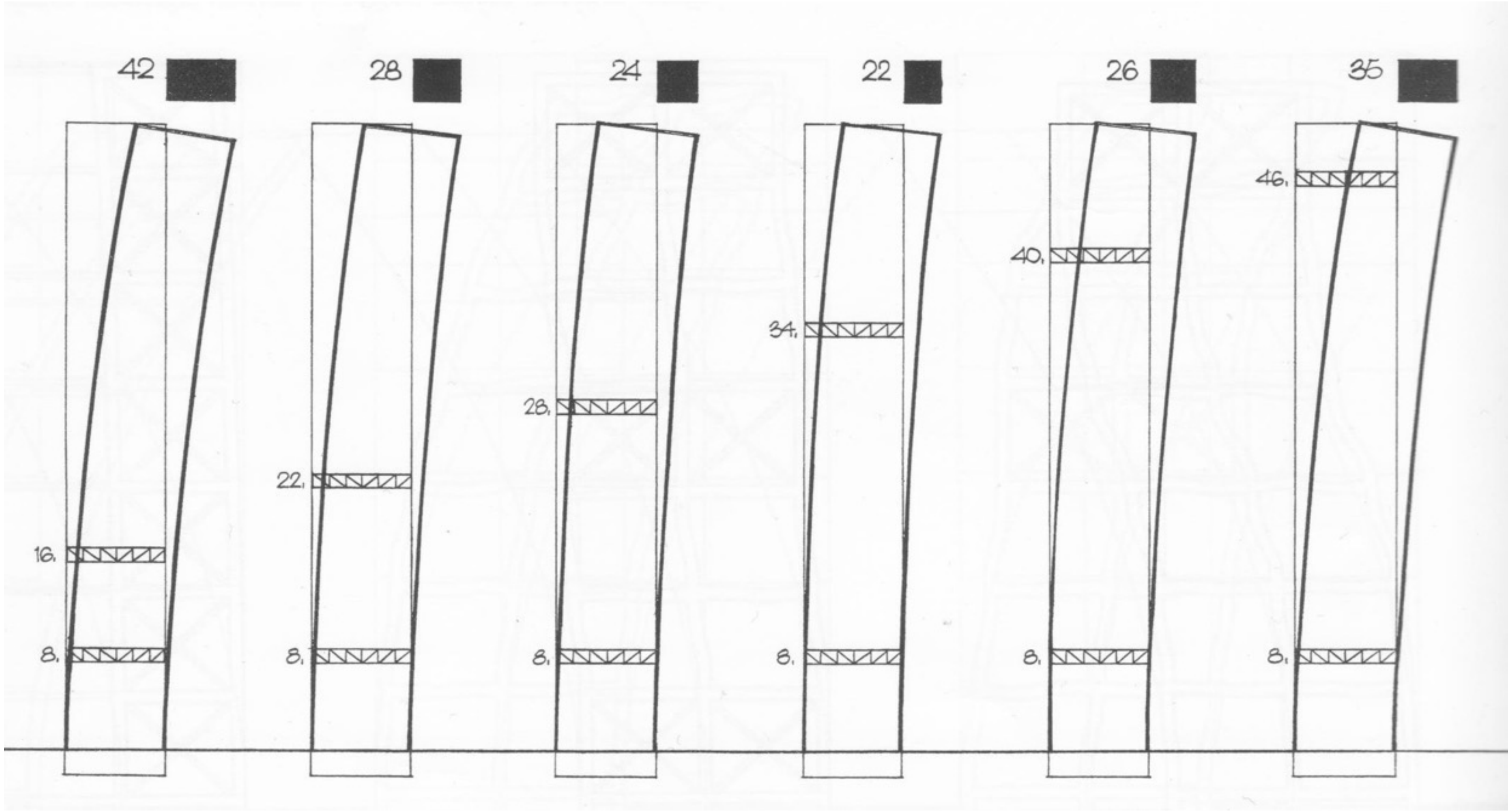
- **Decisive position → 1 stiffening belt**



Ideally 3/5 of the height

Floor belts

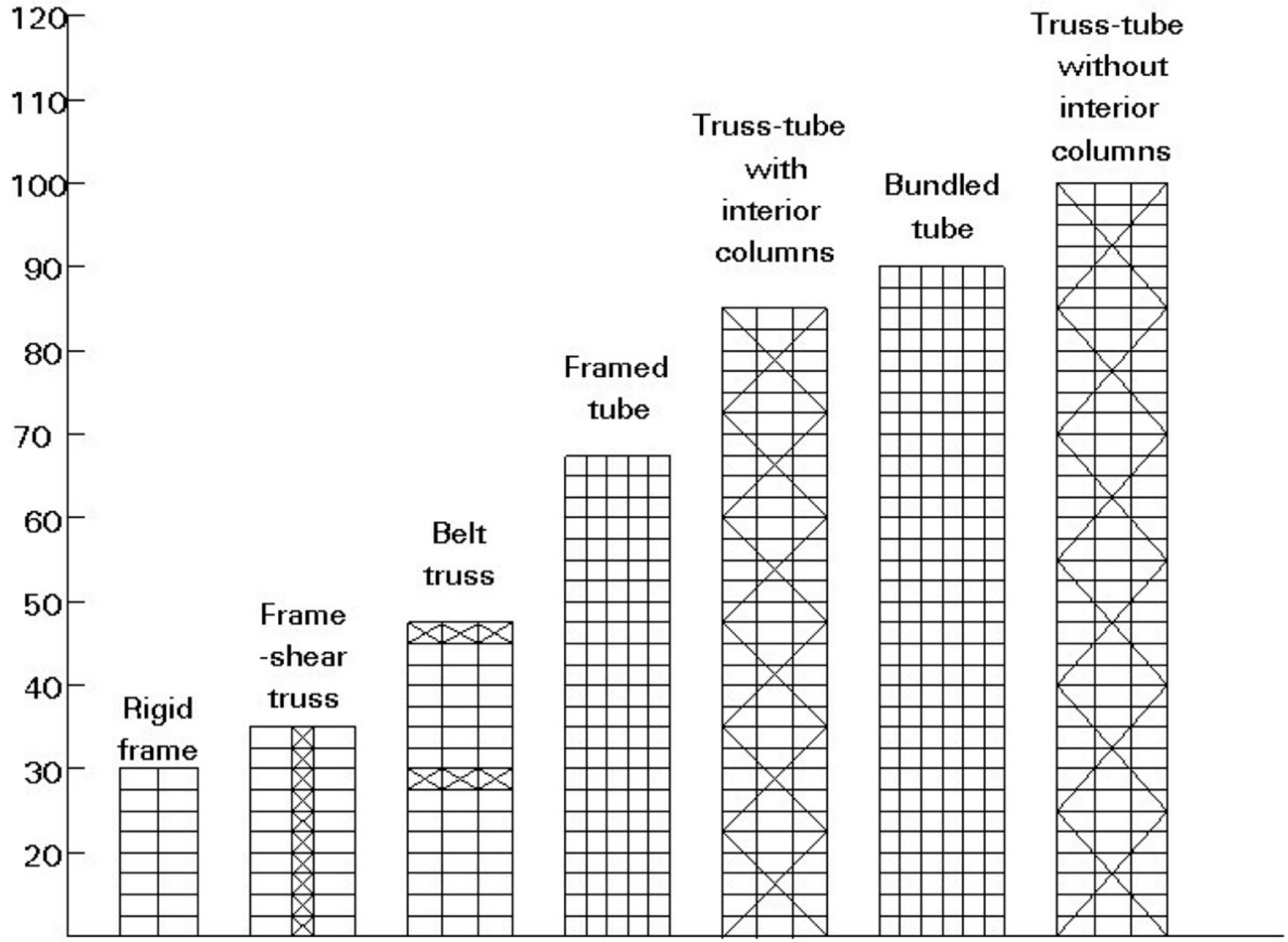
- **Decisive position and number → 2 stiffening belts**



The number of possible combinations complicates design

Summary of structural steel systems by number of storeys

Number of storeys in building



Structural system

Source: Prof. Z. A. Siddiqi, UET