GLOBAL STABILITY OF THE LOAD BEARING STRUCTURES

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Building damages

Picture gallery

As shown on the pictures there are during the time constructed a lot of buildings without the necessary security against collapse.

The reasons to the large damages are related to many different circumstances as for instance:

1. Faulty workmanship, bad execution of activities of craftsmen.
3. Design failure. Missing project review - and quality assurance of the project.
4. Missing control with the transfer of forces through the building and force transferring joints.
5. Bad communication between the project supervisors and the participants in the construction phase.

During the recent years a lot of attempts have been made to prevent all the terrible damages. All the parties in the building industry are of course interested to avoid those, but there are still too many failures in the building sector.

Which actions can reduce the amount of damages:

**Ad 1:**
Better inspections on the building site. Better communication between the project supervisors and the contractors/craftsmen..

**Ad 2:**
Should not exist. Quality assurance of the project. Calculations should always be controlled by an independent person (third person).

**Ad 3:**
Improve the communication between the involved parties in the construction supervision. Architects, engineers, construction architects, technicians etc.

**Ad 4:**
Additional focus on the transfer of forces and force transferring joints. To perform and documentate transfer of forces in all projects, even minor constructions. There are incredible many building damages today related to residential houses. Not so often and so violent as shown on the pictures.
But many minor damages like cracks and deformations that do not result in collapse, but they disfigure very much. There are incredible many complaints from the client to those defects.

So therefore - get an overview and control of all the deflections in the constructions before the construction phase.

There are many craftsmen and contractors that "saves" the cost of an engineer or do not consult an engineer when building minor constructions. Unfortunately with the risk of the above mentioned damages.

Ad 5:

Improvement of the communication between the project supervisors and the contractors written as well as orally.

**Follow-up of point 3 4 and 5.**

- To avoid design failures you have to attend the interdependence between the statical analysis and the subsequent design of the load bearing structures.

- You have to verify that the general stability of the main constructions is okay, and clearly identify and document the transfer of the forces down through the building.

- Identify the force transferring joints.

- Design the joints/nodes so that they can transfer the necessary forces.

- To assure the stability of each element of the building components which are included in the construction.

- To assure that all the needed information is exchanged between the involved parties.

- Because of the many failures in building, the Danish Housing and Building Agency has written new demands in the Appendix 6 in of the Danish Building Regulations - BR95.

  Here they line up the demands of the statical calculations - "Statistical documentation statement". Especially in the early phases the "static design report" is the document that helps you to prevent all the problems mentioned above. You find this document in the Fronter archive for the course GSA BS1.

In the course GSA-BS1 we will in the first 5 double lessons try go give you students some tools that can be used in connection with the above mentioned follow-up.

We will examine how the forces are transferred through a construction, examine the global stability of the main constructions and examine the force transferring joints.
Stability

That a building is stable, means, that it is in **equilibrium with all external forces**, related to forces as self-weight, snow load, wind load etc. We name it **the global stability of the construction** - in some literature it is also named **main stability**. Beside this you can also look at the stability of a single building component where you examine whether it is stable for the imposed load.

In the beginning of this course we will look at the global stability. Later we return to the stability of the individual elements.

When we look at the building damages we must note that the global stability seems to be okay in many cases, but there is a substantial risk of failures in the joints between the individual building components.

On the shown damages a violent **uncontrolled deformation** has occured which means the collapse of the whole construction.

Even if the deformations are not so big that they cause the shown dramatically results they can result in a minor "catastrophe" (crack formation, local rupture ect.).

Therefore two considerations must be taken when we design constructions:

1. **Stability by equilibrium with all external forces.**
2. **Prevent uncontrolled deformations.**

If you attempt to fulfill specially point 2 the construction engineer should be involved as early as possible in the design phase. Already in the outline proposal phase (draft design) the architect and the engineer in cooperation can design a building that satisfies both the demands of the client and the architect. Simultaneously the constructions can be designed in a way so that the deformations will be within the acceptable limits of the concerned building.
**Statical analysis**

**Historic**

In relation to the design of the building and the load bearing constructions, it would be very suitable, to perform a statical analysis. This analysis can demonstrate a statical model of the entire building.

In the early phases this is often done as sketches.

A statical analysis can for instance be a 3D sketch/drawing of the constructions of the building supplemented with a description of the constructions. This gives a good overviev how the constructions should functionate together. The sketch can also be added with a description of the course of the forces though the building.

**Support types**

**Pinned support.**

- **Statical picture:**
- **Signature:**
- **FBD/Free Body diagram:**
  - 2 reactions

**Roller support.**

- **Statical picture:**
- **Signature:**
- **FBD/Free Body diagram:**
  - 1 reaction

**Fixed support.**

- **Statical picture:**
- **Signature:**
- **FBD/Free Body diagram:**
  - 3 reactions
Examples of buildings

Industrial buildings (shear wall halls, column/beam halls, combination halls):

Type 1

Type 2

Type 2

Type 1
Residential building:

Type 3
Examples of statical models:

Building 1:

- Roof acting as a shear wall (we call it diaphragm)
- Facade acting as a slab
- Gable acting as a shear wall

- Roof acting as a diaphragm
- Facade acting as a shear wall
- Gable acting as a slab
Roof acting as a slab

Facade acting as a column

Roof diaphragm

Cross section:

Gable acting as a shear wall

Roof acting as a diaphragm

Gable acting as a shear wall

The roof diaphragm:
Longitudinal section:

Facade as a shear wall

Roof acting as a diaphragm

Facade acting as a shear wall

The roof diaphragm:
Building 2:

Roof acting as a diaphragm

Facade acting as a slab

Gable acting as a shear wall
- alternative in gable and wind bracing

Roof acting as a diaphragm
- alternative wind bracing

Alternative wind bracing

Facade acting as a shear wall

Gable acting as a slab
Roof acting as a slab

Beam function

Column function
Transfer of forces through the structure

We introduce some demands for the statical way of behavior of the components.

**Slab function** - the ability to transfer loads perpendicular to the plan of the component.

**Wall function** – the ability to transfer loads parallel with or just inside the plan of the element.

**Column function** – the ability to transfer loads parallel with the longitudinal axis.

**Beam function** – the ability to transfer loads perpendicular to the longitudinal axis.
The methods of the analysis

CONSTRUCTION

model

STATICAL ANALYSIS I

roof as beam

(slab)

walls as columns

free - body

vertical load
STATICAL ANALYSIS II

roof as diagram

case 4 and 5 as shear walls

case 2 and 3 as beams

horizontal load ⊥ on facade

STATICAL ANALYSIS III

roof as diagram

wall 4 and 5 as beams
(and walls)

case 2 and 3 as shear walls

horizontal load ⊥ on gable
If the wall has 1 fixed support line it is moveable.

If the wall has 2 fixed support lines it is moveable.

If the wall has 3 fixed support lines it is stable.

In the determination of how to transfer the forces we introduce some demands for statical way of behavior of the structure.

Early in the outline proposal phase you determine the transfer of forces in the overall statical system of the structure.

At this time you are normally not bounded by certain choice of materials and therefore the determination of the transfer of forces can be determined entirely by statical principles. Furthermore you combine the building components to form a structure which is globally stable.
Principles

Principles to reach these goals can be one or more of following:

   a) To set up statical demands of behavior of the individual building components.

   b) To use "self bracing" building components in the structure

   c) To use bracing triangles (additional constructions).

   d) To identify the transfer of forces from one building component to another.

ad. a)

There are worked with demands for statical functions to the individual building components.

Slab function

The ability to resist loads perpendicular to the planar face.

Wall function (shear wall, diaghragm)

The ability to resist loads in plan with the component.
**Beam function**

The ability to continue loads perpendicular to the longitudinal axis.

![Beam function diagram]

**Column function**

The ability to continue loads inside the planar of the element.

![Column function diagram]

**ad. b)**

Of common existing system can be mentioned:

Column-girder system with cantilevered fixed columns.

![Column girder system diagram]

2 pin-jointed arch.

![2 pin-jointed arch diagram]

Flat-roofed portal frame with rigid jointed corners.

(2 pin-jointed frame)

![Flat-roofed portal frame diagram]
Pitched-roofed portal frame with rigid jointed corners and pin-jointed in the top. (3 pin-jointed frame)

ad. c)

Triangle constructions

Diagonals made as tension and/or compression bars. In the structure they act as stable simple triangles or truss.

ad. d)

This could be essential for the design of the joints.

For instance:
- How are horizontal forces transferred from a diaphragm to the end of house.
- How is a force transferred from a wind bracing to the structure below.
**The individual building components**

There is of course also demands to the stability of the individual building components. The components will additionally be loaded for instance by forces caused by temperature fluctuation, eccentric acting forces due to deviation in execution etc.

Attention to those forces must be taken later in the engineering design phase.

Below follow examples showing how the transfer of forces can be identified and how to illustrate it during the planning.

This can be performed in many different ways. Here two essentially different methods are shown.

**Method A:** A mixture of text and sketches.

**Method B:** A strictly schematic form.
Example 1

Determination of the transfer of forces in a minor single-story building.

Outline - example

Extract of construction description

Roof construction:
Wing tiles on battens with underlay of plastic foil.
Wooden trusses - 45° roof inclination.
Ceiling facing - 19 mm rebated boards.
200 mm insulation mats.

Masonry:
Outside: 350 mm hollow wall with insulation and steel wall ties.
Inside.: 11 cm wall.

Light weight facades:
Timber skeleton frame.
200 mm insulation.
High impact outside and inside cladding.

Method A

Disposition of the transfer of forces.

Wind load on facades

The load is transferred by slab function in the facade to the ceiling area (diaphragm) or the roof and the foundation of the facade.

Through the diaphragm function or through the stiffness of the roof area (shear function or wind bracing) the load is leaded to the gable areas, that by shear wall function deliver the load to the foundation of the gables.
**Wind load on gables**

The load is transferred by the gable area to the facades and the roof and ceiling area. By shear wall/diaphragm function the load is transferred to the facade.

**Vertical load**

The load from the roof area is transferred through the trusses (beam function) to the facades and then through beams, columns and masonry to the foundations (column function).

**Method B**

Disposition to force transferring

Signature:

BF = beam function
SF = slab function
CF = column function
WF = wall function
WB = wind bracing

**Wind load on facades**

No diaghragm function in the ceiling area here!
Wind load on gables

Vertical load
Example 2

Determination of the transfer of forces in a minor single-story hall building.

Outline - example

Extract of construction description

Load bearing structure:
3 charnier arch on pad foundations.

Roof construction:
Cardboard on underlay of 250 mm insulated roof components with completed down side.

Masonry:
Outside: 400 mm hollow wall with insulation and steel wall ties.

3 pin-jointed frame
**Method A**

Disposition of the transfer.

**Wind load on facades**

The load is transferred from the wall area by slab function to the 3 pin-jointed frames/arches and by their self stiffening function they transfer the load further to the pad foundation in the facade.

**Wind load on gables**

The load is transferred from the wall area by slab/beam function to vertical wind beams and then further to gable foundation and roof area.

Through the purlins of the roof area (compression members) the load is transferred further to wind bracings and then by tension to the foundation of the facade.

**Vertical load**

The load from the roof area is transferred through the purlins (beam function) to the 3 pin-jointed frames/arches in the structure.

By beam-column function the arches transfer the load to the pad foundations in the facade.

**Method B**

Disposition to force transferring

Signature:

BF = beam function

SF = slab function

CF = column function

WF = wall function

WB = wind bracing

AF = self stiffening function
Wind load on facades

Wind load on gables

Vertical load
Example 3

Determination of the transfer of forces in a minor two-story building.

Introduction to example 3

Extract of construction description

Roof construction:
Cardboards on boards.

Ceiling construction:
Class 1 facing with insulation.

Suspended floor:
Precast hollow floor units.

Walls:
First floor:
Outside: Precast concrete sandwich components
Inside: precast concrete components

Second floor:
Wooden based light weight wall with external board facing and internal class 1 facing.

Design phase/feasibility study.
Method A

Determination of the transfer of forces.

**Wind load on facades**

**First floor:**
The load is transferred from the wall area by beam function to suspended floor and roof area/ceiling area.

Through the wind bracing of the roof area or the diaghragm function in the ceiling area the load is transferred to the gable areas that by wall function transfer the load to the foundations of the gables.

**Ground floor:**
The load is transferred from the wall area by slab function to the foundation of the facade and the suspended floor.

Through the diaghragm function of the suspended floor the load is transferred to the gable areas that by wall function deliver the load to the foundations of the gables.

**Wind load on gables**

**First floor:**
The load is transferred from the wall area by beam function to suspended floor and roof area/ceiling area.

Through the wind bracing of the roof area or the diaghragm function in the ceiling area the load is transferred to the facades that by shear function transfer the load to the foundations of the facades.

**Ground floor:**
The load is transferred from the wall area by wall function to the foundation of the gable and the suspended floor.

Through the diaghragm function of the suspended floor the load is transferred to partition wall and facades that by shear function transfer the load to the foundations.
**Vertical load**

The load from the roof area is transferred by the trusses by beam/column function to the light weight facade that by beam- and column function transfer the load further.

The load on the suspended floor is transferred by slab function to the facades and the partition wall and from here further down to the foundation by column function.
Method B

Disposition to force transferring

Signature:

BF = beam function
SF = slab function
CF = column function
WF = wall function (shear wall or diaphragm function)
WB = wind bracing

Wind load on facades
Wind load on gables

Vertical load
Force transferring joints

Due to our knowledge about the transfer of forces through the structure, we can now evaluate the force transferring joints.

In the early phases hand sketches of the essential force transferring joints are made. In this way the geometrical conditions can be identified. You must think of which principles of joints you will would use. Will you for example use mechanical connecters (like for example bolted joints) in the joint you are sketching and is there sufficient space for the connecters? An estimate of the forces acting on the building components can be used to perform an estimate of the dimension of the individual elements and eventually an estimate of the transfer of forces in the force transferring joints.
Connection between steel frame sandwich element and foundation

Sandwich element fastened to steel frame

Steel frame IPE 300

Bolts / 4 pcs.

Encased fitting

Point foundation below steel frame

Stribe foundation below facade element

Connection between gable and roof construction - roof area

Problematic connection → Battens

Poss. bolt

Ties

Spacing sticks Bolts

Foot

Outer leaf Inner leaf/element
Connection between facade and roof

Tie bars folded above head of trusses

Wall plate bolted to inner leaf

Tie bars directed to foundation

Connection between wall and floor partition

"Stringer" element floor

Joint reinforcement

Facing brick wall
Connection between gable and floor partition

Facing brick wall  Inner leaf/elements

Ties

Floor timber
Spacing sticks

Bolts
Different building components able to act with "wall function".

**Reinforced concrete:**

*In-situ casted.*

**Concrete elements:** Be aware of constructions joints and eventually stringers.

**Porous concrete:***

*Leca (fabric name!), Siporex, Aereated concrete* ect. Follow the manufacturers instructions for arrangement and joints.

**Masonry:**

*Loaded masonry.*

*Unloaded masonry:* Very problematic in particular to the joints.

**Wood:**

*Boards of plywood, particle boards, fiber boards ect.* Format at least 1,2 m x 2,4 m.

**Gypsum boards.***

*Half-timbered houses and tension bar in steel.* Follow the manufacturers instructions for arrangement and joints. Often a calculation is necessary concerning the numbers of nails and screws ect. See also brochures and TOP-booklets.

**Steel:**

*Thin trapez formed sheet metal plates:* Follow the manufacturers instructions.