GLOBAL STABILITY OF THE LOAD BEARING STRUCTURES

Drawn up by Nicolai Green Hansen and Hans Emborg august 2007.
Building damages

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 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 are visual unsightly. 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 the engineer in 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 oral.

**Follow-up of point 3 4 og 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 had 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 they can transfer the necessary forces.
- To assure the stability of all building components that are included in the construction.
- To assure that all the needed information are 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 for the statical calculations - "Statical 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 (in wholeness ...udelades) is in equilibrium with all external forces, related to forces as self-weight, snow load, wind load ect. 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 to 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 the defomations will be within the acceptable limits for the concerned building.
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 overwiew 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.

Roller support.

Fixed support.
Examples of buildings

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

[Images of industrial buildings shown in the document]
Residential building:
Examples of statical models:

Building 1:

Roof acting as a wall (we call it a diaphragm)

Facade acting as a slab

Gable acting as a wall

Roof acting as a diaphragm

Facade acting as a wall

Gable acting as a slab
Roof acting as a slab

Facade acting as a column

Roof diaphragm

crosssection

Gable acting as a wall

Roof acting as a diaphragm

Gable acting as a wall

The roof diaphragm
Longitudinal section:

The roof diaphragm.

Facade acting as a wall

Facade as a wall

Roof acting as a diaphragm
Building 2:

Roof acting as a diaphragm.

Facade acting as a slab

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

Roof acting as a diaphragm - alternative wind bracing.

Facade acting as a 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
dæk som skive

væg 4 og 5 som skiver
væg 2 og 3 som bjælker

vandret last → på facade

væg 4 og 5 som bjælker (eg skiver)
væg 2 og 3 som skiver

vandret last ↓ på gavl
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 global 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 functions to the individual building components.

**Slab function**

The ability to resist loads perpendicular to the planar face.

![Slab function diagram]

**Wall function**

The ability to resist loads in plan with the component.

![Wall function diagram]

**Beam function**

The ability to transfer loads perpendicular to the longitudinal axis.

![Beam function diagram]

**Column function**

The ability to transfer loads inside the planar of the element.
ad. b)

Of common existing system can be mentioned:

Column-girder system with cantilevered columns.

2-charnier arch.

2-charnier frame with moment stiff corners.

3-charnier frames with moment stiff corners.
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 where the component becomes unstable for a specific load called the stability load. 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 - 45º 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

Disposion of the transfer of forces.

Wind load on facades

The load is transferred by the wall to the wall foundation and the roof. The wall has a slab function.

Due to the stiffness of the roof ("wall function" or wind bracing) the load is transferred to the gables and further by wall function to the foundations.
**Wind load on gables**

The load is transferred by the wall area to the facades by slab function, and then by wall function to the foundation of the facades.

**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 of the transfer of forces.

Signature:

BJ = beam function

PL = slab function

SØ = column function

SK = wall function

VB = Wind bracing
Wind load on facades

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.

Light weight gavle area:
Skeleton construction with 200 mm insulation. High impact outside and inside cladding.
Method A

Determination of the transfer of forces.

Wind load on facades

The load is transferred from the wall area by slab function to the 3-charnier 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 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-charnier archs in the structure..

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

Determination of the transfer of forces.

Signature:

BJ = beam function
PL = slab function
SØ = column function
SK = wall function
VB = wind bracing

Wind load on facades

Wind load on gables
Vertical load
Example 3

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

Outline - example

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.
**Method A**

Determination of the transfer of forces.

**Wind load on facades**

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

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

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

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

**Wind load on gables**

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

Through the wind bracing of the roof area the load is transferred to the facades that by wall function transfer the load to the foundations of the facades.

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

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

The load from the roof area is transferred by the trusses by beam 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 longitudinal wall and from here further down to the foundation by column function.
**Method B**

Determination of the transfer of forces.

Signature:

BJ = beam function
PL = slab function
SØ = column function
SK = wall function
VB = 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 about which principles of joints you will use. Will you for example use mechanical connecters (like for example bolted joints) in the joint you sketching and is there sufficiently 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.
SAMLING I MELLEM STÅLRAMME
SANDWICHELEMENT OG FUNDAMENT

Sandwich element
fastgøres til stålramme.

Stålramme
IPE 300
Bolte / 4 stk.
Indstiftet Fundbeslag

Klodsfundament
under stålramme.

Strikfundament
under facaden element.

SAMLING I MELLEM GAVL OG TAKKONSTRUKTION - TAKFLADE:

Problematisk
samling

Logeter

Hoved

Bindere

Mellomloftsblads
Bect
Foot

Formur
Bagmur/element
SAMLING I MELLEM FACADE OG TAG.

SAMLING I MELLEM VÆG OG ETAGEDESKILDELSE.

SAMLING I MELLEM GAVL OG ETAGEDESKILDELSE.
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, Aerated concrete etc. 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 etc. 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 etc. See also brochures and TOP-booklets.

Steel:

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

Assignment 1  Global - determination of the transfer of forces

Purpose: To exercise the understanding of statical systems and their behaviour in relation to global stability to vertical and horizontal actions.

Statical system: The statical system of a structure means the complex of building components that together constitute the bearing main structure, through which the forces acting on the structure are transferred to the ground.

Outline proposal: In the outline proposal phase you examine the size of the main system (the structure) and examine how it works (transfers the forces). On the basis of this you decide whether the structure can be used in the further engineer design work or whether it should be dismisses or reworked.

Assignment: On the subsequent pages some statical systems from different constructions (A, B, C, D, E and F) are shown. The global stability of the systems should be analyzed.

If the system is unstable a proposal how to obtain spatial stability is wanted. More alternative proposals are welcome. If the system is stable an explanation is also wanted.

Working procedure: The assignment is must be solved as group work with 3 - 4 members. The solution could be drawings/sketches, best as 3D supplemented with text. Additional a smaller model made of paper board showing how the structure acts for external actions has to be made. The solution has to be supplemented with an oral statement.

Evaluation: The class and the lecturer evaluate the exercise in community. The solution is presented in plenum for all involved. An opponent group is appointed for each team. They should in particular see critical on the proposal of the solution.

Materials: Paper board, thin covings, glue and overhead transparencies are distributed. Knifes, covings scissors, saws, glue pistols and indian link pen to transparencies can be borrowed.
Assignment 1A

Material description:

Roof:
Cardboard and boards on trusses per 0,80 m.

Outer wall:
North: Masonry
South: Open
East: Open
West: Masonry

Assignment 1B

Material description:

Roof:
Eternit boards on purlins per 0,80 m.

Outer wall:
North: Light weight wood construction
South: Light weight wood construction
East: Windows parties
West: Simple supported reinforced concrete wall
**Assignment 1C**

**Assignment:**

Wanted: "Largest possible glass area".

Two proposals for solution has to be prepared.

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**Assignment 1D**

**Assignment:**

Wanted: "Largest possible glass area".

Two proposals for solution has to be prepared.
Assignment 1E

Assignment:

Carports:

The construction must be "light" and open, but has of course to be supported for horizontal actions.

Additional posts and walls of board on timber framing are allowed, but not in the access area.

Wing tiles on prefabricated trusses from a certified factory are used.

At least 2 principal solutions to the supported system must be formed.

A statical analysis (transfer of forces) on the selected system has to be formed.
SITUATIONSPLAN

Dispositionsforslag.
Carporte.
Assignment 1F

Assignment:

On the enclosed drawings the form for roof- and room design is shown. This design has to be complied.

The roof construction is made as beam- column system, but the client wants as few columns as possible in the room.

The principal construction for roof and substructure are not decided.

The gable triangles are made with glass.

Materials for roof- and wall faces are not decided.

A proposal for the principle of the construction has to be formed.

A statement for spatial global stability without calculation has to be formed.
Assignment 2  Global stability analysis of a building

Assignment: A client had asked an architect to make a draft design for a carport with a room for equipment.

In terms of the wishes of the clients the architect has made an outline proposal (see the sketch below). He now asks you to evaluate this in relation to global stability.

You should give a principal proposal for structural design. This includes the explanation of the statical function (beam, column etc...) of all components and the transfer of forces through the structure. As supplement you can eventually make some considerations in relation to the force transferring joints.

Key words: Transfer of forces, isometri, exploded isometry, walls, boards, beams, columns. Literature in Danish: “Er dit hus stormfast”, SBI 186 Småhuses stabilitet, bracing elements.

Working procedure: The assignment is solved in the same groups as in the exercises for global stability.

Delivering form: One proposal per group (A4 loose sheets). A combination of sketches and text would be pleased.
Assignment 3  Stability- and course of forces of a building

Assignment: Below plane and facades of a residential house are given. The house has a size of approx. 189 m² including a carport.

1) Give proposals for selection of materials and design of the load bearing and bracing structures

2) Explain the transfer of forces for the residential house (on sketch level).

In addition to the given window units in the sitting room the owner also want glass units in the entire facade to the south (the kitchen also situated to the south).

3) Explain which influence this would mean to the stability, and specify the additional actions that possible should be taken.

Working procedure: The answering is individual.

Delivering form: A4 loose sheet on sketch level with explanatory text.