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WAREHOUSE BUILDING - STORAGE AREAS FOR RACKING
- Guidance for Stakeholders -

Industrial concrete floor manufacturing

High tolerance requirement

"Laser screed" method

FEM RACKING AND SHELVING PRODUCT GROUP

(FEM R&S)

Guide 10
Warehouse Building - Storage Areas for Racking
- Guidance for Stakeholders -

September 2018

Disclaimer

The recommendations and advice contained in this Guidance Note are based on specifications, procedures and other information that have been collected by the FEM from its members and external experts in the field of industrial concrete warehouse floors. They represent what is, as far as FEM is aware, the best available data at the time of publication on the instruction and use of the equipment concerned in the general conditions described an are intended to provide guidance for such use.

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1. SUMMARY

Frequently warehouse buildings are constructed without a specific End User. There are many factors that need to be considered to prevent that a warehouse building, and in particular:

- the floor slab and its foundation;
- position of building columns;
- overall width and height,.

do not significantly restrict the logistic operation.

There are a number of key-stake holders involved, between which effective interface communication and specification is important, to achieve at the end a combination of warehouse building and intended storage system (racking in combination with mechanical handling equipment) complying with the project specifications and within the budget resp. targeted capitalised yearly costs.

Effective communication between all stakeholders in all stages of the project realisation is therefore of the outmost importance (see Figure 1). Important stakeholders are:

- Developer / Investor of the warehouse building, if any
- Warehouse building owner
- End User of the Storage System
- Warehouse building designers
- Floor Designers / Floor Manufacturers
- Specifier / Storage System Designers
- Suppliers Mechanical Handling Equipment
- Suppliers Racking / Shelving / Mezzanines

The storage system (racking in combination with mechanical handling equipment) will be designed on the assumption that the loaded floor does not deform by a significant amount over time. What is “significant” depends on e.g.:

- Rack type
- Rack operation
- Rack installation tolerances required.

Guidance is given by FEM 10.2.14 – 01 / 4.103 – 01, FEM 9.831-1 / FEM 10.3.01-1 and FEM 9.832.

However, in many practical cases this assumption may not be realised in which case the effect of all of the influencing factors needs to be considered on a project by project basis to achieve a good cost effective and operationally effective outcome.

This Information Bulletin, in combination with the relevant EN standards and FEM Codes mentioned, provides guidance to realize this. The guidance is even more relevant when the End User of the warehouse building is not known yet and the prospective building owner together with his design team has to produce warehouse buildings with sufficient flexibility to comply with the needs for more than one storage system.

2. STANDARDS AND CODES

EN 15620	Steel static storage systems – Adjustable pallet racking – Tolerances, deformations and clearances .
EN 15629	Steel static storage systems – Specification of storage equipment
EN 15635	Steel static storage systems – Application and maintenance of storage equipment
EN 15878	Steel static storage systems – Terms and definitions
EN 1992-1-1 + C2:2011	Design of concrete structures – Part 1-1: General rules and rules for building structures
FEM 9.223	Basic data and criteria for the construction of automatic high bay warehouses with distribution systems
FEM 10.2.14 – 01 / 4.103 – 01	Warehouse floors – Storage system areas operated by Industrial Trucks – Part 1: Tolerances, deformations and methods of measurements.
FEM 4.103 – 02	Warehouse floors – Storage system areas operated by industrial trucks – Part 2: Requirements for design – Interface with Industrial Trucks
FEM 10.2.14 – 02	Warehouse floors – Storage system areas operated by industrial trucks – Part 2: Requirements for design – Interface with Racking
FEM 9.223	Basic data and criteria for the construction of automatic high bay warehouses with distribution systems
FEM 9.831 - 1 / 10.3.01 - 1	Basis of calculations for storage and retrieval machines – Tolerances, deformations and clearances in the storage system – Part 1: General, Single deep and Double deep Beam Pallet racking
FEM 9.832	Basis of calculations for S/R machines: Tolerances, deformations and clearances in automatic small parts warehouses (not silo design)
FEM 9.841 / FEM 10.2.10	Storage systems with rail dependent storage and retrieval equipment - Interfaces
WTCB TV 204	Wetenschappelijk en Technisch Centrum voor het Bouwbedrijf – Technische Voorlichting 204: “Cementgebonden bedrijfsvloeren”

NOTE FEM Codes of Practice, reference to www.fem-eur.com/product-groups.
FEM 4. = Industrial Trucks ; FEM 9. = Intralogistic systems ;
FEM 10. = Racking & Shelving

3. INTRODUCTION

This Information Bulletin is a first introduction of the importance of warehouse building properties in relation to the intended storage system, with the intention to contribute to the required awareness of all stakeholders.

A storage system comprises a number of "components" all interfacing with each other, such as:

- Mechanical handling equipment (MHE), e.g. industrial trucks (IT), stacker cranes / Storage & Retrieval (S/R) machines, shuttles, conveyors.
- Racking or shelving (R&S).
- Unit Loads (UL's) to be stored, e.g. pallets, box-containers, bins, cartons
- Automation of MHE, if any.
- Warehouse management system.
- Warehouse building (walls, roof, columns, installations, etc.)
- Warehouse floor, foundation of the Storage System.

Because all these components are interfacing with each other, the combination of the components determine the performance of the storage system, e.g. capacity in terms of storage volume and throughput as well as safety in use.

Effective communication between all stakeholders in all stages of a storage project realisation is therefore of the outmost importance (see Figure 1). Important stakeholders are:

- Developer / Investor of the warehouse building, if any
- End User of the Storage System
- Warehouse building designers
- Floor Designers / Floor Manufacturers
- Specifiers / Storage System Designers
- Suppliers Mechanical Handling Equipment
- Suppliers Racking / Shelving / Mezzanines

To design a warehouse building one first has to specify the intended occupancy. The purpose of a building determines its dimensions and imposed loading.

The function of warehouses and distribution centres is the cost effective storage and retrieval of all kind of goods, in general stacked on load make up accessories such as pallets, containers, bins, cartons etc.

To be cost effective the storage might be in a certain type of racking or shelving, operated by certain types of industrial trucks or storage/retrieval (S/R) machines. In combination with a certain warehouse management system.

Warehouse buildings can be realized without knowing the specification requirements coming from the Storage System to be implemented by the End User. This can result in an inefficient or compromised Storage System affecting the original investment decision.

To guide all parties involved, with the aim to minimise the chance on “disappointments”, Product Groups of the “European Materials Handling Association” (FEM) have published a number of “FEM Codes of Practice” related to the Warehouse:

FEM 10.2.14 – 01 / 4.103 – 01	Warehouse floors – Storage system areas operated by Industrial Trucks – Part 1: Tolerances, deformations and methods of measurements.
FEM 4.103 – 02	Warehouse floors – Storage system areas operated by industrial trucks – Part 2: Requirements for design – Interface with Industrial Trucks
FEM 10.2.14 – 02	Warehouse floors – Storage system areas operated by industrial trucks – Part 2: Requirements for design – Interface with Racking
FEM 9.223	Basic data and criteria for the construction of automatic high bay warehouses with distribution systems
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FEM 9.841 / FEM 10.2.10	Storage systems with rail dependent storage and retrieval equipment - Interfaces

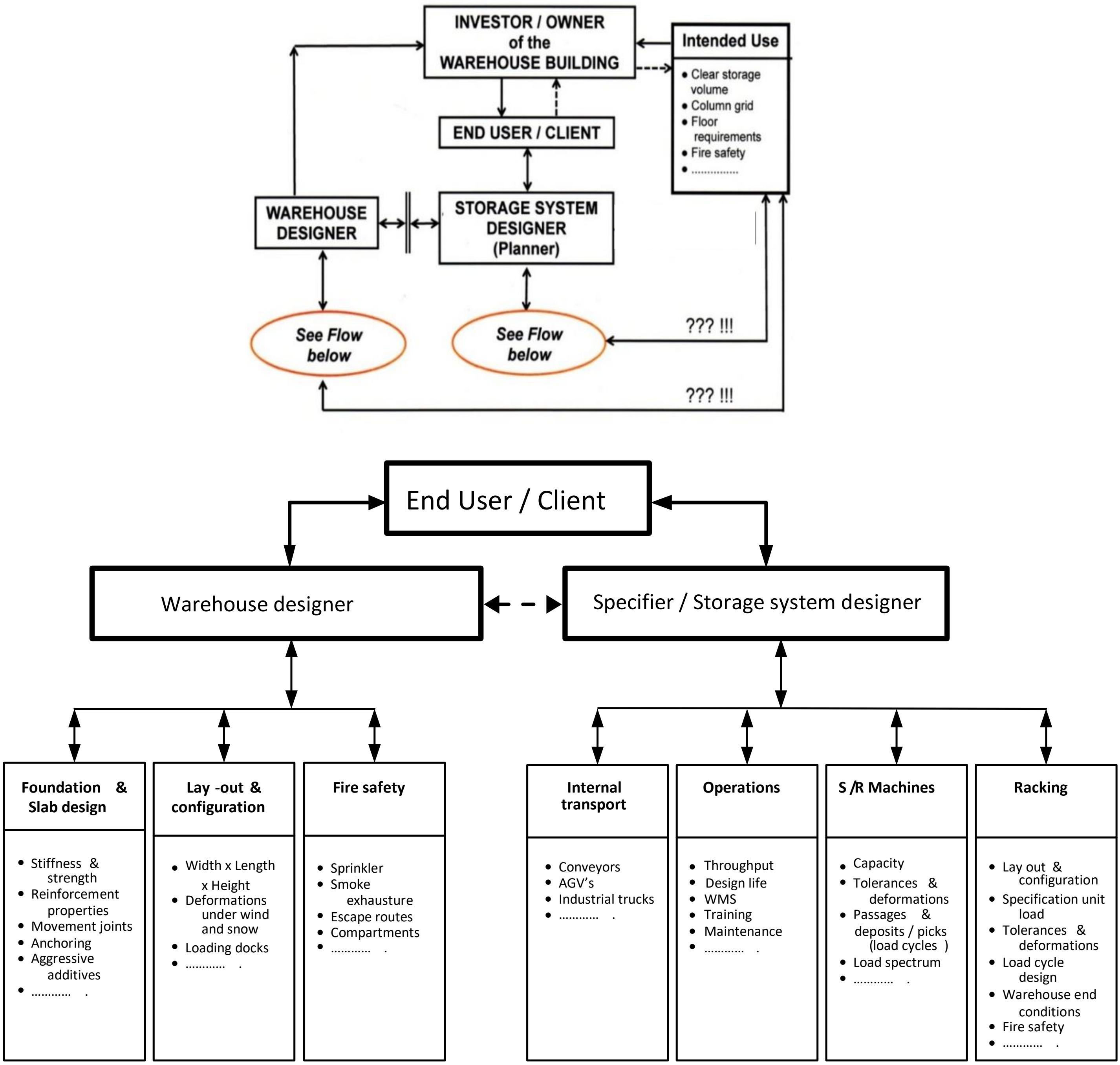


Figure 1: Logistic warehouse design information flow

It shows a typical example, but responsibilities can change / be spread and it does not give contractual relationships

4. TERMS AND DEFINITIONS

For terms and definitions, see EN 15878, FEM10.2.14-1/FEM4.103-1 and FEM 10-2.14 – 2. In addition the following are used in this document or are relevant in the context of this Guide.

deformation	displacement due to actions
End User	company or person who manages and operates the storage system on a daily basis and is responsible for the continuing safety of the system
mechanical handling equipment / MHE	mechanical equipment used to transport the Unit Load to be stored
pattern loading	load combination where certain parts of the structure are not or partially loaded by live loads, which might result in a determinative load combination for certain structural components. In case of warehouse floors: loading situation where the storage area might not be uniformly loaded, e.g. due to variation in stored weights and/or different types of storage equipment and/or the presence of transfer areas adjacent to the storage area
S/R systems ; S/R machines	Storage & Retrieval systems / machines
Specifier System designer	the person or institution responsible for the overall design and functionality of the system, this can be the logistic consultant or the general contractor or the client himself and shall be defined on a project by project basis
sub base / foundation layer	layer of material laid on the subgrade
sub grade	native material (undisturbed soil) under the sub base
tolerance	permissible range of variation of a dimension with respect to nominal, arising from manufacture, assembly or erection, or a combination of these
Warehouse building owner	the person or company responsible for specifying and ordering the building and after realisation the owner of the building

5. WAREHOUSE BUILDING – OWNER IS AN INVESTOR

Warehouse buildings can be realised by investors, who generally do not know the actual way of operation in the future. In such cases a design approach based upon flexibility is recommended.

Special attention is required for the Investor to safeguard that the warehouse building will not be in conflict with the cost effectiveness and safe use of the storage system the End User intends to operate. See also the flow chart of Figure 1.

The warehouse building can also be owned by the End User.

6. SPECIFIER (Storage System Designer in case of S/R systems)

The Specifier is a person or institution responsible for the overall design and functionality of the Storage System, this can be the logistic consultant or the general contractor or the client himself and shall be defined on a project by project basis.

It is the task of the Specifier to combine all relevant factors in such a way that an optimally functioning storage and retrieval system is realized in terms of:

- Capitalized costs
- Customer contentment
- Operational risks are acceptably small
- Safe operation.

This principle of approach is not only relevant to the more complex Storage Systems, but also valid for the more straightforward systems, like e.g. pallet racking operated by reach trucks. In such cases the End-User can be a Specifier (see e.g. EN 15629). Pallet racking operated by Very Narrow Aisle (VNA) trucks are in between. Examples of storage systems racking is involved are shown in Figure 2.

A sound communication between:

- Developer / Investor in coordination with the End User , and
- Specifier

is therefore very important, because Developer / Investor / End User are the persons who are responsible for the warehouse building specification and are directly communicating with the warehouse designer.

7. END USER

The End User is a company or person who manages and operates the storage system on a daily basis and is responsible for the continuing safety of the system

The End User is responsible for the operation of the Storage System in terms of:

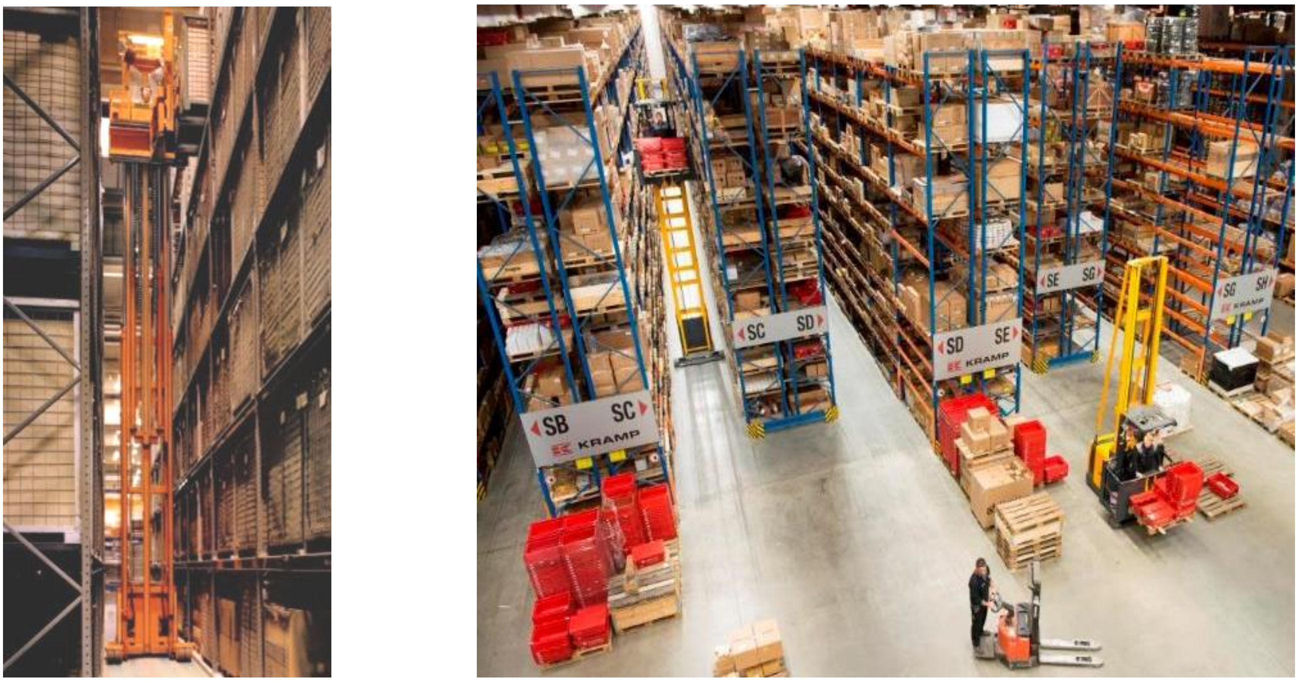
- Operation in accordance with rules and legislation and health & safety of workers at work.
- Operate the system as designed (see EN15635)

The End User is therefore a key stakeholder in the design process of a warehouse intended for Storage Systems.

Reach trucks with

(a) Pallet racking, standard and high lifting

(b) Drive-in racking



c) VNA trucks with pallet racking

Figure 2A Examples of "relatively simple" storage systems, although more and more (partially) automated VNA truck operation

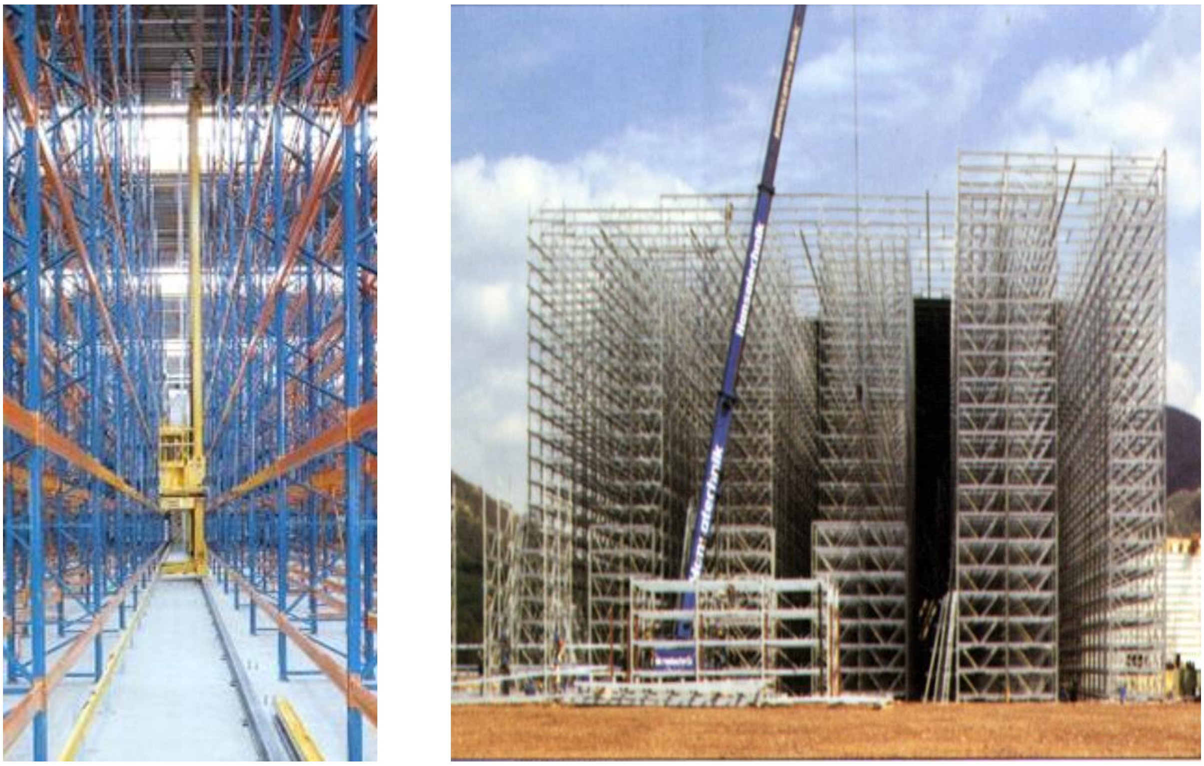


Figure 2C Crane operated racking: free standing and in "clad" rack

Figure 2 D Automated "small part shuttle racking", is becoming more and more important because of the web shops and also requiring very tight floor deformations

Figure 2E A storage system including mezzanine floors

8. WAREHOUSE FLOOR AND ITS FOUNDATION

A successful performance of the storage system depends also on a sound foundation of it: a sufficient strong and stiff warehouse floor. In general it is a concrete floor. If the floor has excessive deformation under load then the performance of the logistic system can be reduced.

The present design standard for concrete structures (EN 1992-1-1) does not specify a requirement for the floor stiffness: deflection or rotation limit value. Therefore the floor stiffness requirement has to be specified on a project to project basis by the principal depending on the occupancy (intended use) of the floor. It should be the outcome of good communication as indicated in Figure 1 and Chapter 5.

The previous version of EN 1992-1-1 (ENV 1992-1-1) did specify as a minimum requirement for floors:
Deflection not more than Span / 300

There are also specific publications by the industrial flooring industry in relation to warehouse floors. Only the Belgium WTCB – TV 122 considers floor deformations and recommends a maximum deflection of 1 / 500 for the occupancy "storage systems".

The following two principle alternatives can be distinguished for the support of the floor slab (see Figure 3)

a. Ground bearing: a floor slab directly supported by the sub grade.
b. Suspended floor: a floor slab not directly and not continuously supported by the subsoil but locally supported by structural elements such as piles, beams, columns.

However, in relation to the effect of floor deformations on:

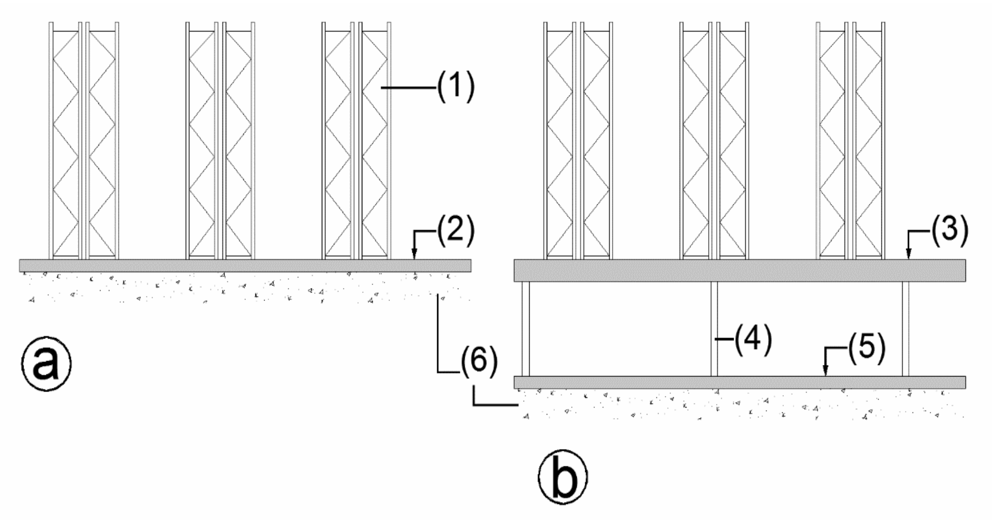
- the performance of storage systems;
- the additional material stresses in the rack structure ,

it is not the deflection but the local floor rotation which is important. See Figure 4.

The ratio between deflection and rotation for a uniformly loaded simply supported beam / plate (see Figure 5) is ca. a factor 3.
For this case, a deflection limit of span / 500 results in a maximum rotation of ca. 1 / 170.

For floors intended to support racking this is quite a high rotation, resulting in an extra out of plumb of a single rack upright frame for a 9 m high rack of ca. 55 mm !!!

Therefore the careful specification of the allowed floor deformation due to the loads induced by the storage system (e.g. racking, mezzanines, mechanical handling equipment) is important !!



Key

1 Pallet racking
2 Ground bearing floor (floor on grade)
3 Suspended floor (here: intermediate building floor)
4 Building column, resp. piling
5 Ground bearing building floor, resp. load bearing pile support
6 Sub soil

Figure 3 Basic types of floor support: ground bearing (a) and suspended (b)

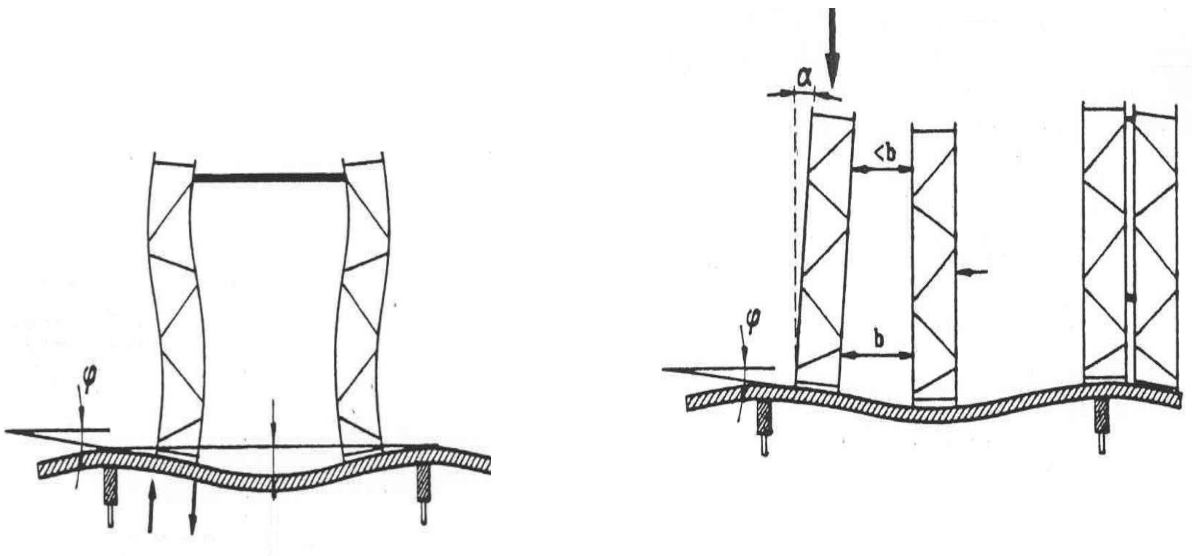
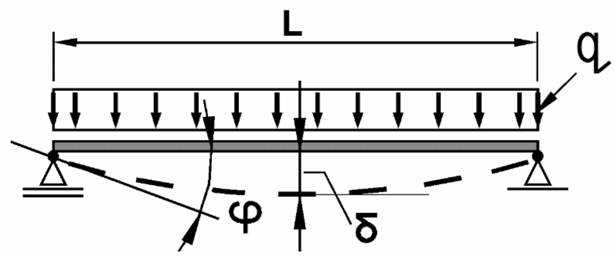


Figure 4: Examples of the inter-relationship rack - floor slab rotation



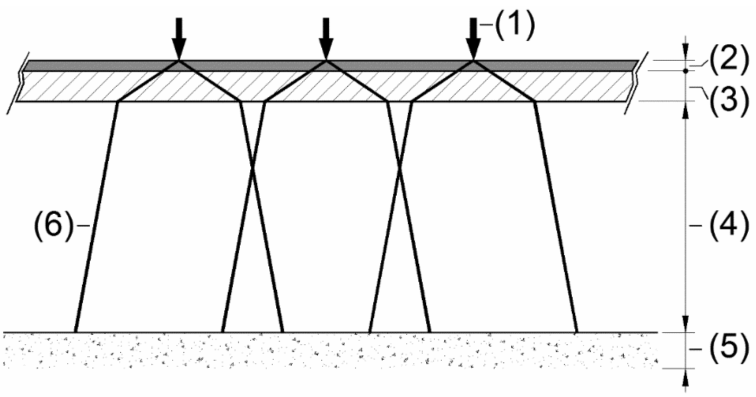
Key

L Span
q Uniform floor load
δ Maximum deflection
φ Maximum rotation

Figure 5 Deformation of a single span suspended floor under uniform load

Deformations of the floor in combination with its foundation, will occur due to a number of factors (see also Figure 6), such as:

- Sub grade / sub soil / deep soil / (original undisturbed soil) behaviour (short term and long-term effects).
- Sub base / base soil (foundation layer) behaviour (short term effects).
- Pile settlement (if present).
- Quality of soil improvement / foundation layer, if any.
- Slab thickness
- Slab reinforcement
- Joints in slab
- Long-term behaviour of concrete (creep)
- Loading



Key

1 Concentrated load, e.g. rack upright load
2 Concrete floor slab
3 Base soil (popular term: “foundation layer”)
4 Sub soil (popular term: “deep soil”
5 Stiff soil, e.g. sand or rock
6 Load spread

Figure 6 Example of load spread for a typical ground bearing slab

Geotechnical factors can cause non-uniform deformations of the floor slab of many centimetres which might result in problems. Soil settlements (as well as the concrete slab creep) are time depending, so potential problems might arise just after a period of 2 – 5 years.

Uneven settlements can be caused by.:

- Possible inhomogeneous subsoil properties over the floor slab area.
- The difference in settlements of the soil that is not loaded (bordering the warehouse) compared to the soil directly beneath the warehouse slab that is loaded
- Non-uniform / pattern loading of the floor slab.
- A combination of the above.

Therefore one should not underestimate the importance of professional geotechnical investigations and design.

Where the floor is in direct contact with the building construction foundation, or both the building and the floor are founded on piles, there is non-uniform floor support. Local differential deformations and cracking of the floor slab can be expected at such locations.. Careful detailing is required to reduce the risk of rack non-verticality and other remedial actions. See Figure 7. The concentrated rotation for situation (a) is much more abrupt than for situation (b): $\varphi_a >> \varphi_b$. Detailing at the building column foundation in line with (b) is recommended.

Evaluation of the factors listed above requires the involvement of the following parties who will need to coordinate their efforts:

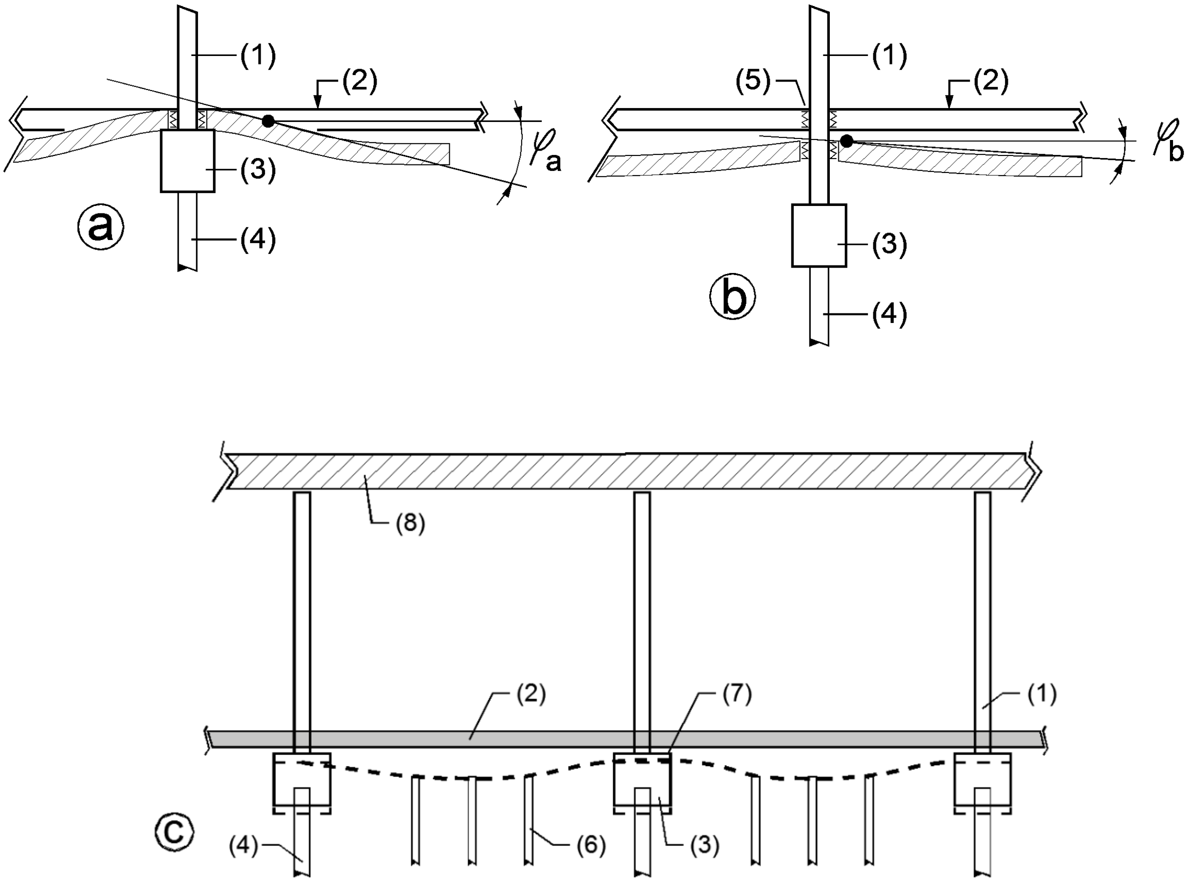
- Geotechnical engineer – soil properties or soil improvement
- Foundation engineer – design of piling (if any)
- Slab engineer
- Rack engineer (if known)
- Specifier

In general the geotechnical engineer will investigate the soil quality and will produce a deformation prediction of the soil + floor with its long term loads.

The foundation engineer will design the foundation of the structure and the foundation of the slab (improvement of the soil or type, grid and depth of the piles).

The slab engineer will design the floor based on the outcome of both geotechnical engineer and the foundation engineer.

In some cases the foundation engineer and the slab engineer are combined in one engineering company.



Key

1	Steel or concrete building column
2	Original position of floor slab
3	Foundation block for the column (foundation string)
4	Pile(s) to support foundation block
5	Separation material
6	Piles to support floor slab. In general relatively weak support compared to foundation block
7	Area floor slab is supported by the column foundation block. Relatively stiff support
8	Roof or intermediate floor

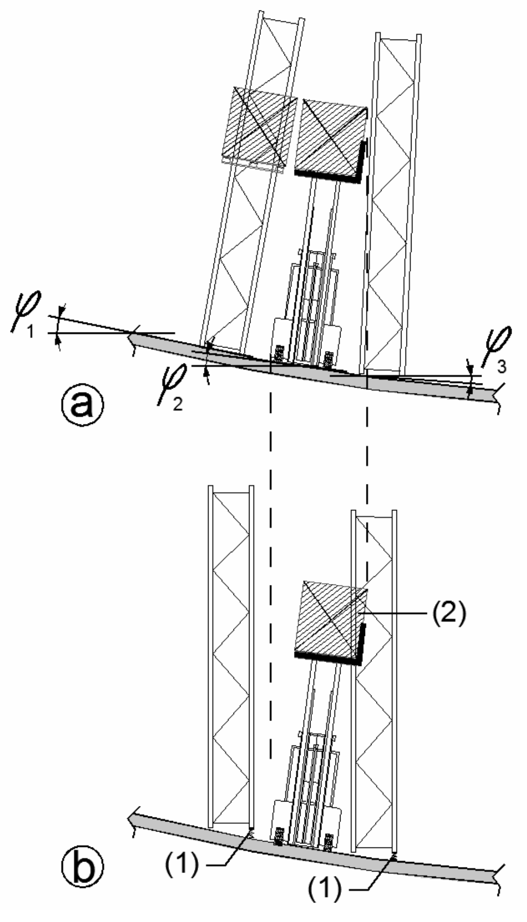
Figure 7 Example of a discontinuity in floor slab support at locations of building column foundations in case of a ground bearing floor,

It is apparent from the above that soil conditions at some sites will have a significant effect on the chance of a successful outcome. Some sites may not be suitable for particular types of Storage Systems, even in combination with piling or soil improvement, and in such circumstances it is unlikely than an enhancement to the slab can overcome the inadequacies of the soil.

9. WAREHOUSE FLOOR INTERFACES

The FEM Codes mentioned in the Introduction are a guidance for considering the interface between the rack structure(s), the mechanical handling equipment (industrial trucks or S/R machines) and the supporting floor. Floor requirements and/or end conditions are given for e.g. :

- Concrete floor flatness and levelness (relating to the type of MHE and optimal performance)
- Floor loads and requirements for design (dependent on the type of storage system)
- Floor deformations (affecting the rack and MHE operation and design). See Figures 4 and 8 ($\varphi_1 > \varphi_2 > \varphi_3$).
- Floor joints (affecting location of storage equipment and MHE guidance; causing local floor irregularities affecting MHE operation)
- Survey methods for floor tolerances.



Key
(a) Situation prior to shimming
(b) Situation after shimming
1 Shimming material
2 Conflict

Figure 8 For safe operation minimum clearances are required (EN 15620). Too large floor deformations may endanger this. Remedial upright frame verticality might get things worse. Example for Very Narrow Aisle Truck racking.

The storage system (racking in combination with mechanical handling equipment) will be designed on the assumption that the loaded floor does not deform by a significant amount over time. What is “significant” depends on e.g.:

- Rack type
- Rack operation
- Rack installation tolerances required.

Guidance is given by FEM 10.2.14 – 01 / 4.103 – 01 for racking operated by industrial trucks) as well as by FEM 9.831-1 / FEM 10.3.01-1 and FEM 9.832 for racking operated by automatic S/R machines..

The floor deformation requirement for racking operated by S/R machines is ca. a factor 3 (!!!) more severe compared to the requirement for standard pallet racking operated by reach trucks. The first versions for FEM 9.831-1 and FEM 9.832 are published quite some years ago: 1995 resp. 1994. The FEM Codes for warehouse floors in relation to industrial trucks are recently published.

However, in many practical cases for racking operated by industrial trucks this assumption may not be realised in which case the effect of all of the influencing factors needs to be considered to achieve a good cost effective and operationally effective outcome.

10. WAREHOUSE BUILDING SUPERSTRUCTURE

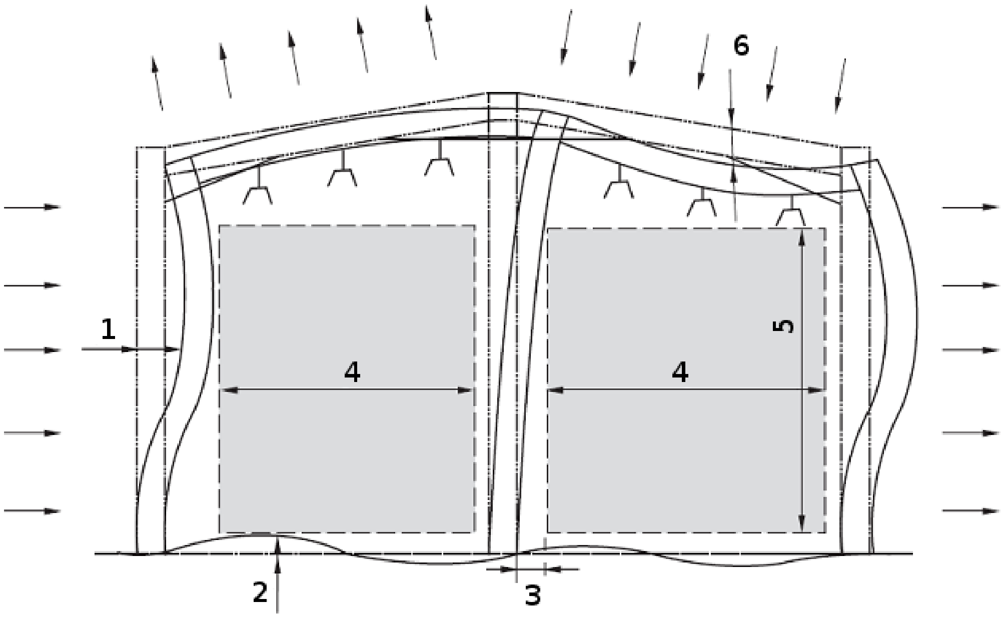
Also the warehouse building is a component of the storage system to be realized within the building. For instance, when determining the internal effective volume for storage in the warehouse building, also the negative effects of deformations and tolerances of the warehouse itself (e.g. columns, roof, wall) must be taken into account. See Figure 9.

In principle it is possible to deviate from specified requirements in relation to the storage system, for technical or economic reasons or in case of an existing warehouse, provided that the functionality and safety in use of the whole system can be guaranteed. However, in this case clear agreements have to be reached between parties regarding the means by which the main aims will be achieved.

The storage volume needed is determined by e.g. :

- Type of racking.
- Rack operation determined by dimension of Unit Loads and mechanical handling equipment.
- Installations: heating, lightning, sprinkler, etc.
- Tolerances and deformations of storage equipment and MHE.

Pallets with overhang (Figure 10) will need more storage volume. When this is overlooked in the design specification of the warehouse and/or Storage System design, it will lead to loss of storage locations within the available storage volume.



Key

1 side wall structure wind deflection based upon National Standards design wind load
2 highest point on the floor
3 deformation of the column
4 effective clear width between columns
5 effective clear height between the floor high point and the lowest ceiling obstruction
6 deflection of the roof

Figure 9: Example of building deformations due to wind and other loads of importance in assessing the effective volume available for storage in racking (= Sum of blocks (4) x (5))

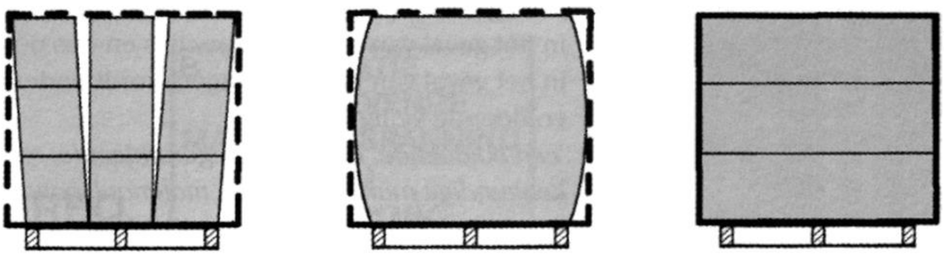


Figure 10 Examples of a Unit Load: "Pallet with overhanging goods"