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Light-weight Steel Based Floor Systems for Multi-storey Buildings

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LIGHT-WEIGHT STEEL BASED FLOOR SYSTEMS FOR MULTI-STOREY BUILDINGS

by

ECCS-Committee AC 1 "Multistorey Buildings" conducted by

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1. Introduction

In the design of structures for multi-storey office and residential buildings, schools, hospitals etc. floor construction is of great importance with respect to performance and economy. The floor is not only a space-enclosing and load-bearing member, but rather a technical subsystem subjected to functional requirements such as fire protection, sound insulation and climatic protection as well as the zone of horizontal distribution of heating, ventilating and sanitary installations, power supply and communicating systems. Consequently, the economy of floor systems depends not only on the construction expenses which constitute a large part of the total building shell costs, but to a high degree on the ensuing costs for satisfying the functional requirements mentioned above.

The object of this paper is to present new trends in the development and application of steel based floor systems.

It mainly covers "dry" steel floor systems, in contrast to the well known composite floors of concrete and trapezoidal sheeting, i. e. floor systems where loadbearing steel elements are combined with sheet products of other materials. The supporting structure consists of linear or plane steel elements, the superstructure consists of elements satisfying the functional requirements as well as possible. The load carrying capacity is ensured either by the supporting structure alone or by the composite system. Another possibility is to make "passive" use of the composite action, i. e. the increased stiffness caused by the composite action is accounted for only in the working load state.

A characteristic feature of these floor systems is the relatively small weight of the floor (in relation to the surface) which poses particular problems with regard to sound insulation as well as the use of combustible materials which requires special fire protection measures.

The purpose of this paper is to present fundamentals for the development of adequate products and to show the possibilities of using lightweight floors as well as the limitations.

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The paper refers primarily to those in the relevant industry and to architects and consulting engineers doing project work in multi-storey construction. Furthermore, the paper applies to manufacturers of prefabricated single or two-storey residential houses as in this field lightweight construction on the basis of thin-walled cold-formed sheet steel can lead to economical product improvement.

2. General Functional Requirements /1/ - /3/

The ceiling is a subsystem of the total technical system of a building and has loadbearing, space-enclosing and servicing functions (see Fig. 2.1).

An essential part of the project work is to satisfy the functional demands including overriding functional requirements specified in technical building regulations as well as specific application-oriented requirements and economical aspects. The combination of essential and quality-oriented requirements implies the careful optimization of the system taking account of servicing requirements.

The problem of horizontal servicing in the floor zone is illustrated by a one-corridor office building and a residential building, respectively (see Fig. 2.2).

As can be seen, considerable space is required for servicing. This means in any case that either the overall height of floor and supporting structure must be limited or necessary clearance must be available, which, on the other hand, affects the structural design of the floor.

The "general functional requirements" mentioned below are requirements for the design of the floor made by the construction authority, the users or the owner. These functional requirements may be listed as follows:

I) load carrying capacity
II) stiffness
III) durability
IV) fire protection
V) sound insulation
VI) climatic protection
VII) room environment
VIII) servicing facilities

The requirements I - III are overriding and independent of the type and utilization of the buildings, whereas the other requirements are "building-dependent" and - beyond the minimum requirements - quality oriented. The minimum requirements are specified in national standards; quality oriented requirements - at the request of the users or the owner - can be considered as improvement measures and are subject to economy aspects.

Requirement VII, room environment, includes, beyond requirements I - VI, those qualities that are necessary for the physiological well being of the users. A pleasing atmosphere has a considerable influence on whether a building method is acceptable to the users or not.

Requirement VIII (servicing facilities) has a special position as installations are laid in vertical and horizontal zones of the structure, and it therefore has an important influence on the structural design of the floor and the realization of requirements I - VII.

Technically, the above requirements are not independent of each other; the only purpose of the formal breakdown is to facilitate the analysis of appropriate measures to satisfy the requirements.

2.1 Requirements on the part of the building authorities

The requirements on the part of the building authorities are defined in national standards. As a rule, they are minimum requirements and cover the following necessary statements:

I)	load-carrying capacity:	analysis of stability and serviceability under designated nominal loads
II)	stiffness:	observance of deflection limitations
III)	durability:	preservation of the functional stability (I + II) considering the long-term behaviour of the components and the expected load pattern
IV)	fire protection:	observance of the fire resistance grade depending on the type of structure and the fire-related function of the floor considering material properties such as inflammability, combustibility, development of fumes, toxity of fumes
V)	sound insulation:	observance of tolerance dimensions depending on the type of structure and the sound-related function of the floor (airborne sound, footstep sound, flanking transmission, sound absorption, annoyance caused by noise)
VI)	climatic protection:	observance of thermal insulation requirements depending on the climatic conditions or, respectively, the utilization above and below the floor; particularly when the floors cover the walled-in space from the external climate, problems such as vapour diffusion, air permeability, convection and heat capacity have to be taken into consideration

2.2 Requirements on the part of the users

The minimum requirements on the part of the users are covered by the building authorities' regulations. Increased demands may be the result of special utilization requirements and are then part of a contract with the owner. They can be improvements or special solutions concerning stiffness (III), sound insulation (V), climatic protection (VI), room environment (VII) or servicing (VIII). A carefully designed floor system should allow for such functional improvements or modifications.

2.3 Requirements on the part of the owner

The requirements on the part of the owner are mainly value and quality improvement measures beyond the minimum requirements of 2.1 and include the requirements of 2.2. As before, they are either increased functional demands or measures allowing for future modifications in utilization or equipment standard, e.g. improved load carrying capacity of the floor, variable interior finish, updating of heating system etc. A floor system must be variable enough fur such modifications as well.

2.4 Consequences and conclusions

The total demand on a floor system is the sum of

minimum requirements,	partly generally valid, partly building dependent, defined in technical building regulations, and
additional demands,	quality or value improving measures at the user's or owner's request.

It is therefore essential for floor construction that a basic system is available which fulfils the minimum requirements and can be modified by appropriate measures to satisfy additional quality demands.

As the type and extent of minimum requirements also depend on the type of structure and components, it is advisable to prepare application oriented quality profiles defining the minimum and additional requirements qualitatively and quantitatively and to use them as a basis of the product development. Section 3 gives examples of such quality profiles.

3. Specific Quality Requirements (Quality Profiles)

The specific functional requirements of two selected floor types are exemplified below. In order to explain the different quality demands, various floor types (office building, residential building) and ambient conditions were chosen.

Consider requirement VIII (servicing facilities) to be a planning problem and presume that the application oriented requirements on servicing (extent, space requirements, replaceability of short-life components) are considered in the functional requirements I - VII.

As international regulations are not uniformly stringent, the requirements are presented in a six-grade scale:

0 =	no requirements	3 =	moderate requirements
1 =	low requirements	5 =	high requirements

These grades can then be quantified according to the respective national regulations (e.g. different time requirements concerning fire resistance s. Fig. 3.1). As the partial requirements of the indicated functional requirements (I - VII) have more or less influence on the design of the floor, they are subdivided further in the following examples (Figs. 3.2 - 3.3). The variables which are of particular importance and have to be taken into account will have to be assessed for each individual case. The quality diagrams presented in this paper are only models as the planning fundamentals are not specified in detail. However, they illustrate the whole spectrum of possible quality demands.

3.1 Multi-storey office building; ceiling (Fig. 3.2)

The characteristic features of the ceiling in a multi-storey office building are stringent requirements concerning fire protection and sound insulation as well as stiffness. The comparatively stringent requirements concerning installations in the ceiling area are covered by requirement VIII.

As in Fig. 3.1, the quality requirements are subdivided into "minimum requirements" and "additional requirements". The additional requirements are illustrated by examples whereas the minimum requirements are given in the pertinent regulations. The quality profiles given are not complete and have to be supplemented in each individual case.

3.2 Single-storey residential building; attic floor (Fig. 3.3)

The most important feature of roofs in residential buildings (unless the attic is habitable) as well as in office buildings is the thermal protection. Fig. 3.3 shows a quality profile which takes into account two essential additional requirements of the owner, i.e. that the thermal protection exceeds by far the minimum requirements and that the attic can be made habitable which has to be considered in the static design of the floor. For such alternatives it is therefore advisable that the construction should be variable, i.e. in this case, the thermal insulation should be arranged above the floor.

4. Appropriate Building Materials and Components

The different functional requirements shall be satisfied by an appropriate floor system. As there is no ideal material which is able to perform all functions, the problem is to satisfy different single requirements at the same time by choosing appropriate components. This, however, results in "composite systems", in the broadest sense of the word, where the compatibility of the different combinations of materials and the composite action are particularly important.

It must be pointed out that the elements referred to in the following are sheet products which are offered on the building material market.

Further product development should yield products able to satisfy more complex quality demands (e.g. materials which have at the same time several protective capacities).

4.1 Steel components

It is essential for the construction of lightweight floors that the carrying capacity is provided primarily by steel components. For composite structures with concrete it can be presumed without any restriction that the ultimate load state is characterized by the failure of the composite system; for composite structures of steel components and other sheet materials, considering the actual state of knowledge, the restriction is that the working load is just supported by the steel section. The loadbearing members can be linear and plane steel components. (Examples are shown in Fig. 4.1 and 4.2)

As a rule, a zinc coating of 275 g/m^2 provides sufficient protection against corrosion unless the floor is subject to exceptional humidity conditions.

The choice of the loadbearing members depends on the required load carrying capacity and the necessary stiffness considering the expected composite action.

For cold-formed loadbearing members, product development, depending on the possible manufacturing process, should be made considering the following parameters:

a) function of the loadbearing members
b) types of loading and failure
c) material strength
d) initial width of coils
e) cold-forming process (bending press, folding machine, continuous rolling)
f) protection against corrosion (continuously galvanized steel sheet, $t \leq 3$ mm)
g) type of fasteners
h) stackability of elements
i) combinations of elements

4.2 Supplementary components for composite structures

The traditional type of composite construction is the combination of steel elements and in-situ concrete. (See "Composite Structures", ECCS-publication 1981 /4/.)

This paper discusses "dry" floors, i.e. built up of different components of inorganic or organic materials, e.g. plates of fibre concrete, gypsum, asbestos cement, plywood or wood fibres (see Fig. 4.4). The connection between steel component and supplementary composite material can be elastic or rigid. It can be achieved by mechanical fasteners or by bonding.

The basis of design is the elementary theory of composite construction, where the geometric parameters of the composite section are, as usual, referred to the elastic modulus of the steel section. The time- and load-dependent physical properties of the composite section have to be taken into account.

Besides thin concrete, plates of plywood, chipboard and gypsum plaster are suitable for such floors as they can contribute to the carrying capacity. At present, however, there are only few significant data on the long-term behaviour of the physical properties under the permissible stresses in such materials. The relatively low elastic moduli indicate the necessity to develop special shapes for composite systems. As the plate thicknesses of the mentioned materials are relatively small, the effective width of a compressed cross-section is limited accordingly ($b_e = 200 - 400$ mm)

The composite action can therefore be reasonably considered to be:

a) reinforcement of thin-walled sheet steel susceptible to buckling
b) two-dimensional composite action for sheeting and panels
c) linear composite action for cold-formed section and beams.

The effect of a plane composite structure (b) can be illustrated by means of the equivalent value of the steel thickness t_{si} for different plate materials and thicknesses in Fig. 4.4, where, in particular for plywood boards, the value t_{si} is of the order of magnitude of the actual sheet thickness (t = 1,0 mm).

The effect of other materials must not be underestimated, if compressed zones susceptible to buckling are stiffened (a), as this increases the effective width of the steel section. These ratios are shown in Fig. 4.3 for a C-section in bending (type 1 - 4). In case (c) it has to be considered that the plate materials act as the compression flange of the composite structure and that the load is transferred transversely. With regard to this and to the limited effective width of the plate material, the spacing of linear load-bearing members is restricted and should not exceed about 400 mm for floors with wooden boards. The linear composite action is therefore especially convenient if cold-formed sections are used. The effect of such a composite system is shown in Fig. 4.3 (type 5) for an "inverted" C-section.

The fundamental statement of Fig. 4.3 is that

1. using wooden or gypsum boards in two-dimensional action, the stiffness of a thin-walled steel section susceptible to buckling can be raised to a value corresponding at least to the stiffness of an unbuckled section,
2. in the case of linear composite action considering the load carrying capacity of the composite material and appropriate profile geometry, the stiffness can be considerably increased.

The same applies to the load carrying capacity provided that the composite action is guaranteed until the limit state is reached (design load) (see section 5).

With regard to the fact that in the working load state the stresses in the composite section are relatively low and the stiffness of lightweight floors is of particular importance, it is efficient to actively utilize the increased stiffness due to composite action.

The means of achieving composite action can be mechanical fasteners, such as self-tapping screws, drilling screws, rivets, nails or powder actuated fastners, or - in the case of prefabrication - appropriate adhesives (e.g. polyurethane) perhaps in combination with screws or nails. In order to determine the composite action the load carrying capacity and the flexibility of the connections, experimental investigations have to be carried out. It is pointed out that some flexibility of the connections often has a favourable antivibration effect.

4.3 Further supplementary components

In order to satisfy the remaining functional requirements such as fire protection, sound insulation and climatic protection, further components with appropriate protective qualities are required. In the following, they are described as types of materials; the object of further development, however, is to integrate several functions with a minimum of materials.

4.3.1 Fire protection

The required fire resistance of lightweight floors is achieved by means of mineral fibre, glass fibre or gypsum boards or appropriate combinations of theese materials. In principle, all plate materials providing adequate fire protection in conventional steel construction can be used. General rules for thicknesses and types cannot be given, as the fire resistance depends on the general design of the floor.

Components, whose fire resistance cannot be determined on the basis of current regulations, must be approved by the construction supervising authority.

The following data on the fire protective effect of ceilings, which can be used as guide lines for the design, have been gathered from Swedish studies /5/:

For lightweight floors, suspended ceilings of gypsum, vermiculite, perlite or mineral fibre products are often used. The following steel temperatures δ_s [°C] depending on the fire duration t [min] and the insulating property d_i/λ_i [$m^2 \cdot °C/W$] of the ceiling can be used as guide lines for the design of thin-walled steel sections: (d_i = thickness of ceiling [m]; λ_i = thermal conductivity [$W/m^2 \cdot °C$])

d_i/λ_i [$m^2 \cdot °C/W$]	t =	30 min	60 min	90 min
0,05	δ_s	340	460	550
0,1		210	350	410
0,2	[°C]	150	220	290
0,3		110	180	220

Besides the influence due to fire from the lower side, the effect from the upper side as well as the pertinent regulations concerning inflammability and smoke development of the surfaces have to be taken into account.

Furthermore, space-enclosing members are subjected to regulations concerning

- prevention of fire spread,
- allowable temperature rise on the side opposite to the fire,
- prevention of the development of combustible gas,

as well as to to conditions depending on the required fire resistance class.

4.3.2 Sound insulation

A characteristic feature of "dry" lightweight floors with regard to sound insulation is the relatively small mass and the multi-layer construction.

In order to attain sufficient insulation against airborne and footstep sound, the floors has to be constructed of adequate layers of flexible and rigid elements. This applies not only to the floor structure proper, but also to the combination of floor and sub-floor. "Floating" facings (similar to the floating floor finish) provide good airborne and footstep sound insulation. If lightweight partition walls are used, special measures (e.g. severance cuts in the facing) may be necessary to avoid sound bridges. Separate shells (e.g. floor and sub-floor), perhaps in combination with a soft intermediate layer, have a similar, favourable effect. Textile covers provide good airborne and footstep sound insulation.

The airborne sound insulation depends on the inert mass of the member and - for multi-layer structures - on the flexural strength and the insulating property of each layer.

Structural sound insulation is achieved by preventing sound excitation (e.g. flexible floor coverings or intermediate layers), sound distribution (e.g. flexible, insulating sub-floors) or by interrupting the sound transmission (e.g. by floor shells which are independent of each other).

The prevention of sound bridges near floor supports, wall joints and installations as well as the airtightness of the structure or the layers, respectively, is particularly important.

As a rule, the observance of required sound insulation has to be proved by tests. The requirements concerning sound insulation can be satisfied by the mentioned protective materials or by multi-layer construction.

4.3.3 Climatic protection

Effective thermal insulation is usually achieved by insulating materials on the basis of mineral fibres or glass fibres, by rigid expanded plastics, cork insulants or by insulants in bulk. Such insulating layers can be applied within the structure, between floor and ceiling and, for attics, above the floor.

For floors under varying temperatures and humidity conditions, measures may be necessary to avoid water condensation.

4.3.4 Stiffness

Lightweight floors are vibratory systems which can be excited by foot traffic and may be felt as unpleasantly springy in the case of unfavourable combinations of vibration characteristics such as amplitude, natural frequency, acceleration, damping.

At present, the detailed analysis of the mentioned vibration parameters is, as a rule, replaced by criteria based on the stiffness.

A Dutch paper /7/ makes the following suggestions:

1. Avoidance of subjective aspects (visible sagging) $\delta \leq \frac{L}{250}$
2. Avoidance of building failure (cracks in partition walls) $\delta_{add} \leq \frac{L}{500} \div \frac{L}{600}$; $\delta_{add} < 10 \div 20$ mm
3. Avoidance of resonance for floors subjected to normal foot traffic (residential buildings, office buildings) $\delta_{stat} \leq 18$ mm
4. Avoidance of subjective aspects due to vibrations $\delta_{stat,f} \leq 0.5$ mm
5. Avoidance of building failures due to vibrations $\delta_{dyn} < 3$ mm

where

- δ deflection under dead weight and working load ($t \rightarrow \infty$)
- δ_{add} deflection after mounting of partition wall
- δ_{stat} deflection under dead weight and half the working load ($t=0$)
- $\delta_{stat\ f}$ deflection under a concentrated load of 1 kN
- δ_{dyn} amplitude of vibrations under dynamic loading

Reference /7/ gives several sources concerned with the design of lightweight floors on the basis of dynamic loading /8/- /10/.

The above-mentioned stringent requirements concerning stiffness seem to restrict the usability of lightweight cold-formed sections. The required stiffness, however, can be achieved by plate materials, which are necessary anyway, as parts of composite structures with elastic or rigid connections. The problems of composite structures of lightweight cold-formed sections and other materials are discussed in /11/. Fig. 4.5 shows that the stiffness of a C-section can be doubled if it is combined with a plywood board or even with a soft board. In this case, the composite components cause the increase of the effective width of the lightweight section.

4.4 Appropriate combinations of materials

It can be concluded from the analysis of functions and materials in sections 4,1 to 4.3 that, by using appropriate materials, different functions can be satisfied at the same time. Insulating materials on the basis of mineral or glass fibres, which are suited for protection, obviously play a central part. By reasonable combination with other "loardbearing" components, lightweight floors can be developed which are able to satisfy the general functional requirements of section 2. Fig. 4.6 illustrates in detail the suitability of the mentioned materials and types of products.

4.5 Fabrication of lightweight floors

The above considerations concerning the structural design and the examples of section 6 show that there are technical solutions to satisfy extensive requirements on function and quality. However, lightweight construction includes, like all other techniques, the criterion of economy including a great number of aspects, such as costs for material, fabrication, transport and mounting and, above all, the questions, who fabricates, on what scale and at what cost ?

The problems arise from the complexity of the components, the harmonization of materials which are generally alien and the problem of functional reliability. Some basic considerations are exemplified in the following for the floor structures according to Fig. 6.2.

The basic element, the principal functional requirements of which are load carrying capacity and stiffness, is an industrially fabricated cold-formed sheet section. The sections are so designed that they can be stacked at least for transport.

In order to improve the load carrying capacity and the stiffness or to satisfy certain functional requirements it may be necessary to connect particle boards frictionally with the sheet section by adhesive or by drilling screws. In order to limit the numer of site connections and to achieve sufficient transverse rigidity, the overall width of the element should be 2400 mm.

To satisfy these conditions, it is apparent that industrial fabrication is necessary for rationalizing the fabrication procedure and for satisfying the application dependent quality requirements. The basic element must be subjected to further product optimization to satisfy the functional requirements of the end product. According to Fig. 6.2 only the sub-floor should be assembled on site, whereas the other components should be supplied as elements.

By means of this example, the most essential aspects of project work in lightweight construction with regard to fabrication can be illustrated. Fig. 4.7 shows that the problem of localizing fabrication is of great importance as both production and processing of the members have to be co-ordinated with actual transport conditions.

It must be pointed out that the materials used often provide little resistance against impact. The degree of processing in the workshop is therefore closely related to the transport and erection conditions as well as to the structural design of the member edges and the chosen protective measures during transport and erection. Otherwise, project work has to follow the general conditions of building with prefabricated elements.

5. Safety Aspects Concerning the Composite Action of Dry Floors

The load carrying capacity of dry composite structures can be determined by means of the theory of composite construction on the basis of specific mechanical properties; as a rule, the load carrying behaviour has to be confirmed experimentally.

The safety analysis must consider the fact that the mechanical properties of the materials used are variable during the service life of the structure owing to environmental conditions (e.g. moisture, shrinkage, creep, chemical reactions etc.). So the sheet section should provide about 40-60% of the carrying capacity of the composite structure.

Besides the structural safety, the working state with regard to serviceability (e.g. changes in shape or angles, vibrations) has to be analysed. Here, the composite section may be completely allowed for.

6. Examples of the Structural Design of Lightweight Floors

The lightweight floors illustrated in Fig. 6.1 to 6.2 differ mainly in the chosen sound insulation measures, which determine the required expenditure.

The common feature of the chosen floors is that the load carrying capacity and the stiffness are provided by the composite action of sheet sections and plate materials such as plywood, flat pressed particle board or cement-bound particle board. The composite action is achieved by adhesive-bonded joints in combination with nails and drilling screws providing at the same time safety against failure of the adhesive-bonded joint. Thus, high quality requirements according to Fig. 3.2 to 3.3 can be satisfied.

Fire protection is, for all types, provided primarily by gypsum boards, the thickness of which depend on the required resistance duration. The fire resistance class F90 (90 min) can be achieved by a double layer of gypsum board in combination with about 50 mm mineral wool (see Fig. 6.2). The chosen system can thus be developed further to satisfy stringend requirements.

For ceilings, climatic protection usually is of minor importance, and can be achieved by mineral wool products. For roofs and unheated attics it is advantageous to apply the necessary heat insulation on the floor. The requirements of an adequate room atmosphere can be achieved by plate materials.

The difference between the floor types considered is the achievable quality with regard to sound insulation.

The floor shown in Fig. 6.1 satisfies only low requirements of sound insulation and can therefore only be used as a roof or cellar floor in single-storey residential buildings, i.e. where sound insulation is of minor importance.

The double-layer floor of Fig. 6.2 is designed for high demands and is able to satisfy the demands on ceilings in residential buildings.

The examples show the way to efficient product development which tends to a basic element satisfying "moderate" statical, thermal and acoustical requirements and is capable of development for higher requirements. For reasons of economy it is not advisable to choose a general system satisfying all requirements.

7. Summary

Lightweight floors on the basis of thin-walled cold-formed sheet steel in combination with plate materials, providing adequate protection from fire, sound and climatic effects, are alternatives to concrete floors. Load carrying capacity and stiffness of the floors can be increased by the composite action of steel sheet sections and plate materials. Further functional requirements can be satisfied by adequate material combinations. Lightweight construction allows prefabrication in the workshop and proper quality control.
Lightweight floors can be used in office buildings, residential buildings, schools or leisure facilities. As to product development, the basic type of the floor structure should be so designed that it satisfies moderate functional requirements and is capable of being developed further to satisfy higher, application oriented demands. It is recommended that the suitability of the chosen system should be verified experimentally after previous theoretical considerations with regard to the function criteria: load carrying capacity, stiffness, fire protection and sound insulation.

8. References

/1/ Hart/Henn/Sontag:
Stahlbauatlas Geschoßbauten. 2. Auflage. Institut für internationale Architekturdokumentation. München, 1982.

/2/ Baehre, R.:
Building Systems in Housing Construction - Perspectives of Development of Housing Industrialization. Swedish Council for Building Research. Stockholm, 1973.

/3/ Baehre, R.:
Entwicklungsmerkmale der Leichtbautechnik, Aussteifungen - Komponenten - Verbund. Document D8 - 1978, Swedish Council for Building Research. Stockholm, 1978.

/4/ Composite Structures. ECCS 1981. The Construction Press, London and New York.

/5/ Pettersson/Magnusson/Thor:
Fire Engineering Design of Steel Structures. Swedish Institute of Steel Construction. Publication 50. Stockholm, 1976.

/6/ StBK-N5. Tunnplåtsnorm. AB Svensk Byggtjänst, 1979. (Swedish regulations for the design of thin-walled, cold formed structural components).

/7/ ISSN 0077 - 5606 Canada Institute for Scientific and Technical Information "Deformation Requirements for Buildings". National Research Council Canada. Ottawa, 1980.

/8/ Koten, H. van:
Sensitivity to Floor Vibration; a Study Related to the 4,4 Hz Requirement of TGB 1970. TNO - IBBC Report BI-70-11.

/9/ Dynamic Problems in Constructions. CUR Report 57. Concrete Association. Zoetermeer, 1972.

/10/ König, J.:
Transversally Loaded Thin-Walled C-Shaped Panels with Intermediate Stiffeners. Document D7 - 1978. Swedish Council for Building Research. Stockholm, 1978 and the Composite Beam Action of Cold-Formed Sections and Boards. Document 1981. Swedish Council for Building Research. Stockholm, 1981.

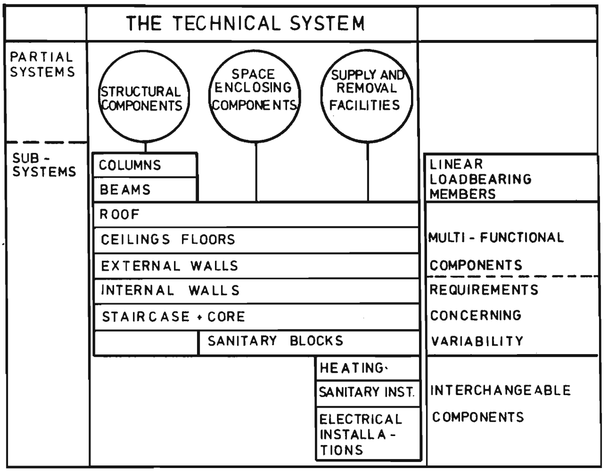


FIG. 2.1: THE TECHNICAL SYSTEM OF A BUILDING WITH PARTIAL SYSTEMS AND SUBSYSTEMS

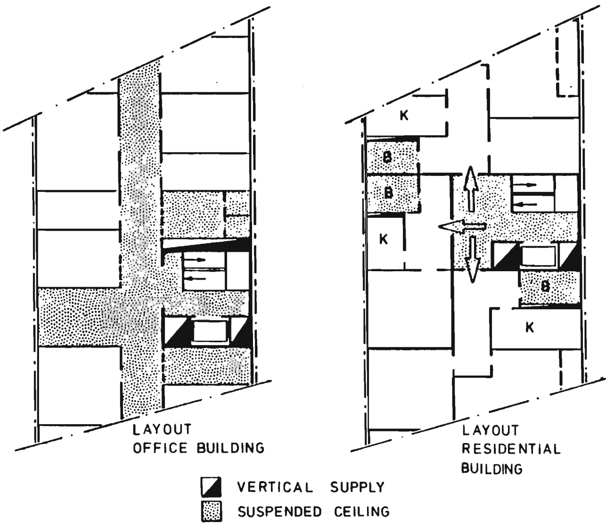


FIG 2.2: ILLUSTRATION OF SERVICING DEMANDS

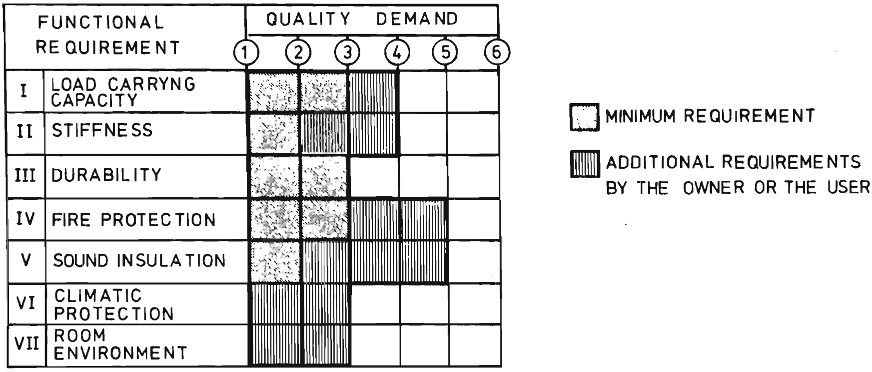


FIG. 3.1: SCHEMATIC SET-UP OF A QUALITY PROFILE

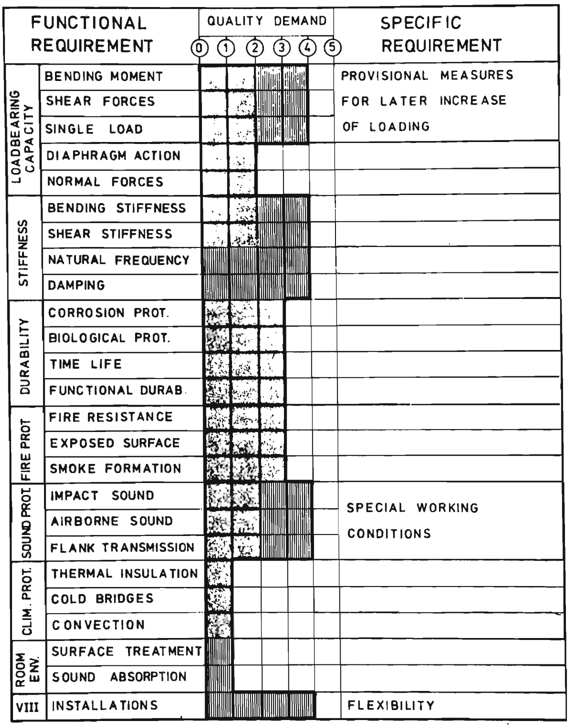


FIG. 3.2: QUALITY PROFILE:
FLOOR IN MULTISTOREY BUILDING (OFFICE)

MINIMUM REQUIREMENT   ADDITIONAL REQUIREMENT

FUNCTIONAL REQUIREMENT		QUALITY DEMAND 0	1	2	3	4	5	SPECIFIC REQUIREMENT
LOADBEARING CAPACITY	BENDING MOMENT							PROVISIONS FOR FUTURE UTILIZATION OF ATTIC
	SHEAR FORCES							
	SINGLE LOAD							
	DIAPHRAGM ACTION							
	NORMAL FORCES							
STIFFNESS	BENDING STIFFNESS							PROVISIONS FOR FUTURE UTILIZATION OF ATTIC
	SHEAR STIFFNESS							
	NATURAL FREQUENCY							
	DAMPING							
DURABILITY	CORROSION PROT							
	BIOLOGICAL PROT							
	TIME LIFE							
	FUNCTIONAL DURAB							
FIRE PROT	FIRE RESISTANCE							PROVISIONS FOR FUTURE UTILIZATION OF ATTIC
	EXPOSED SURFACE							
	SMOKE FORMATION							
SOUND PROT	IMPACT SOUND							PROVISIONS FOR FUTURE UTILIZATION OF ATTIC
	AIRBORNE SOUND							
	FLANK TRANSMISSION							
CLIM. PROT.	THERMAL INSULATION							ENERGY SAVING (THERMAL INSULATION MAY BE REDUCED AFTER COMPLETION)
	COLD BRIDGES							
	CONVECTION							
ROOM ENV	SURFACE TREATMENT							
	SOUND ABSORPTION							FUTURE COMPLETION
VIII	INSTALLATIONS							

FIG. 3.3: QUALITY PROFILE: ATTIC FLOOR IN SINGLE - STOREY RESIDENTIAL BUILDING (ATTIC UNINHABITED)

☐ MINIMUM REQUIREMENT ▥ ADDITIONAL REQUIREMENT

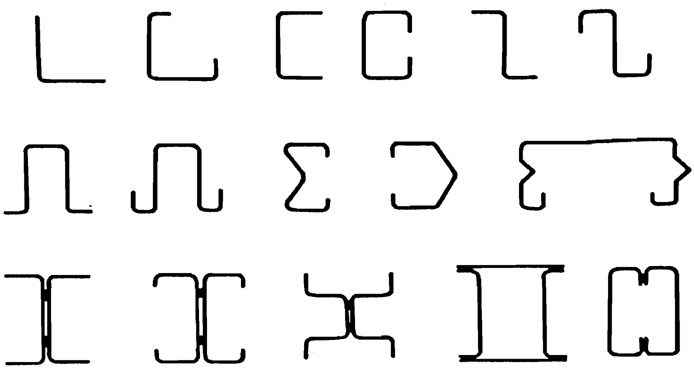


FIG. 4.1: EXAMPLES OF LINEAR STEEL COMPONENTS

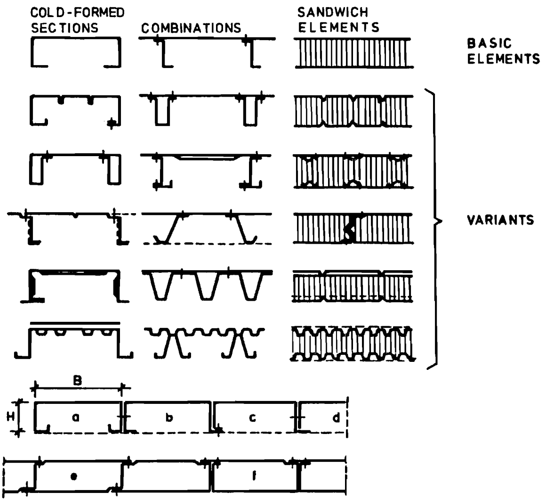


FIG. 4.2: EXAMPLES OF PLANE STEEL COMPONENTS

	SECTION	EFFECTIVE SECTION	EQUIVALENT FLANGE THICKNESS t_{Si} (mm)	RELATIVE MOMENT OF INERTIA I/I_{St}^{*}
1	b, 60	t_F, $b_e = b$	0,7	2,3
2		1/2 b_e	0,7	1,0
3	12 mm PLYWOOD	$b_e = b$, 0,7, 1,1	0,7 + 0,4 = 1,1	2,6
4	13 mm GYPSUM BOARD	$b_e = b$, 0,7, 0,82	0,7 + 0,12 = 0,82	2,4
5	12 mm PLYWOOD	$t_F = 2,7$, 0,7, 0,7	0,7 + 2,0 = 2,7	4,7

FIG. 4.3: THE EFFECT OF COMPOSITE ACTION BETWEEN THIN-WALLED SECTIONS IN BENDING AND DIFFERENT COMPOSITE MATERIALS

material type of product	plate thickness d (mm)	weight per unit area (kg/m^2)	characteristic value of strength (N/mm^2)	Young's modulus (compression) (N/mm^2)	$n = \frac{E_S}{E_V}$ (-)	equivalent plate thickness t_{si} (mm)
1 steel sheet	1.0	8	β_S = 280-350	210 000	1.0	1.0
2 sandwich type plaster board	12.5	13	β_B = 7	2 000	105	0.12
3 sandwich type plaster board	18.0	18	β_B = 5	2 000	105	0.17
4 fibre concrete/steel fibres	20	50	β_D = 600	21 000	10	2
5 asbestos cement sheeting	4	7	β_B = 26	18 000	12	0.33
6 plywood boards AW 100	13	8	β_B = 20	7 000	30	0.43
7 plywood boards AW 100	22	15	β_B = 20	7 000	30	0.73
8 wood fibre boards (hard)	10	8	β_B = 35	2 000	105	0.1
9 particle boards	32	20	β_B = 12	2 000	105	0.3
10 chip board (mineral binder)	12	15	β_D = 15	3 000	70	0.17
11 mineral fibre board (mineral binder)	12	11	β_D = 11	3 500	60	0.2

Fig. 4.4 : Examples of mechanical properties of composite materials and equivalent values of plate thickness (d) referred to sheet steel ($t_{si} = d / n$)

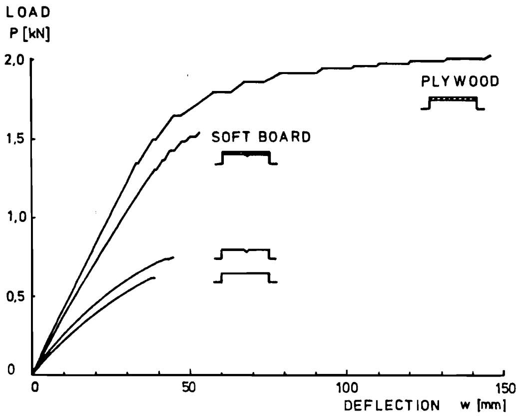


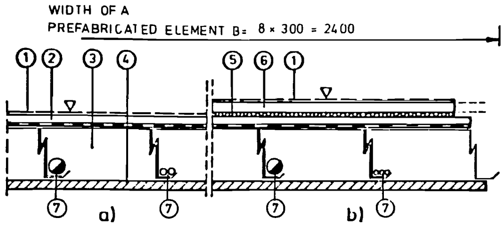
FIG. 4.5 : LOAD-DISPLACEMENT FOR A SINGLE-SPAN GIRDER IN MID-SPAN

BUILDING MATERIALS		FUNCTIONAL REQUIREMENTS						
[■] SUITABLE FOR HIGH REQUIREMENTS [□] SUITABLE FOR MODERATE REQUIREMENTS [ ] SUITABLE FOR LOW REQUIREMENTS [-] UNSUITABLE		I LOAD BEARING CAPACITY	II STIFFNESS	III DURABILITY	IV FIRE PROTECTION	V SOUND PROTECTION	VI CLIMATICAL PROTECTION	VII ROOM ENVIRONMENT
1	UNSTIFFENED SHEET PANELS (GALV)	□	□	□	–	–	–	–
2	AS 1. GALV. + COATED	□	□	■	–	–	–	–
3	STIFFENED SHEET PANELS (GALV)	■	■	□	–	–	–	–
4	AS 3. GALV. + COATED	■	■	■	–	–	–	–
5	20mm FIBRE REINFORCED CONCRETE	□	□	■			–	
6	13mm GYPSUM BOARD			□	□		–	□
7	26mm GYPSUM BOARD	□	□	□	■	□	–	■
8	13mm PLYWOOD	□	□	□			–	□
9	FIBRE BOARD					–	–	■
10	CHIPBOARD	–	–		–			□
11	FIBRE BOARD (MINERAL BINDING)	□	□	□	■		–	■
12	MINERALWOOL	–	–	□	■	■	■	–
13	PLASTIC FOAM			□		□	■	–

Fig. 4.6: Synoptical table of the protective qualities of composite materials

PRODUCTION STEPS	ASPECTS OF PROJECT WORK	CONSEQUENCES
product manufacture	various alien materials in the manufacturing process steel sheets, hard particle boards, mineral fibre boards, plywood boards, mineral wool	storage storage equipment, temperature, humidity, handling
		production line space requirements, stock feed, transport, quality control
	suitable materials for manufacture supply sizes, dimensional tolerances, handleability, mechanical resistibility, working conditions	processing of components shaping of sections, machinery for material processing, rational joining technique
	product quality product control, performance test, documentation, product and performance guarantee, degree of processing	production of elements production time, production capacity, variant limitation, control measures
transport	localization of production stationary production or decentralized production in regional or site factories	degree of processing taking account of transport conditions (road/rail), volume, distance, labour conditions
	transport capacity making available the required capacity, guarantee of supply of components and elements	means of transport optimum utilization of standard vehicles, special vehicles, loading and unloading, lifting devices
	protective measures avoidance of damage in transport owing to mechanical impact	protection suitable protective measures to avoid damage (packing)
erection	lifting devices making available suitable erection equipment	erection units dimensions, weight and fastening of elements
	erection capacity matching of erection capacity and planned construction work progress	erection sequence minimization of time required, optimum utilization of lifting devices

Fig. 4.7: Aspects of project work in lightweight construktion with regard to fabrication



1 FLOOR COVERING

2 PLYWOOD OR FLAT PRESSED PARTICLE BOARD (GLUE AND NAIL WITH 3)

3 COLD FORMED SECTIONS (e g 50/150/300, t=1,0) OR PROFILED SHEETING

4 GYPSUM BOARD

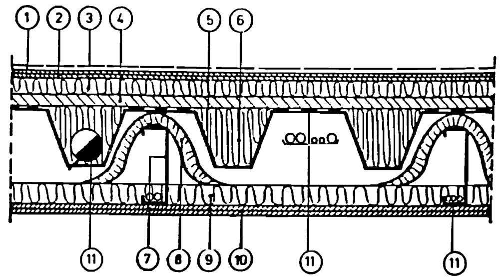
5 MINERAL FIBRE BOARD (GLUED)

6 PARTICLE BOARDS WITH GROOVE AND TONGUE (OR HARD PLASTER BOARD)

7 INSTALLATIONS

FIG. 6.1: EXAMPLE OF A LIGHTWEIGHT COMPOSITE FLOOR WITHOUT (PART a) OR WITH LOW SOUND PROTECTION (PART b)

UPPER SLAB (FLOOR STRUCTURE)



LOWER SLAB (SUSPENDED CEILING)

1 FLOOR COVERING

2 PARTICLE BOARD (CEMENT BOUND)

3 FOOTSTEP SOUND INSULATING BOARD

4 PARTICLE BOARD (CEMENT BOUND)

(2 - 4 PERHAPS AS PREFABRICATED SANDWICH SYSTEM)

5 COLD FORMED SHEETING (CONNECTED WITH 4)

6 MINERAL WOOL

7 COLD FORMED SECTIONS

8 MINERAL WOOL MATS

9 MINERAL WOOL BOARD

10 SANDWICH TYPE PLASTER BOARD

11 INSTALLATIONS

FIG. 6.2: EXAMPLE OF A DOUBLE SKIN FLOOR STRUCTURE FOR HIGH SOUND AND FIRE PROTECTION REQUIREMENTS (e.g. RESIDENTIAL BUILDING)