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05604

United Nations Industrial Development Organization

Distr.
LIMITED

ID/WG.122/7
16 March 1972

ORIGINAL: ENGLISH

Meeting on Prefabrication in
Africa and the Middle East

17 - 23 April 1972

Budapest, Hungary and Bucharest, Romania

STRUCTURAL PROBLEMS IN SYSTEM BUILDING [1]

by

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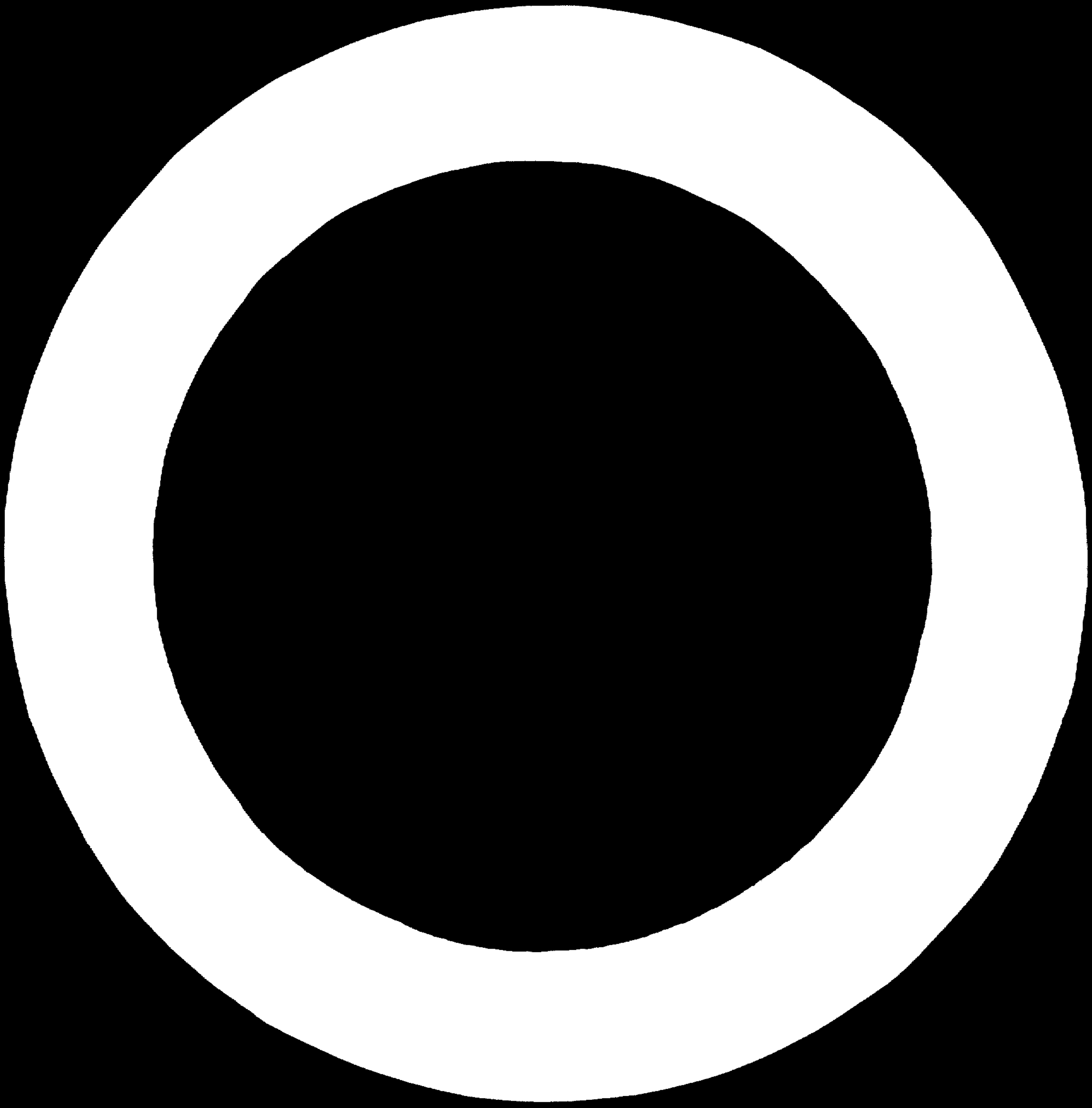


STRUCTURAL PROBLEMS IN SYSTEM BUILDING

2. FUNCTIONAL REQUIREMENTS

2.1. Traditional Legislation

A new type of wall, which will be suitable as dividing wall between two flats, has been invented. The question is whether the inventor shall be able to make the authorities accept this wall. As the first step towards this end it would be natural to study the building codes. Years ago these would probably say that the dividing walls between two flats should be made as a 23 cm brick wall - or the like. The invention - of course - not being a 23 cm brick wall, the job will be to prove that the wall corresponds to a 23 cm brick wall. It is obvious that this wording puts a brake on much progress within building. It cannot be taken for granted that the qualities of the traditional products are on the whole necessary, and if so, that they are sufficient (although as a matter of course they have been). As mentioned before the dividing wall between two flats was formerly almost exclusively effected by means of heavy materials, not because it was demanded that the materials must be heavy, but because until then heavy materials could most easily satisfy the demands for separation of flats.

2.2. List of Functional Requirements

In order not to stop the development of new materials and components it is natural to investigate the possibilities of different solutions. In other words, we must try to set up a list of functional requirements.

From statics we know the formula $\frac{M}{Q} = R$.

In an extended meaning we let M symbolize some kind of external influence (either load, noise, heat, or the like). Q indicates the quality of the building component, its ability to reduce (resist) the influence from outside and R the result wanted, the requirements.

In order to determine the quality of the construction part we must know the influence M and the requirements R.

From the start we are used to consider the influence M as constant within large geographical areas, which of course makes it easier. The influences as noise, heat, etc. should also be considered as constant within large areas. Many examples show that this constant is assumed to be equal to zero. You may be tempted to neglect sound-reducing properties because influences are often small, until one day you are asked to design an office building along a noisy main street, and after construction you will realise that this functional requirement had not been taken into consideration.

In point 2.3 I shall revert to the establishment of influences.

A general list of functional requirements will naturally be impossible to draw up as these depend on the components involved (outer or inner walls, doors, etc.), but examples of detailed lists will be given in point 4.1.

General functional requirements may be listed as follows:

a. Elementary Requirements:

For walls to limit physically
to separate visually
to separate acoustically
to separate termically
to separate air-technically

b. Safety Requirements:

For instance, demands for strength, stability, fire-technical properties.

c. Requirements for Resistance:

For instance, resistance to ageing, use, water, heat.

While a, b, and c could be called primary requirements (indispensable), the following demands could be considered secondary.

d. Comfort Requirements:

Demands for sound-proofing, heat/cold insulation, water- and wind-tightness etc.

e. Technological and Construction-Technical Requirements:

For instance, demands on account of shrinkage and creeping. Demands for transportation and erection.

f. Other Requirements:

For instance, demands for appearance, economy, maintenance.

2.3. Functional Requirements Based upon Scientific Facts

The demands we wish to make on certain components must be quite unambiguous. Obviously quality demands such as "corresponding to 23 cm brick wall" or "good workmanship" are not vary reproducable. We must try to express our demands in measurable values. If we wish to speak about sound reduction in walls for instant, we might try to consider how this demand can be fulfilled. The first demand is made by the client, possibly a demand for a general state of happiness. Doctors, psychologists, sociologists, and people of similar professions can describe this state of happiness as the fulfilment of a number of parametres, one of which is called a certain (low) level of noise. We for our part may determine the demand by saying that loud talking next door may be scarcely heard (but not understood) through the wall. (In this way we have already left out the people to whom the highest kind of happiness is to follow their neighbour's private life.) A still better demand, which is more technical, would be to make a demand for the sound reduction to be at least 50 dB.

From a technician's point of view it is clear that the more parametres for a "state of happiness" can be indicated in numerical values, the more easily the solutions can be found - simply because we know which problems have to be solved.

The moment the functional requirements have been formulated in numerical values, it has been established which methodology is to be used to prove the quality.

Testing methods can roughly be divided into three groups:

a. Laboratory testing methods

b. Control by means of calculations

c. Subjective evaluation by experts

Reverting to the formula $\frac{M}{Q} = R$, M - the size of the influences - is the first factor to be determined before testing. This is quite natural, however, very often our knowledge in this field is limited. Which horizontal loads, static and dynamic, does a light partition wall have to resist - absorb - and how large deflections can we allow ?

When all possible influences have been established - in some instances by loading followed by measuring traditional components - the testing method can be determined.

Functional requirements based upon scientific facts offer the following obvious advantages:

a. Improved communication between client and designer. It is easier to make out specifications if exact and reproducable measuring methods can be referred to.

b. In consequence of item a, improved possibilities of control (and verification) during building (and in some instances after moving in).

c. Provided measuring methods are uniform, the result will be improved possibilities of buying and selling building components between the countries.

d. As pointed out above, it will be considerably easier for the designer and certainly for the manufacturer too, to develop new building components, if it is stipulated in advance which requirements will be made for the ultimate result.

2.4. Conflicting Functional Requirements - the Compromise between Economy and Function

If Q_1, Q_2, ... Q_n indicate the qualities of the component (strength, sound reducing properties etc.), it will be desirable to obtain maximum $Q_1 + Q_2 + \ldots\ldots Q_n$. However, it will often be seen that the optimation of two qualities will be in conflict. This may be exemplified by the wish for good insulation against sound in for instance a wall, which could excellently be fulfilled by using heavy materials, whereas the demand for flexibility is difficult to satisfy if the wall is build of heavy materials. Furthermore, the classical example of quality-economy can be mentioned. In our society the maximum quality in proportion to the price will probably be in demand. This may be expressed as a maximum $\left\{\frac{Q_1 + Q_2 + \ldots\ldots Q_n}{P}\right\}$, P indicating for instance the price of the component, see Johs.F.Munch-Petersen: "System Building Design Philosophy", page 18, where $P = M + \alpha \cdot L + \beta \cdot I$, so that the formula looks as follows:

$$\text{maximum} \left\{\frac{Q_1 + Q_2 + \ldots\ldots Q_n}{M + \alpha L + \beta I}\right\}$$

To my knowledge this maximum has not yet been found - as this would correspond to the invention not of "a wall" but of "the wall".

As mentioned above qualities can be in conflict, and from one building case to the other, qualities are not necessarily equally important. It would therefore be more correct to put the formula as follows:

$$\max.\left\{\frac{w_1 \cdot Q_1 + w_2 \cdot Q_2 + \ldots\ldots\ldots w_n \cdot Q_n}{P}\right\}$$

The designer's job is to choose among - let us say - the floor components on the market at the moment, the one most suitable for the purpose (the floor component which fulfils the most functional requirements in the best way).

This procedure of selection can often be difficult. It requires on the part of the "judge" an accurate evaluation of the importance of the qualities (w , w ,.......), and also on the manufacturer's side an ability to give sufficient information about the qualities of their product, and that this information must be based on uniform measuring methods.

3. TOLERANCES - DANISH EXPERIENCES

As our buildings are made by putting components together, and as we realise the insufficiency of nature, i.e. that the required measures of components cannot be kept 100%, it is necessary to introduce the concept of tolerance.

Danish experience shows that tolerances can be regarded as a "legal" tool on line with the "technical" meaning of the word.

In the following I shall state the justification of this view more closely.

Tolerance, which, as will be known, indicates the limits of variation for a required measure, is most interesting if we consider addition of tolerances corresponding to addition of components.

The first and quite certain principle of addition of tolerances is the so-called rule of addition, where the sum tolerance $T_s \geq T_1 + T_2 + \ldots\ldots\ldots T_n$, where $T_1, T_2, \ldots\ldots\ldots T_n$ is the tolerance of the individual components to be put together as a whole. If components have the same tolerance T, we have for n components $T_s \geq T \cdot n$.

With a large number of components the sum tolerance T_s will be high. If we consider the sum tolerance T_s from a principle of probability, i.e. that the composition most probably consists of both "too large" and "too small" components among each other and not of only large and only small components exclusively, it can be proved that $T_s \geq T \cdot \sqrt{n}$, which means a considerable reduction of T_s. This last method of calculation, however, can only be used under the condition that the number of measures is equally distributed around the measure required, which is practically hardly ever fulfilled.

Form wear for instance will involve a distribution around a value higher than the measure required. Although producers work hard to control deviations, two things must be taken into consideration:

a) The production is so large that control measuring of every single component is not justified from an economic point of view.

b) The production on the other hand is so small that it would not be economically justifiable to discard large quantities of the daily production, as may f.i. be the case by mass production of bottles, bolts etc., where a control measurement may result in scrapping f.i. 100 units without considerable economic loss.

In the above we have deliberately emphasized the economic consequences exclusively, as measuring control, possibly involving scrapping in a factory, must be closely compared with the economic consequences of delivering the component on the building site.

According to our experience the foremen of the Danish building sites have learned to distribute the inaccurancies from one or more components over the other components so that problems seldom arise.

Furthermore, in extreme cases there are different emergency solutions at hand, e.g. for large joints where mounting of a board as shuttering for later concreting saves the calamity. Or for small joints where concrete must be replaced by f.i. elastic sealant.

These are both solutions which are safe (the safety and health of the population must be considered), but which on the other hand are only a matter of economy.

In special cases, where high accuracy is desired, it is also the designer's task to try to use some co-ordinate tolerances to secure as high accuracy as possible. Under certain unfavourable circumstances, however, it may be impossible to mount a component because there may not be room enough.

In such cases it is important to be able to decide who is to carry the economic responsibility, and the specified tolerances are an excellent tool for this purpose.

4. JOINTS

4.1. List of Functional Requirements

As a rule, floor and wall joints will have structural functions only. Facade joints may have many more functional requirements to fulfil, such as the functions listed below, taken from the ISO document ISO/TC 59/SC 5/W61 - 16E.

General Check List for Functions of Joints

Draft proposal for an ISO recommendation.

Functions grouped under Design Aspects

A Control of Environment

A1 To resist passage of insects and vermin.
A2 To resist passage of plants, leaves, roots, seeds,and pollen.
A3 To resist passage of heat.
A4 To resist passage of sound.
A5 To resist passage of light.
A6 To resist passage of electro-magnetic radiation.
A7 To resist passage of air.
A8 To resist passage of odeurs.
A9 To resist passage of water.
A10 To resist passage of water vapour.
A11 To resist condensation.
A12 To resist generation of sound.
A13 To resist generation of odeurs.

B Loadbearing Capacity

B1 To resist stress in one or more directions,
  (a) compression.
  (b) tension.
  (c) bending.
  (d) shear.
  (e) torsion.
  (f) stresses due to impact.

C Safety

C1 To resist passage of fire.
C2 To resist pressure due to explosion.

D Accommodation of Deviations

D1 To accommodate variations in the sizes of the joint at assembly due to deviations in the sizes and positions of the joined components.

D2 To accommodate continuing changes in the sizes of the joint due to thermal, moisture and structural movement, vibration and creep.

E Fixing of Components

E1 To support joined components in one or more directions.
E2 To resist differential deflection of joined components.
E3 To provide fixing of components to structure.

F Appearance

F1 To have acceptable appearance.
F2 To avoid promotion of plant growth.
F3 To avoid discoloration due to algae, moulds or efflorescence.
F4 To avoid pattern staining.

G Economics

G1 To have economic first cost.
G2 To have economic depreciation.
G3 To have economic maintenance cost.

H Durability

H1 To have specified minimum life.
H2 To resist unauthorized dismantling or damage by man.
H3 To resist damage by animals and insects.
H4 To resist damage by plants and micro organisms.
H5 To resist damage by water, water vapour or aqueous solutions or suspensions.
H6 To resist damage by polluted air.
H7 To resist damage by light.
H8 To resist damage by electro-magnetic radiation.
H9 To resist damage by freezing of water.
H10 To resist damage by extremes of temperature.
H11 To resist damage by airborne or structure-borne vibration, shock waves or high intensity sound.

J Maintenance

J1 To permit partial or complete dismantling and re-assembly.

K Ambient Conditions

K1 To perform required functions over specified range of temperatures.
K2 To perform required functions over a specified range of atmospheric humidity.
K3 To perform required functions over a specified range of air pressure differentials.
K4 To perform required functions over a specified range of joint clearance variation.
K5 To exclude if performance would be impaired:
  (a) insects.
  (b) plants.
  (c) micro-organisms.
  (d) water.
  (e) ice.
  (f) snow.
  (g) polluted air.
  (h) solid matter.

Under D I should like to add "shrinkage" and "settlements of the structure". Furthermore, (under F, H, and K) some further functional requirements may be added, such as discoloration or damage on metal flashings (aluminium) from water containing other metals (copper) or acids (H5 or H6 ?), chemical interaction between mastics and surface-treatments, hatching of small birds in open joints (early morning noise) or of insects, snakes, vermin, etc.

4.2. Structural Joints

The following is a short description of considerations on which the design of Danish structural joints are based.

All joints are designed so that the entire floor or the entire wall can act as a plate transmitting in-plane forces only. The individual components have transverse loading as well (viz. wind on facades, dead and live load on floors etc.). All horizontal joints (longitudinal and transverse) are reinforced (sometimes even posttensioned in high-rise blocks), but the components are not welded together. The co-action of the components is based upon the shear-keys on the edges of floors and walls together with reinforcement in the joints. Compression, and in certain cases friction, will also contribute to the structural stability.

4.2.2. The Floor Joint

The floor joint (figure A) requires no formwork, and the chamfered edges of the components enable differences of up to 3 mm between the undersides of the slabs to be camouflaged. The tolerance for component width ± 3 mm is small, and the edges must be straight and smooth.

The finished floor consists of beechwood parquet boards mounted on bearers which rest on soft pads (e.g. wood-fibre) on the concrete slab, the underside of which is painted.

The beech flooring is (with traditional Danish wage rages) the cheapest on the Danish market. This "Floating Floor" has excellent sound-insulation capacity, and provides a space very suitable for placing electrical wiring and pipes for central heating. Flooring involving less labour will bee developed in view of the probable future wage and price levels of an industrialized economy.

As mentioned above the entire floor is assumed to act as a plate for the transfer of wind forces to the bearing (cross-)walls. For this purpose the edges of the slabs are toothed. The teeth act as shear-keys in the cast joint.

An unequally distributed vertical load on floor components can also, owing to the toothed joint edges, be taken up by a diagonal compressive stress between the floor components. The resulting tension component perpendicular to the joint is taken up by the longitudinal joint reinforcement in the floor-wall joint (see this). Tension perpendicular to the joint cannot be taken up by the cast joint mortar, which makes it necessary to reinforce the joint (see later section).

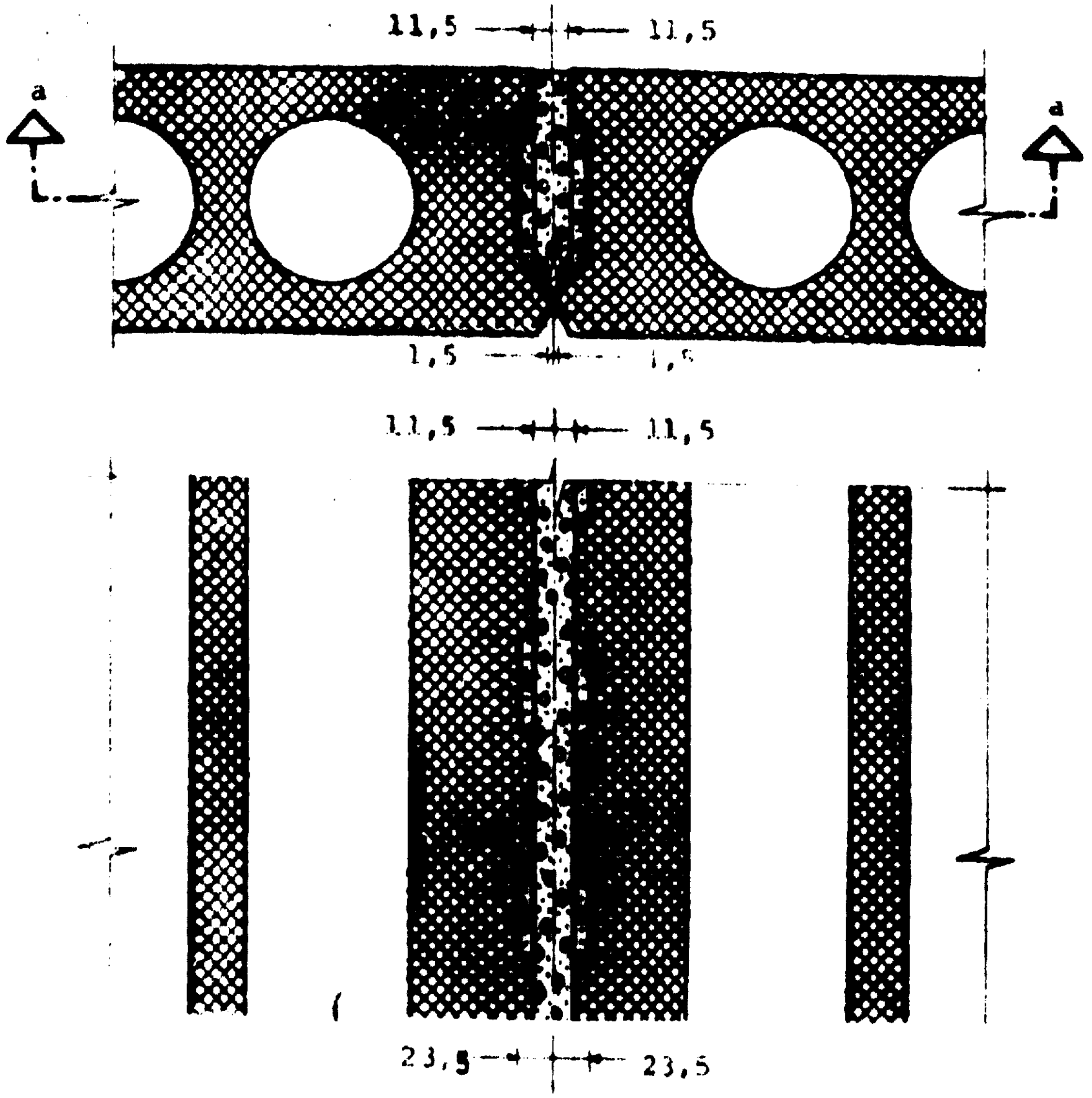


Figure A.

4.2.2. The Wall Joint

The wall joint (figure B) likewise requires no formwork, and the edges of the component are also toothed, so that the entire wall acts as a plate for resisting the wind forces.

Wall components do not as floor components have chamfered edges along the joint for "absorption" of possible inaccuracies, as wall components are filled up and covered with wall paper, whereas the underside of floor components are normally visible.

Walls with cross sections such as L, U, T, etc. are formtechnically very difficult to make, and wall components are therefore joined in the corners. An example of such a corner joint is shown in figure C. Considering the static functional requirements the joint can be reinforced.

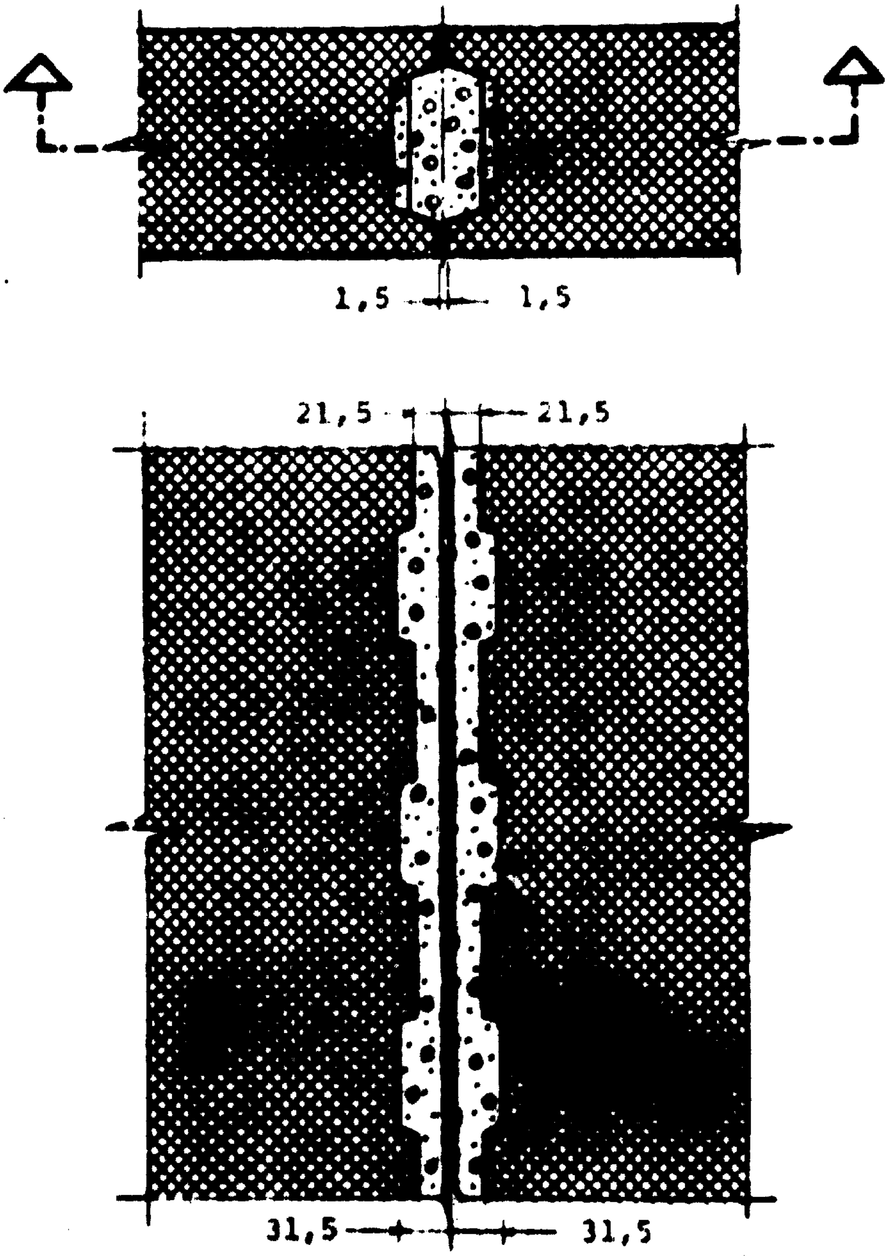


Figure B.

It may be considered to form the joint as shown in figure D. However, attention must be paid to the fact that the concrete of the cast joint will shrink and that the adherence between the concrete of the joint and the wall component is very bad so that sound bridges are very likely.

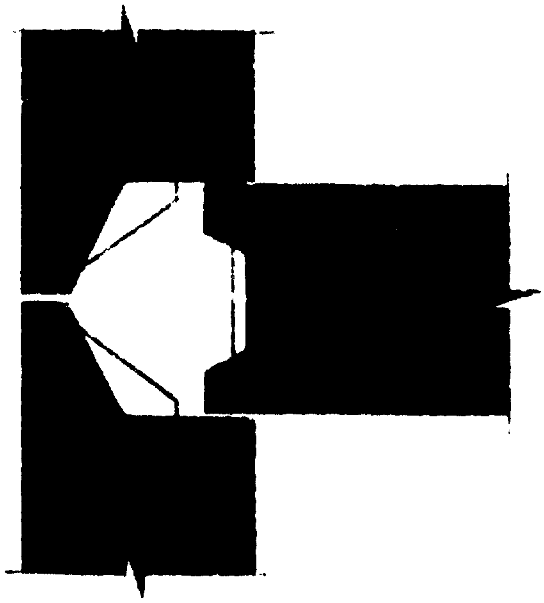


Figure C.

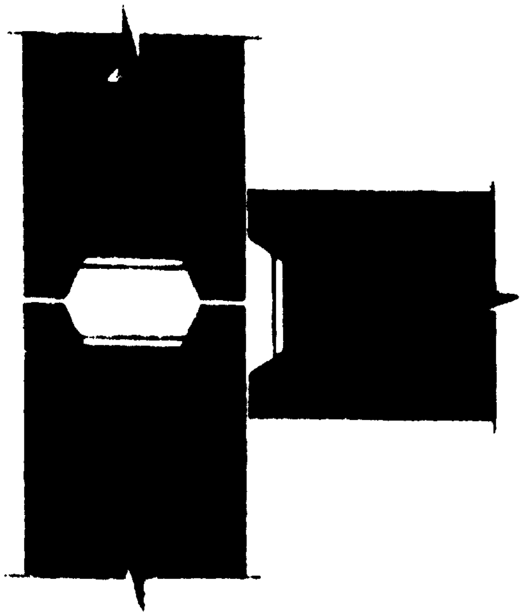


Figure D.

The most important influences to which the wall joint is exposed will be horizontal forces along the joint, these are wind- and mass-forces which are led to the top of the wall by the floor slabs to be passed on by the wall. A number of theories have been made to explain how these shearing forces are absorbed or rather transferred from one wall component to the other.

As for the transmission of shearing forces it is generally so that the more or less pure shearing stresses in the concrete of the joint will involve sloping tensile stresses which will, on reaching a certain level, make cracks in the concrete, this resulting in a widening of the joint. This widening is counteracted by the reinforcement in the floor-wall joint (see this) or by a cross-reinforcement in the joint when a compressive stress from the reinforcement is introduced in the joint reducing the further formation on cracks and "keeping together" the joint until the final state of cracking.

In Denmark engineers normally allow a maximum shearing stress of 2 kp/cm^2 calculated over the total joint cross-section. If a calculation shows higher shearing stress the joint is reinforced. This cross reinforcement between wall components is established by casting so-called "hairpins" in the wall sides, see figure E. Co-action between this reinforcement will arrise partly from the cast joint concrete, and partly from the vertical reinforcement shown.

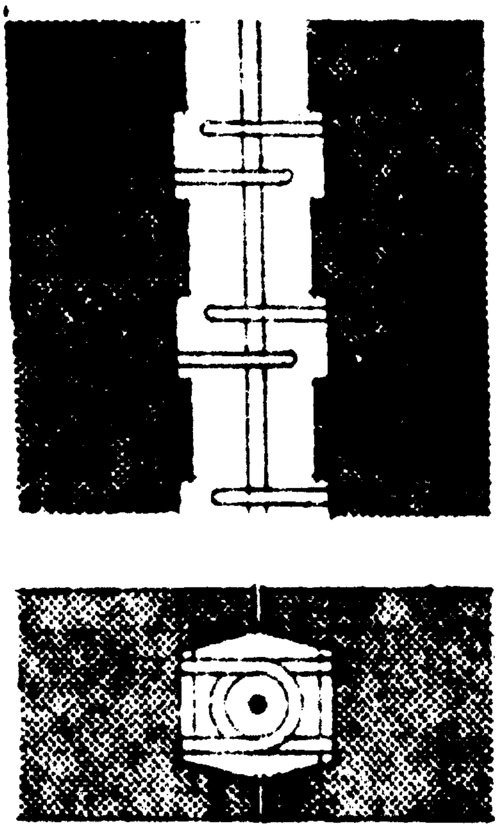


Figure E

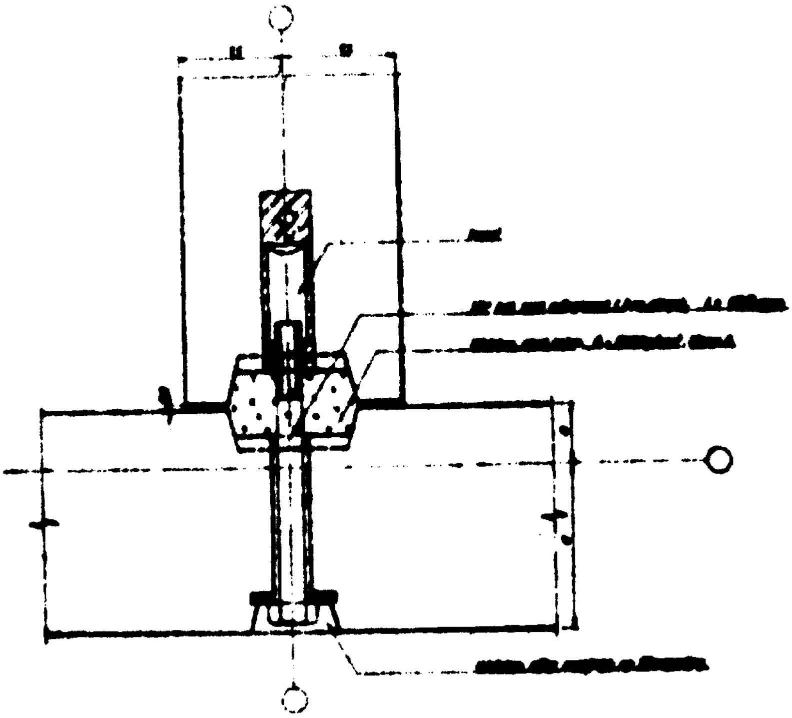


Figure F

Where possible, f.i. in corners, simple bolt joints can be used as shown in figure F.

4.2.3. The Floor-Wall Joint

This joint is shown in figurs G and H. The load on the floor-slabs must be transferred to the wall on which they rest. The load from the wall above the joint must be carried downwards. Regard must be paid to production and erection tolerances. Figure I shows the reinforcement which ensures the co-action of wall and floor components.

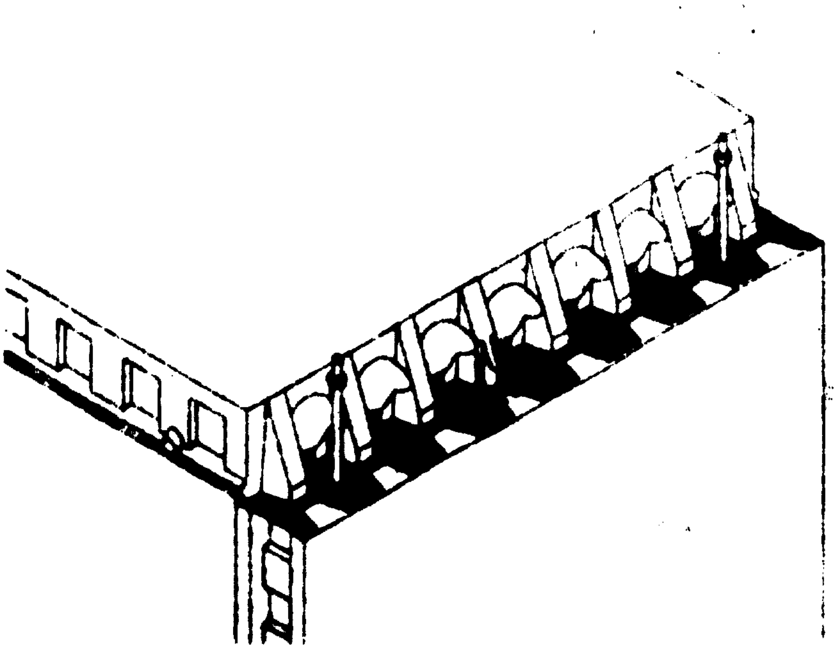


Figure G

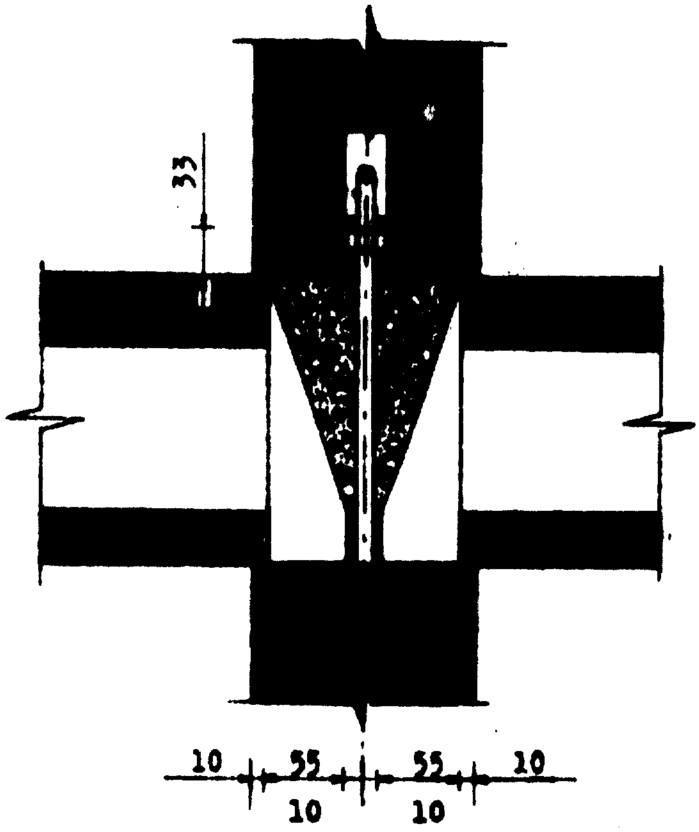


Figure H

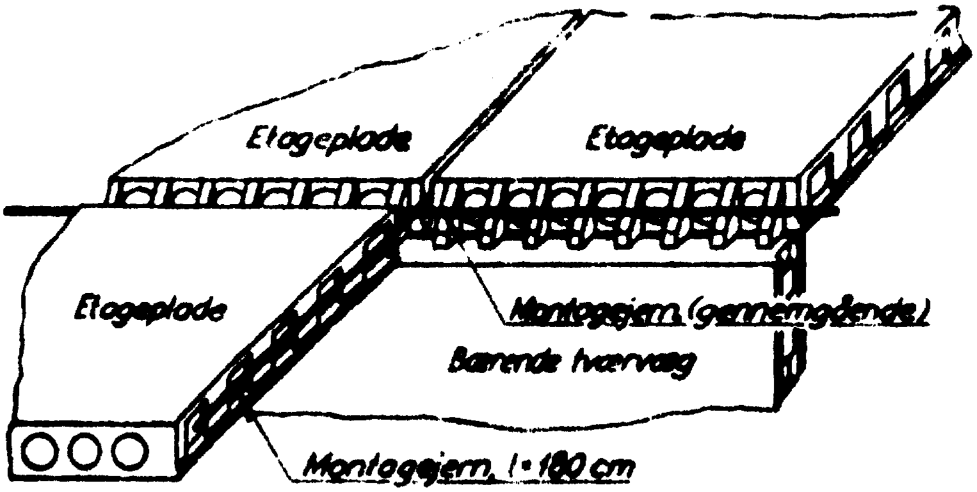


Figure I

The vertical forces in the walls cannot be carried through the floor slabs: The floor slabs contain hollow corres, and the narrow zones between them cannot take the forces from a fully loaded wall. Furthermore, the floor slabs (to increase speed of erection) rest on a dry joint. (Thus, the stress distribution is a function of small irregularities in the component surfaces.).

Therefore, the vertical forces must be transmitted directly, i.e. through the cast-in-situ concrete in the joint, the cross-section of which is only slightly smaller (75%) than that of the wall. The load is transmitted centrally, and stress distribution is fairly well known.

Finally, figures G and H shows the lifting bolts and nuts used for handling the components, as well as securing the tolerances of the structure.

The nuts are levelled before erection of the wall above, inaccurancies do not add up from storey to storey. The 33 mm gap between the cast-in-situ concrete and the wall component is packed with mortar. The loads on the floor slabs are transmitted to the wall top by a row of cams at 150 mm intervals. Concerning these details see point 5. Figure J shows the formation of the floor-wall joint in case the longitudinal sides of the floor component form the limitation.

Please notice that the upper edge of the wall component has been lowered in proportion to the underside of the floor component, and thus in proportion to the wall components described above. If the wall components are not lowered, it will be impossible to lay floor components with deflection. It has also been considered important to have as large a cross-section area of the cast concrete as possible, by placing the floor component 40 mm from the edge of the wall component and letting the floor component on the other side of the floor-wall joint be a special component.

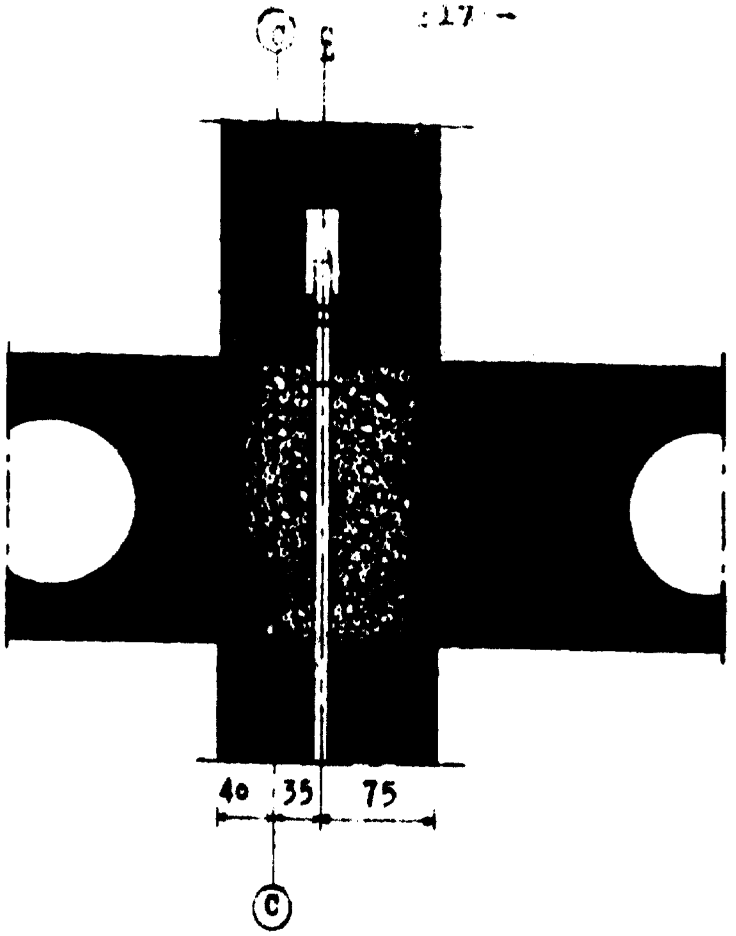


Figure J

4.3. Facade Joints

Some of the early prefab houses had one-stage vertical facade-joints, and most of them leaked. In a one-stage joint the water-seal and the air-seal is combined Although some vertical one-stage facade joints, sealed with a good sealant, do not leak, it is very unlikely that a completed building with one-stage joints should not have a number of leaks (some are unnoticed as the joint-details often provide some kind of drainage). One-stage joints sealed under laboratory conditions have much better performance than the joints sealed on a building-site.

All sealants will ultimately fail. Some may serve for a long period of time, but probably none will serve for the life time of a building. Therefore, a seal must be placed so that maintenance is easy.

Shrinkage, creep, temperature, warp, etc., in adjoining components will deform the sealant, and the permissible deformation will decrease with the aging of the sealant. It is wise to say, that a plastic sealant should never be used on the outer side of a building, and on the inner side only where cracks are acceptable.

The adhesion to the joint surfaces is often doubtful, as wet, cold humid, dusty, painted, impregnated, asphalted, etc., etc., surfaces are unsuited for sealing with most types of sealants. Most surfaces on a site are certainly either wet or cold or something else.

If the surface is profiled, rought or have exposed aggregates, the application of a sealant is difficult.

Furthermore, a guarantee will quite often cover the material only, not the labour, and is nullified, if the priming is wrong (priming is often wrong). No firms give a guarantee for a reasonable period of time (10 years or more).

Finally, application and supervision are rather difficult.

Even small gap can give unacceptable leakage, when the full air pressure difference acts on a facade covered with a water film.

Conclusion A: It is wise to use specialists for sealing, to use elastic sealants only, to avaoid the use of sealants on the outer faces of a building, and to avoid one-stage joints.

Conclusion B: A two-stage seal is better, consisting of a baffle (seal, strip or the like) as the outer, almost water-tight stage, and of an air-tight seal as the inner stage, with a ventilated, drained cavity between the two seals (the outer seal does leak a bit, but leaks less if no air pressure difference acts across the baffle, seal, strip, or the like).

Figure K illustrates the two principles, the one-stage and the two-stage vertical joint. The two-stage joint is often called "the open joint" or "the ventilated joint" ("rain-screen-principle", "pressure-equalization", etc.). It was developed and successfully used in Denmark 12 years ago. Its functioning was checked by experiments in the Norwegian, and later the British and Canadian, Building Research Institutes. The two-stage joint is the only recommended principle to-day in prefab construction. See also the submitted papers for the CIB Symposium "Watertight Joints for Walls", Norway 1967.

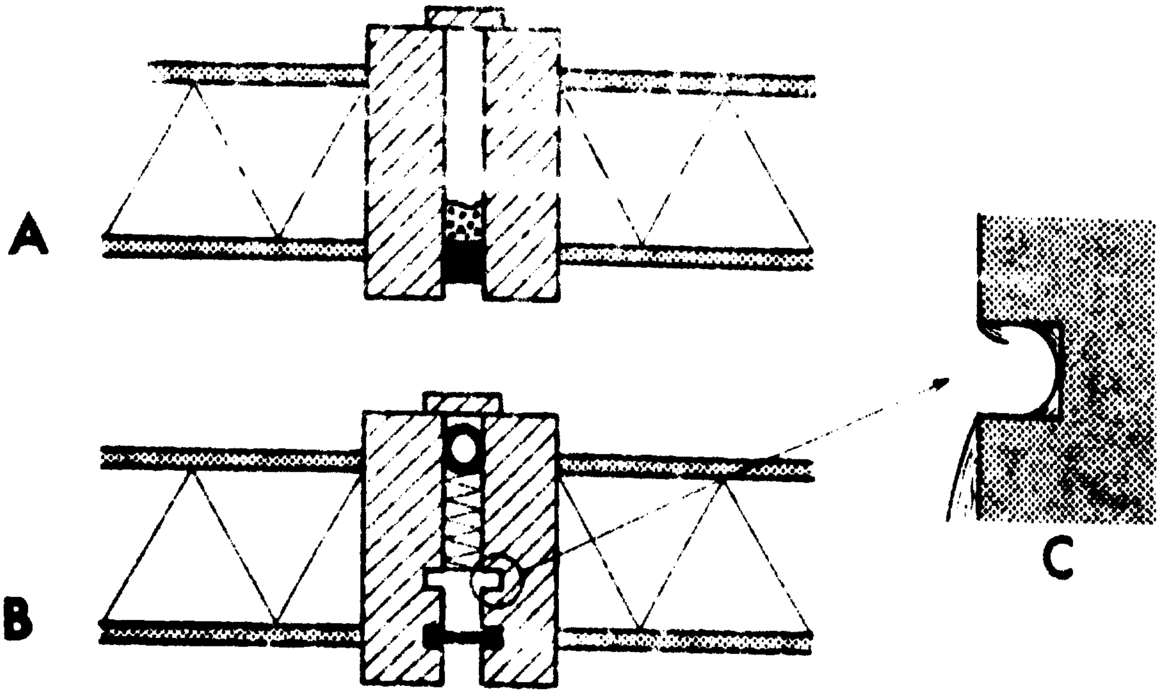


Figure K. One- and Two-Stage Joints in Wood-Framed Facades

Figure K.A illustrates the one-stage joint. A sealant acts as combined water- and air-seal. A crack in the sealant due to aging or deformation, or a gap between the sealant and the component due to failing adhesion, or any other small opening will primarily give a (possibly) acceptable air-leak. During rain, especially driving rain on multi-storey facades, a water film will cover the facade and the air pressure difference will press the water through the leak. Quite often cover strips (as in figure K.A.), profiled edges or the like will lead the water, making the tracing of the actual outer leak difficult.

Figure K.B illustrates the two-stage vertical joint in a wood-framed facade. Near the outside (down in figure K.B.) a baffle is slid down in grooves in the adjoining components. The baffle may be of neoprene, PVC, impregnated wood, metal, etc. The baffle will stop driving rain, but some water may seep through at the grooves. The cavity hebind the baffle is ventilated (throught the horizontal, overlapping joint) so that no static air pressure difference (but possibly a minor dynamic difference) will press water across the grooves. Water intruding into the cavity will stop at the next groove and run down along the groove, probably due to surface tension hindering the passage of sharp edges (figure K.C.). The cavity, with the vertical, draining groove is ventilated and drained outwards at the horizontal joints. Behind the cavity is a strip of rockwool (fire protection) and the second stage, the air-seal, consisting of a neoprene tube under compression. Rockwool, pointed into the joint, against a stop, may form an equally good air-seal. The cover strip on the inside is not taken into account.

Figure L. Baffles in Two-Stage, Open, Ventilated, Vertical Joints between Concrete Facade Components.

Figure L illustrates similar baffles in two-stage vertical joints between concrete panels. Again the cavity is ventilated and drained at the horizontal, overlapping joints. The baffle in figure L.A. consists of a 3 mm neoprene strip, slid into grooves. Behind the baffle is a washboard, i.e. inclined grooves, leading the water down, outwards, see figure L.B. (a section through L.A.).

Figure L.C. shows a combined baffle and drain of extruded neoprene. The small cavities between the fins act as vertical drains (Vari-lock).

The width of the joint is 16-20 mm so that dimensional deviations can be taken up, so that variations in width of the joint should not be too visible, and so taht a sufficient gap for placing the neoprene is obtained.

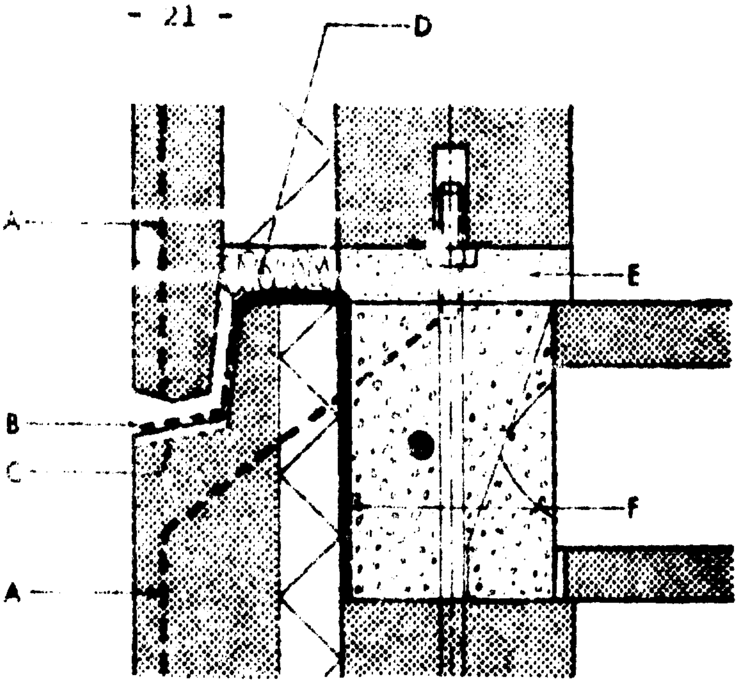


Figure M. Overlapping, Horizontal Joint in Concrete Facade

Figure M illustrates a typical, horizontal, overlapping joint. The downwards projecting part of the component above covers the threshold of the component below the joint, and makes the joint water-tight. The casting and the pointed mortar (E) form the air-seal. A two-stage joint.

D is a rockwool strip forming a stop for the mortar.

(A) indicates the neoprene strip in the vertical joint. The neoprene follows the overlapping, ventilated joint and ends up inside where it is fastened in the casting of the floor-wall joint.

C is a groove stopping horizontal waterflow from entering the vertical joint. B is an alternative, a PVC foil covering the vertical joint. A foil (F) is anyway glued to the top of the component, protecting the insulation against rain during erection.

The minimum height of the threshold is 40-50 mm. The width of the joint is approx. 18 mm so that dimensional deviations can be taken up, and so that the variation in width shall not be too visible.

The horizontal joints drains the vertical joint, and ventilates the joints as well as the insulation.

The air-seals in the vertical and horizontal joints must meet at the joint-intersections if a sufficient air-tightness shall be obtained. This simple fact is quite often ignored. The resulting air-leak may transport water into the building.

5. DESIGN OF COMPONENTS

Before going through the principles of design of components it is necessary to give a brief illustration of some structural systems.

The normal structural designs will, in Denmark, usually be based on load-bearing cross-walls. This is so for a deversity of reasons, some of the more important ones being:

a) The requirements of sound-insulation between flats and between flats and stairwell can be fulfilled by using heavy walls between the flats and around the stairwell.

b) By using load-bearing cross-walls the facade can be made as a light facade (timber framed), which will in many cases give the architect greater scope in designing these facades.

c) A flat containing 2 rooms or more should face opposite directions to make it possible to cross-ventilate the flats. The normal lay-out is that of two flats around the stairwell, see figure N.

d) The balcony, which is nearly always demanded, is easy to design when using load-bearing cross-walls.

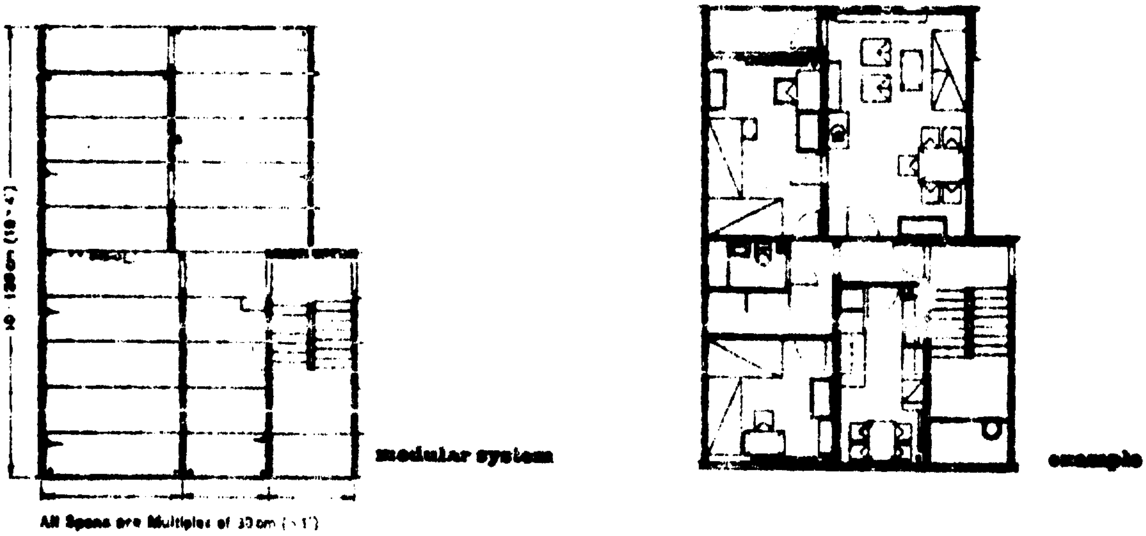


Figure N

The disadvantage of using load-bearing cross-walls is the small degree of flexibility within the flat as it is impossible to move the walls between the different rooms.

Statically the load-bearing cross-wall system acts as follows:

a) The loads on the floor slabs must be transferred to the wall on which they rest. This load as well as the load from the walls above must be carried downwards to the base.

b) The horizontal forces (such as wind-load) will be transferred through the floor-slabs to the load-bearing walls, and through these to the base.

As to the longitudinal horizontal load, this is usually transferred to the wall in the stairwell.

Another structural design is based on the principle of load-bearing longitudinal walls, known from traditional building with a load-bearing facade and a load-bearing longitudinal wall. The transmitting of vertical as well as horizontal forces will in principle be as described above.

5.1. Floor Components

According to Danish standards the planning modules in horizontal direction must be 3M = 300 mm (in vertical direction 2 M = 200 mm).

The dimensions of floor components are named as follows:

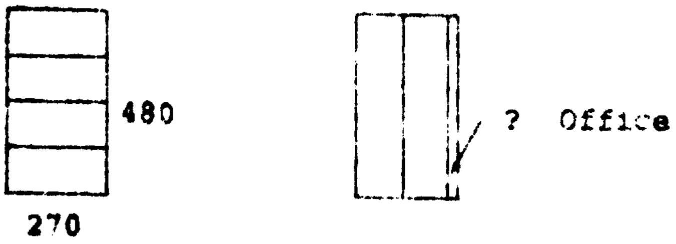
B = width
L = length
T = thickness

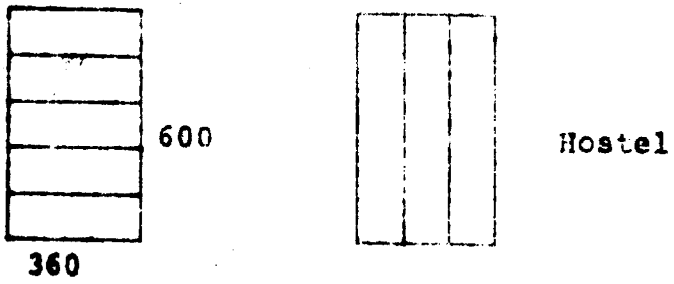
Based on the planning modules we have at first the following "crowd" of measure:

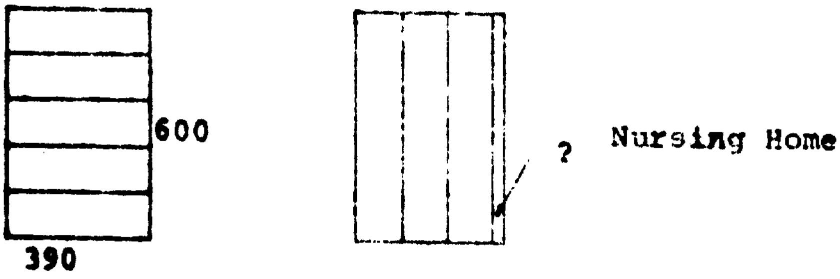
B = 300, 600, 900, ... mm, $r \cdot 300$ mm
L = 300, 600, 900, ... mm, $n \cdot 300$ mm

It is obvious that a combination of these figures will give a very large number of differend components. It is therefore natural to look for some kind of limitation, in the way of keeping either B or L constant. If we choose to keep B constant = 1200 mm, we can decide whether this choice is reasonable by regarding the applications of the components. If the components are applied for a load-bearing cross-wall construction, this means a 1200 mm difference in the depth of the house and a 300 mm difference in the width of the room. They have both proved acceptable in Denmark. For a load-bearing longitudinal wall building conditions will of course be opposite, if, however, the longitudinal walls and facades are straight, it is sufficient that the distance from stairwell to stairwell, possibly the length of the house, is a multiple of 1200 mm. In Denmark B = 1200 mm and L = 1800 + $q \cdot 300$ mm have been chosen.

Below are shown some simple examples showing how the decision of B and L works out and does not work out in common building structures.







The question marks do not signify any important problem since in that kind of building we often have "equalizing rooms" (kitchen, bath, cleaning room etc.), which at a suitable dimension may make the components work out.

Thickness T (normally 185 or 215 mm) is determined on the basis of the functional requirements: strength - fire stability - sound etc.

Floor components, which are hollow core slabs, are cast horizontally, whereby the underside becomes smooth whereas the upper side becomes rather uneven, which is acceptable because of the above mentioned "floating floor".

The loads on the floor slabs are transmitted to the wall top by a row of cams at 150 mm intervals. In practice the slabs do not rest on all the cams, and some are useless because of openings in the floor slab. Many experiments have shown that the bearing capacity of one cam only is approx. 3 tons, provided that the reinforcement is carried at least 50 mm in over the wall (40 mm is the most unfavourable combination of production and erection inaccuracies), i.e. carried through to the end of the cam. Experiments with a normal component, 8 cams, show a bearing capacity of 9 tons, which even for the longest components gives a safety factor of approx. 4.

5.2. Wall Components

The wall components are solid and un-reinforced (except for reinforcement around doors, and except for a light transport-reinforcement).

The height corresponds to the standard storey height of 2800 mm. The width 1200, 1800, 2400 mm. The thickness is 150 or 180 mm to meet the requirements of strength, fire-stability, sound-insulation etc.

5.3. Facade Components

In most blocks of flats the facade panels are concrete sandwich components and/or wood framed facades.

Concrete sandwich components consist of an exterior skin of concrete with a ready-made finish (profiled or exposed aggregates), a layer of insulation (rockwool or expanded polystyrene), and an internal layer of concrete.

The internal layer is usually the statically active layer, taking up the components' deadload and the windload, and sometimes loads from the floor. Facades on cross-wall blocks will transmit their windload to the floors and their deadload to brackets at the ends of the cross-walls (a hanging facade), or the deadload will be transmitted from one component to the next below (a self-bearing facade). When the floors are supported at the cross-walls, the gable components are statically cross-walls, constructed as concrete sandwich panels. Their internal layer transmits the windload to the floors, and takes up deadload of gables and floors above the component in question, as well as the live load on the floors. Finally, the internal layer, together with the other cross-walls, act as windbracing walls for wind orthogonal to the facade. (A gable is a load-bearing facade, and usually also a bracing wall.) Due to thermal movements the outer layer cannot be used as a load-bearing member, and the facades with outer active layer are always hanging facades, never bearing.

The two concrete layers in a sandwich panel have relative movements. The dimensions of the interior layer vary a little annually due to minor alterations of the inside temperature, whereas the exterior skin will have considerable thermal variations in dimensions, diurnal and annual, due to the climate. Therefore, a longish, rigid connection between layers will cause cracks in the tie if not in the exterior skin and/or deflections (shich may open up joints).

Figure O.A illustrates a stainless steel (or alloy) tie suitable for a panel without a window (a gable). The exterior skin, to the left, is hanging in the tie (or ties all located close together above the center of gravity of the exterior skin).

Figure O.B illustrates a tie suitable for use in panels with windows. The outer skin hangs in two ties, one on each side of the window, the ties being long enough to take up thermal movements with low stresses.

Figure O.C illustrates 3 mm galvanized ties used as a supplement throughout the panel, tying the two layers together during demoulding, and hindering warp etc. of the outer layer. The ties reduce the cold-bridge between the layers to an acceptable minimum.

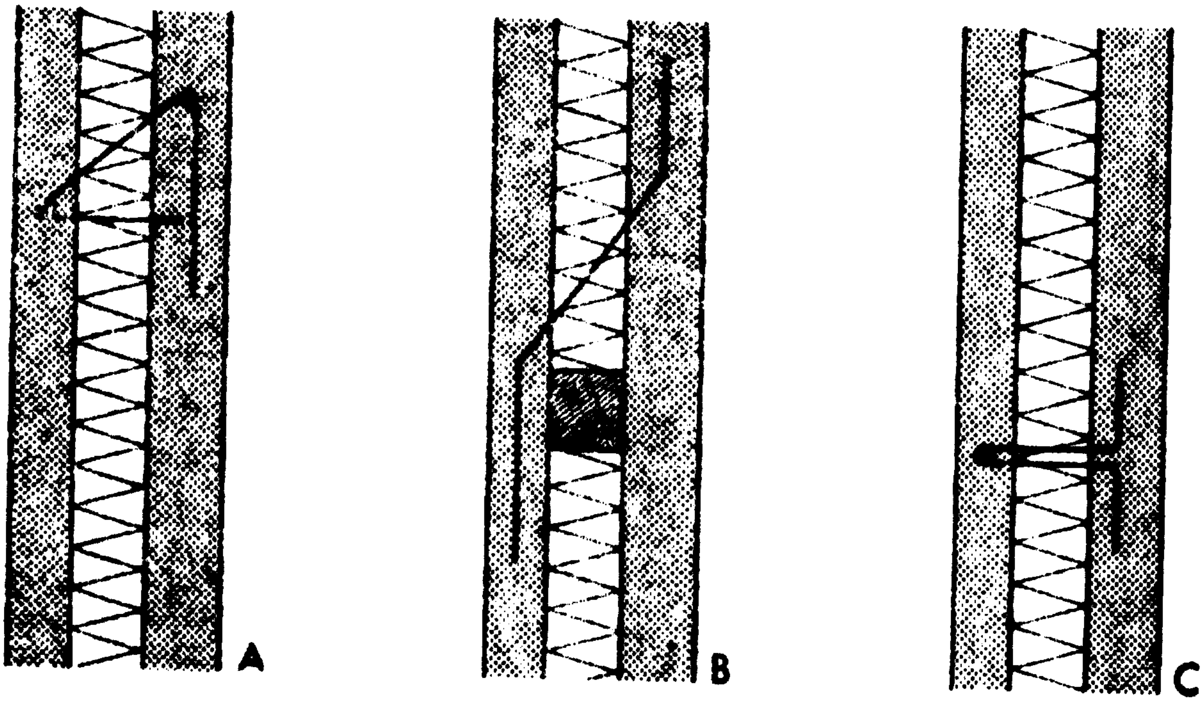
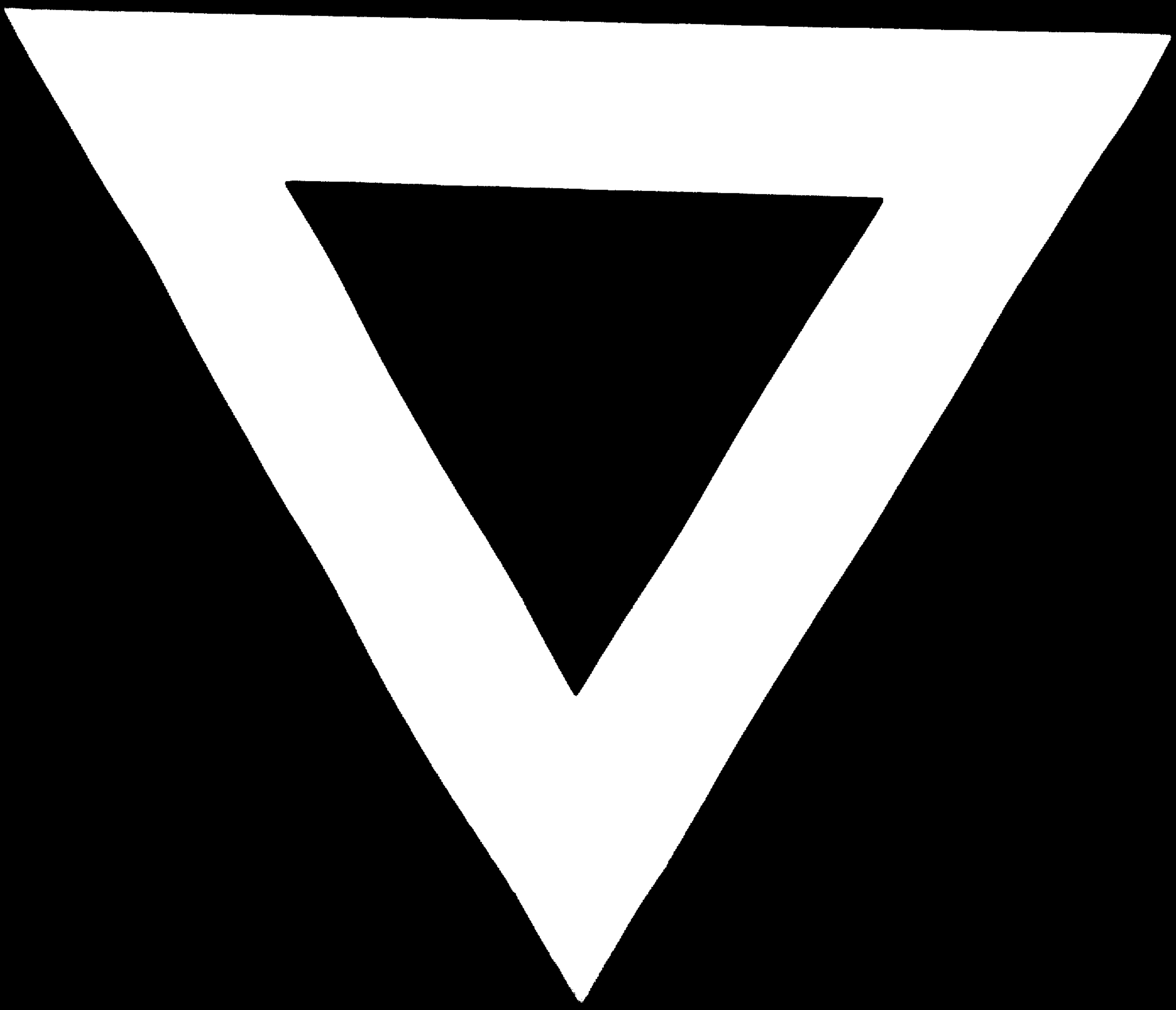


Figure O



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