DEVELOPMENT OF REINFORCEMENT IN CONCRETE SANDWICH PANELS ON THE BASIS OF THE LOADING CONDITIONS AND NONLINEAR ANALYSIS OF THE STATICAL BEHAVIOUR

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SUMMARY

This paper is based on the research projects carried out at Technical Research Centre of Finland.

It is concerned with a study of possibilities of developing the reinforcement of sandwich facade elements for the purpose of minimizing the detrimental effects appearing primarily in the service state on the elements subjected to indirect loading; the solutions applicable in this respect to the truss reinforcement used between the panels are introduced.

Behaviour, manufacture and structure of the types of walls most frequently being used in Finland as well as loads taken by the walls are examined. Furthermore, functions of the reinforcement in the sandwich walls and functional requirements to be set for the reinforcement are mapped.

A proposal for developing the reinforcement in panels and trusses is presented, with some results obtained from the computer analysis on the elements provided with the reinforcement conforming with the proposed requirements.

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1. INTRODUCTION

In most cases, truss reinforcement is used nowadays in Finland for the purpose of connecting the exterior and interior layers of the sandwich facade elements together. This reinforcement is composed of the deformed bars and bent diagonal struts, made of a rustproof reinforcing bar, joined by welding to booms.

The thickness of the concrete layers in the elements to be manufactured vary in the interior panel from 70 to 150 mm and in the exterior disk from 40 to 70 mm. The height of the elements most frequently used is a floor height and they vary in length up to 7200 mm. The heat insulating layer is usually from 80 to 140 mm thick. There are several possibilities of finishing the surface of the exterior disk.

The sandwich wall elements can be either load-bearing or non-load bearing ones depending on the structural system used. Usually not only the self weight but also other loads are being transmitted to the wall.

2. LOADING AND STRUCTURAL REQUIREMENTS OF FACADE ELEMENTS

The facade wall has many important functions as one of the main components of the house. The loading affecting the wall can be devided into external static loads, indirect static loads and into physical and biological loads. The main origins of the loads are the weight of the structures, the loads imposed by machines and weather, as well as by people, animals and other biological organisms. The list of the loadings and the corresponding requirements of the walls is given in table 1.

Table 1. The main loadings and corresponding requirements of the walls.

Loading	Corresponding requirements
1. External static and dynamic loads - static and dynamic loads during the manufacture, transport and erection of the element - loads of the structures of the house on bearing walls and the dead load of all elements - wind load and suction - usual impact loads of the machines, people and animals - exceptional loads, e.g. due to collisions of vehicles and missiles or inside or outside explosions and fire.	- Statical bending capacity in the plane of the wall and perpendicular to it. - Statical stability - Impact strength - Fire resistance - Resistance to the progressive collapse.

2. Indirect static loads due to
   - temperature differences inside the concrete panels
   - shrinkage differences inside the concrete panels
   - shrinkage differences between the concrete panels
   - deflections of the bearing structures and settlement of foundations

- Limitation of the crack widths
- Limitation of the deflections
- Allowance for movement between outer and inner concrete panels
- Allowance for the movement between adjacent outer concrete panels

3. Physical and biologicl loads
   - temperature differences
   - rain
   - moisture movement
   - radiation of the sun
   - pressure differences
   - noise
   - chemical effect
   - biological organisms

- Thermal insulation
- Thermal capacity
- Water-tightness
- Moisture tightness and permeability
- Elimination of moisture condensation
- Sound proofing
- Chemical resistance
- Frost resistance
- Durability against biological effects

3. EFFECTS OF LOADINGS

The main effects of loadings are as follows:

- Cracking and deflections due to the static and dynamic loads.
- Cracking and deflections of the outer concrete panel due to its inside temperature and shrinkage differences and the temperature and shrinkage differences between the concrete panels.
- Warping of the outer concrete panel.
- Defects due to the physical, chemical and biological effects.
- In extreme cases the failure of the element due to the static and dynamic loads.

The effects of temperature and shrinkage differences are the most usual defects in concrete sandwich facade elements. These defects increase with

- the increase of temperature differences
- the increase of the stiffness of thermal insulation
- the decrease of the thickness of thermal insulation

- the increase of the stiffness of the reinforcement between the outer and inner concrete panels
- the increase of the thickness of the concrete panels

4. STRUCTURE OF FACADE ELEMENTS

The bahaviour and structure of the self-supporting concrete sandwich element, typical of the present use, are shown in Fig. 1.

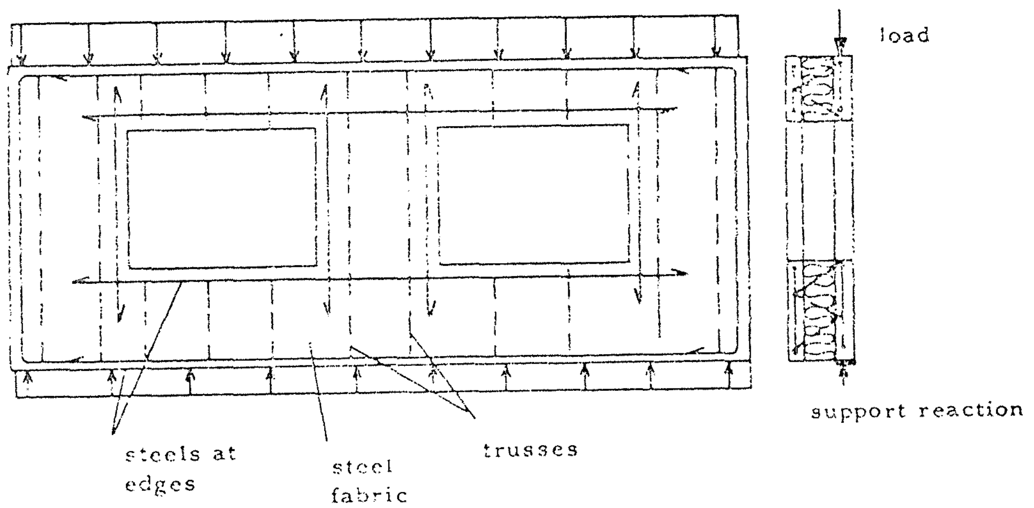


Fig. 1. Structure and behaviour of the self-supporting sandwich wall element (drawing of principle).

The connection of the element to the edge of the wall can be carried out in various ways, but in practice the reinforcement between the panels does not vary to a great extent.

The structure of the elements supported at its ends does not greatly differ from that of the self-supporting element. The suspension steels and shear and bond reinforcements required are inserted in their places only.

The behaviour and structure of the element hung from its ends, typical of the present use, are presented in Fig. 2.

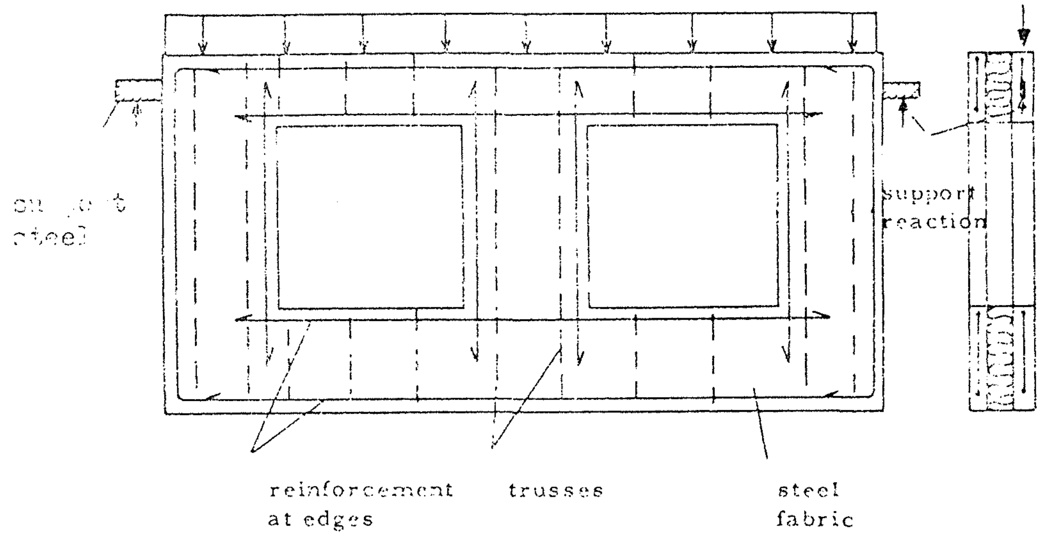


Fig. 2. Structure and behaviour of the sandwich wall element supported at its edges (drawing of principle).

5. FUNCTION OF FACADE ELEMENT REINFORCEMENT AND FUNCTIONAL REQUIREMENTS

In the first place, the function of reinforcement in a concrete panel is to hold together the panel. A bar being placed round the edges prevents the parts of the panel from falling in the cases of splitting, and steel fabric reinforcement in the panel prevents the panel from breaking into pieces. This presupposes a certain ductility of the reinforcement. In addition, the reinforcement acts also for its part as a means of limiting cracks induced by indirect loading. In some cases, it may appear necessary to dimension the fabric reinforcement of the panel for the crack width to be approved. The situation like this is often brought about if the selfsupporting walls and elements supported at edges have rather stiff diagonal trusses.

The function of the truss reinforcement in the sandwich wall elements is to ensure the interaction between the concrete layers in the case of selfsupporting walls, to stiffen the wall and prevent the edges from warping. The interaction between the panels is indispensable to the strength of the self-supporting type of wall, because the stiffness of the wall reduces considerably when the external panel is loosening and stability becomes a decisive factor. Warping of the panel edges tends to develop due to the temperature and moisture differences in the outer and inner face of the exterior panel. If the truss reinforcement is of right design and close enough to the edges of the panel, it can prevent warping of the edges effectively.

On the other hand, other reinforcing problem arises from the fact that, in the self-supporting type of wall, a relatively large quantity of stiff reinforcement has to be used for the purpose of ensuring the interaction between the panels. The diagonal trusses, particularly the stiff ones, prevent effectively the imposed deformations along the trusses. Consequently it gives rise to cracks in panels. Cracking can be limited by increasing reinforcement of the panel. This is possible if the interaction between concrete and reinforcement is good.

In the case of the wall supported at its edges the exterior panel is of no structural importance, and it is not necessary that any other forces but the self weight of the exterior panel is conveyed by the truss reinforcement of the panels. Furthermore, in the case of the wall to be hung it should be born in mind to impose limits on warping of the edges of the exterior panel. It is unnecessary for the truss reinforcement, by means of which the weight of the exterior panel is conveyed, to be nearly as stiff as it should be in the load-bearing wall of corresponding kind, for which reason also the risk of cracking in the exterior panel caused by indirect loading is smaller.

In brief, the functions of the panel reinforcement are
- prevention of cracks
- holding together the panels
- control of cracks

and functional requirements
- sufficient ductility
- good bond characteristics
- short distance between the diagonals in steel fabric.

The function of truss reinforcement is
- to ensure the interaction between the panels in the self-supporting wall
- to transmit the weight of the exterior panel in the case of the wall to be hung
- to effect the smallest possible indirect loading
- to prevent warping of the edges

and functional requirements
- corrosion resistance
- stiffness perpendicular to the walls
- flexibility in the plane of the panels.

6. EFFECTS OF MATERIALS, DESIGN AND MANUFACTURE ON CRACKING AND WARPING

Indirect loads being produced in connection with manufacture can be controlled by various means and in many phases. Without going into details as to the means used in limiting cracking by manufacturing techniques only the most frequent objects of manufacturing processes where cracking can be controlled and the reasons for cracking occurring most frequently are stated.

A fresh concrete should shrink as little as possible. In addition to the external factors it is in this case important to use a proper amount of cement and proper water-cement ratio. In this respect it is attempted to have a low water-cement ratio and cement content. Plasticizers can be used, if needed. The plasticizers and super plasticizers increase shrinkage, if the composition of concrete is not changed correspondingly. By reducing the cement content and, in the first place, the water-cement ratio an advantageous result in the end can be obtained. Also expanded cement for preventing cracking has been used at least in the USA and Soviet Union.

In connection with concreting a development of surface cracks advances if the concrete is separated when compacted. In this case the cement used for the surface is of rich content, shrinks well and has a poor resistance to tension, wheras the rest of concrete does not shrink correspondingly. If the surface treatment of the element, primarily steel trowelling, is carried out close to the initial set it reduces surface cracking, for which reason setting time should be observed. For the walls heat treatment is mostly used, subsequent to this the elements are taken to a storage yard. If the temperature difference between the production halls and storage yard is considerable there may occur surface cracks in elements, because the indirect forces due to rapid cooling and related surface drying exceed the tensile strength of concrete, which is not yet sufficiently hardened.

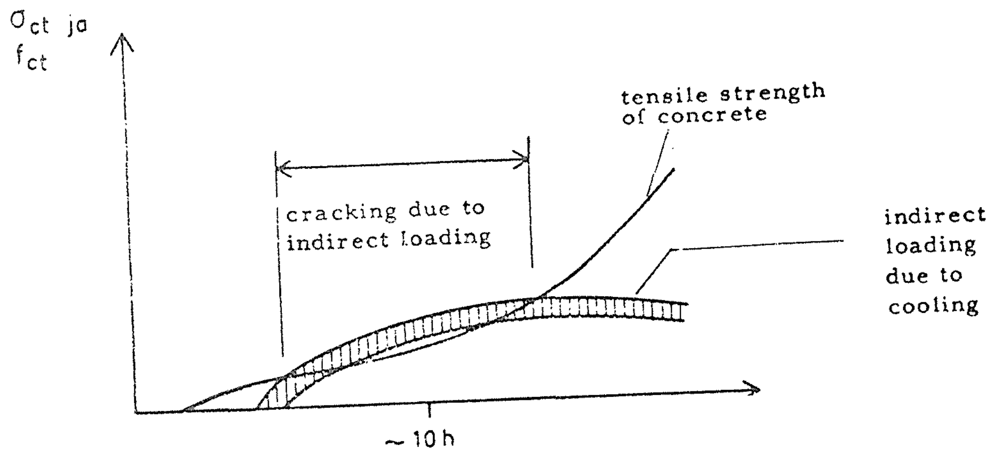


Fig. 3. Possibility of formation of cracks on the surface of concrete at an early age.

Storage or after-curing conditions should be unchanged as far as temperature und moisture are concerned and favourable with regard to the development of concrete strength.

Not only in the manufacturing phase but also at the design stage a limitation to be set to cracking due to indirect loading should be taken into consideration.

The elements can be designed so that no great differences in moisture and temperature are possible or by so arranging that the structures have enough space for the movements resulting from the factors mentioned as well as from loading.

Some other means of limiting cracking are e.g. the use of fibre concrete and prestressing of concrete panels.

The use of such reinforcement that induces indirect forces as little as possible and, on the other hand, limits cracking as much as possible is of great importance.

7. PROPOSAL FOR DEVELOPING REINFORCEMENT

7.1 General

The reinforcement of the sandwich element can be developed in one way by improving truss reinforcement and in other way by improving the reinforcement of the panels.

The truss reinforcement must carry the weight of the exterior panel and/or stiffen the wall together with the interior panel depending on the type of wall. On the other hand the truss reinforcement should not be in the direction of the panel so stiff that it prevents the disk from shrinking and other movements of enforced nature. Further, the truss reinforcement should act efficiently perpendicularly to the panel in order to prevent the warping of the edge of the panel due to the shrinkage on the other side of the panel. As a result of this the truss reinforcement should be placed as near as possible to the edges of the panel. This kind of solution can be considered as being used also in the case of load-bearing walls subjected to light loads, e.g. in the walls of small houses.

As it may be necessary for the stiffness of load-bearing walls to use a sufficiently stiff truss reinforcement, the expected cracking caused by indirect loading must be limited by means of reinforcement of the panel. In this respect qualitative and quantitative requirements must be set for reinforcement as well as for location.

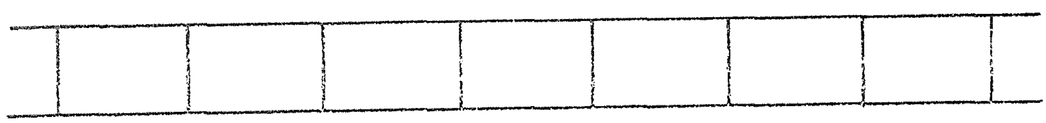
7.2 Truss reinforcement of facade element to be supported at edges or subjected to light load

Since the trusses in this type of wall are not of structural importance their function is to secure only the support of the exterior panel.

Thus the aim is
- flexible tie in the plane of panel
- stiff tie perpendicularly to the panel
- tie which can be placed close to the edge of the panel
- reduction in steel demand
- easier manufacture of truss reinforcement.

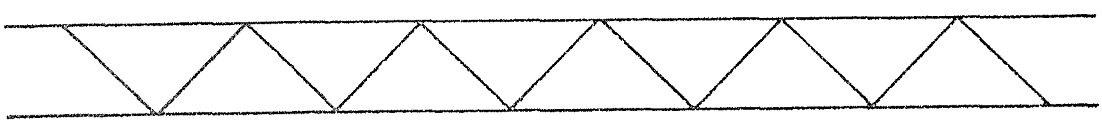
According to this new proposal for reinforcement, in the walls to be hung, the reinforcement of diagonal truss type like the one in use before and the new, so-called ladder like reinforcement are used.

LADDER LIKE REINFORCEMENT TYPE A



- booms ø 6 B 500 P
- transverse ties ø 4 rustproof
- distance between ties 300 mm
- distance from horizontal edge ≤ 150 mm
- distance from vertical edge 150...300 mm

REINFORCEMENT OF DIAGONAL TRUSS TYPE TYPE B



- booms ø 6 B 500 P
- diagonals ø 5 rustproof
- placed at lower edge of element

Fig. 4. Ladder like reinforcement and reinforcement of diagonal truss type.

The diagonal truss reinforcement, where each has at least two tension diagonals, is placed at the lower ege of the element, in which case their anchorage occurs in compressed concrete. The number of the diagonals required depends on the height of the elements and thickness of the exterior disk, and on the distance between the trusses. The number of the diagonals required is obtained from Table 2. In each element, however, two trusses should be inserted, each of them having at least two tension diagonals. These trusses should be placed at the lower corner of the element where the concrete is compressed. The distance between the trusses should be 600 or 1200 mm.

The ladder like reinforcement is spaced also at intervals of 600 mm up to the height of the element. The distance of the ladder like reinforcement from the side edges should be 150...300 mm and that of the first transverse tie from the upper or lower edge not more than 150 mm.

If this structure is used for the load-bearing walls under light load e.g. for the walls of small houses, the bearing capacity of the element shall be clarified separately.

Table 2. The number of tension diagonals required.

Wall height H m	Thickness of exterior panel d mm	Number of diagonals required pieces		Distance between trusses mm	
3.0	50	2		1200	
	60	2		1200	
	70	2		1200	
	80	2		1200	
3.0...5.0	50	3	(2) 1)	1200	(600)
	60	3	(2)	1200	(600)
	70	3	(2)	1200	(600)
	80	4	(2)	1200	(600)
5.0...7.0	50	3	(2)	1200	(600)
	60	4	(2)	1200	(600)
	70	4	(2)	1200	(600)
	80	5	(3)	1200	(600)

1) Values in brackets suffice, if trusses are spaced at intervals of 600 mm.

8. LOAD-BEARING CAPACITY OF THE FACADE ELEMENT

8.1 General

The carrying capacity of the load-bearing facade element is influenced by the interaction between the concrete shells. Depending on the wall tied, the interaction between the shells can be complete, partial, or nothing at all. The best carrying capacity is attainable with complete interaction, which is produced, e.g. by the diagonal truss reinforcement used as wall ties. The diagonal reinforcement induces, however, cold bridges and constraint forces between the shells. The more flexible anchoring methods are therefore recommended when the sufficient carrying capacity is achieved by them.

The purpose of anchoring between the inner and outer concrete layer of the non-load bearing element is generally only to suspend the outer layer from the inner layer. It is then advisable to try to arrange the anchoring as flexible as possible, in which case the constraint forces and cracks and deflections induced through these forces can be avoided.

The outer layer can also be suspended either partially or completely by means of the plastics insulator, if the strength and deformation capacity of the bond between the insulator and the concrete, as well as those of the insulator and the long-term durability of anchoring are ensured.

The carrying capacity of the element and the size of the constraint forces due to temperature differences with different types of truss reinforcement were evaluated by means of computer calculations. The strength of truss reinforcement was examined further in the laboratory tests, in which the outer shell of the element was loaded.

8.2 Nonlinear analysis

The calculations were carried out with the computer program ADINA. The concrete material model of ADINA is a hypoelastic model based on a uniaxial stress-strain relation that is generalized to take biaxial and triaxial stress conditions into account. Tensile cracking and compression crushing conditions are identified using failure surfaces. The use of tensile and compression failure criteria, including strain-softening conditions, prevents that unrealistically large stress and strain conditions are predicted.

The reinforcement is described with truss and beam elements. Element mesh used in calculations is presented in Fig 2.

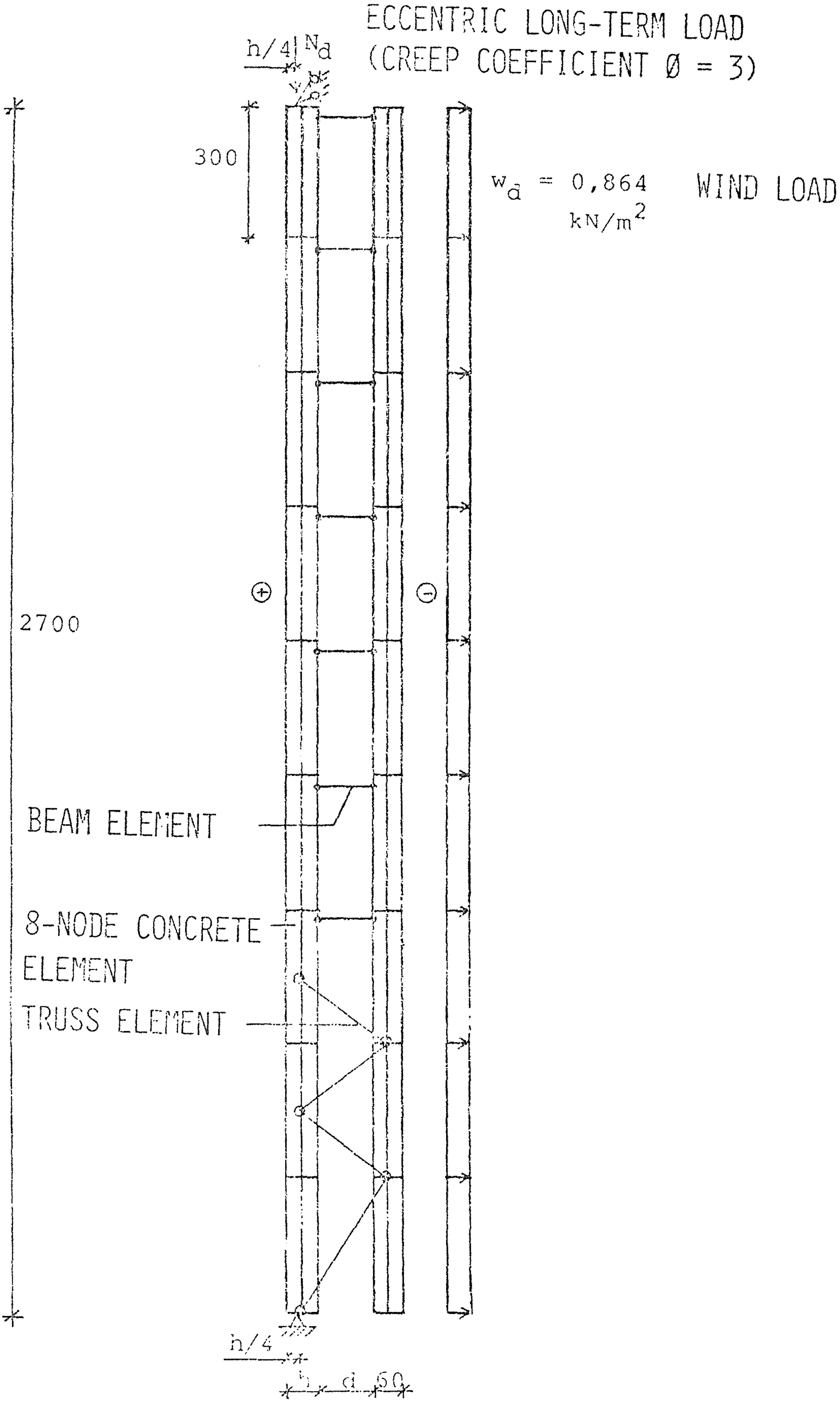


Fig. 2. Element mesh used in calculations.

Some example of the results of calculations are given in figures 3 and 4.

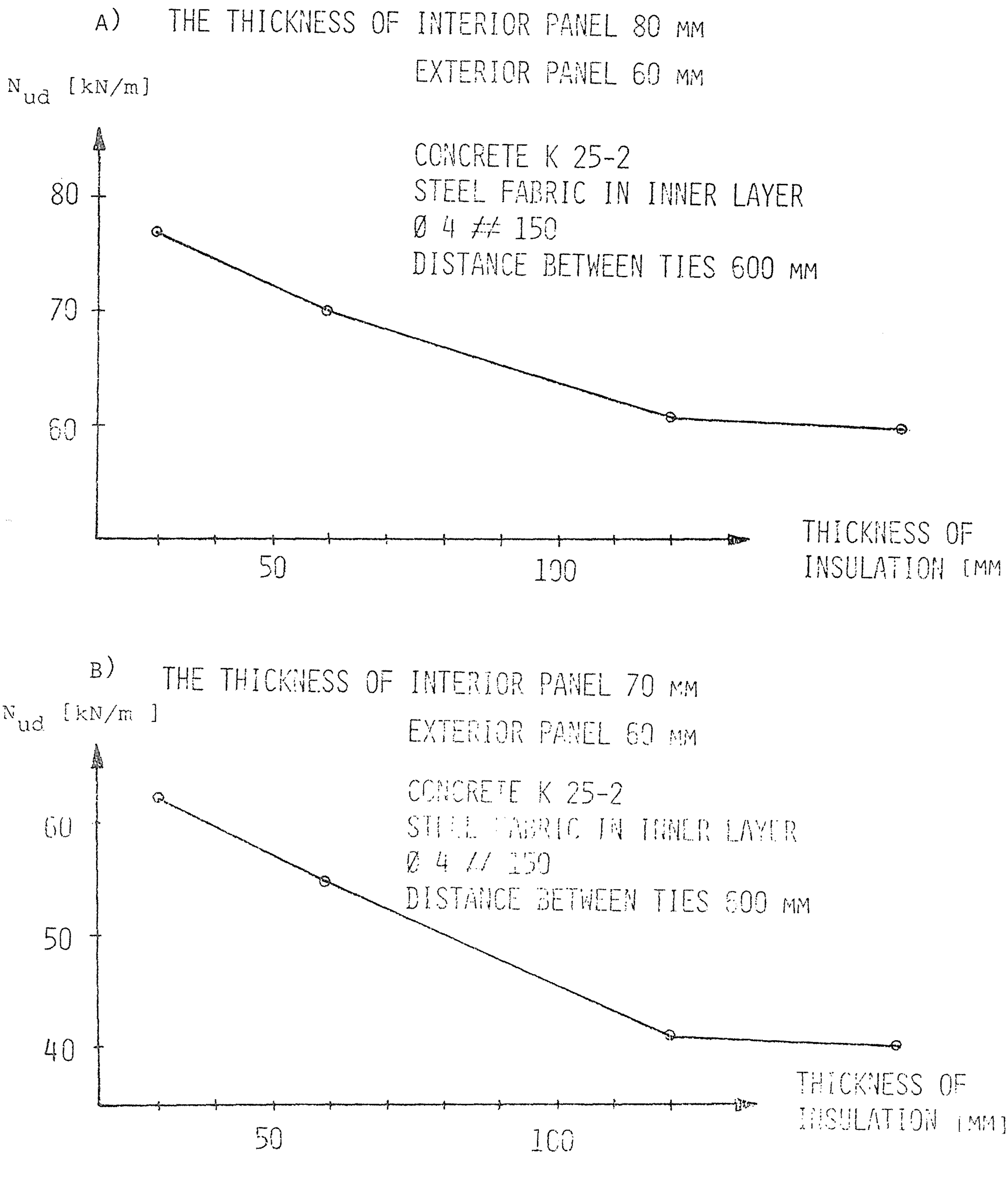


Fig. 3. The load bearing capacity of sandwich element with ladder like ties.

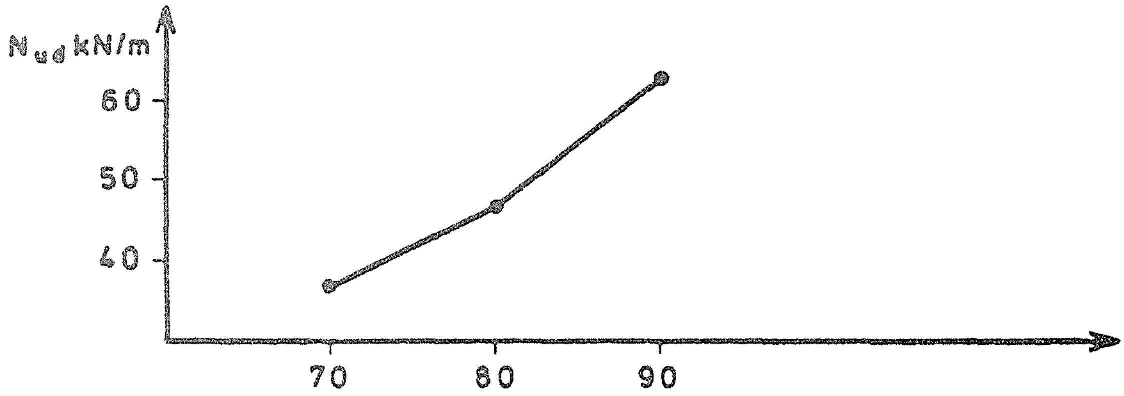


Fig. 4. The load bearing capacity of interior panel

9. CONCLUSIONS

When service defects in concrete sandwich facade elements are observed there is a question of harmful effects of cracking on outward appearance or of warping occurring at edges. In general, these defects appear only in large elements and in most cases they result from the temperature and shrinkage differences in different parts of the element.

Defects can be reduced or prevented in the design and manufacturing phases as well as in the phase of storage and assembly. In this connection it has been concentrated on the prevention of defects due to cracking and warping by designing the reinforcement of the panels and the truss reinforcement between the panels to serve the purpose.

The proposed ladder like reinforcement is better than the present diagonal truss reinforcement in this respect, because it is more flexible in the plane of the panels and stiffer perpendicularly to the panels. It thus allows imposed deformations along the panels without cracking and prevents movement of the panels perpendicularly to the panels.

LITERATURE

1. Jokela, J. & Sarja, A., Development of reinforcement of sandwich facade element. Technical Research Centre of Finland. Research notes 19. Espoo 1981. 65 p.

2. Sarja, A., On the design, strength and deformations of the concrete sandwich walls. Betonituote 1974:2, p. 20-25. (In Finnish).

3. Sarja, A., Possibilities of developing concrete sandwich walls. Betonituote 50 (1980) 1. p. 33...37. (In Finnish).

4. Olin, J., Ratvio, J. & Jokela. J., Development of the heat economy and structure of the concrete walls. Technical Research Centre of Finland. Research Reports 28/1981. Espoo 1981. 170 p. + app. 14 p. (In Finnish).