Centre for Civil Engineering Research and Codes (CUR)

Recommendation 86

BubbleDeck floors®

Supplementary regulations to NEN 6720:1995 (VBC 1995)*

*) Dutch standard NEN 6720: Technical principles for building constructions TGB 1990
Regulations for concrete: Structural requirements and calculation methods (VBC 1995)

New types of concrete constructions are regularly designed and realized for which no structural requirements still exists. This is an inevitable result of innovation. While there are no requirements, rules are being set for each project by the interested parties. It is of course undesirable that this situation continues for a long time. CUR publishes CUR-Recommendations to fill this void in structural requirements.

Subject of this CUR-Recommendation are concrete floors in which hollow spheres are applicated to reduce the weight of the concrete floor.

This floor type is known under the name "BubbleDeck floor®".
At the opinion of CUR-Regulations Committee 58 "BubbleDeck floors®" in practice enough experience is achieved and information is available to draw up regulations for this type of concrete floor. This information consists mainly of test results and theoretical considerations. The Committee has carried out experimental research on shear force capacity. The information is not yet such that a uniform answer is available for all the questions. For this reason extra margins were built in design values. Also the scope has been restricted to floors with a total thickness of 230 mm up to and including 450 mm.

This CUR-Recommendation is drawn up by CUR-Regulations Committee 58 "BubbleDeck floors®". At the moment of publication the composition of the Committee was as follows:
H. Ouwerkerk (chairman), D.J. Kluft, ir J.A. Bunkers, P. de Jong (secretary/reporter),
Prof. C.S. Kleinman, Prof. Dr. J.C. Walraven, J. de Wit, M. van Iperen,
C.A.J. Sterken, F.H. Middelkoop, R. Plug, J.M.H.J. Smit (co-ordinator) and Th. Monnier (mentor).

The Committee thanks ing. M.J.A. van Niekerken who up to 1 January 2001 was the co-ordinator of the Committee.

The Recommendation has been approved by the General Regulations Committee "Concrete" and is supported by NEN/CUR-Committee 35100109/VC20 "TGB Concrete Constructions".

CUR Recommendations 86

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1. Subject and scope of application

1.1 Subject

This CUR-Recommendation contains supplementary regulations and requirements to NEN 6720: Technical principles for building structures TGB 1990 – Regulations for Concrete – Structural requirements and calculation methods (VBC 1995) for BubbleDeck floors®. The supplementary CUR-Recommendation 37 "High strength concrete" and also CUR-Recommendation 39 "Concrete with rough light aggregates" to NEN 6720 are not applicable.

Where in this Recommendation partially supplementary and/or deviating regulations are given to NEN 6720, the rest of each of these articles shall remain valid as it is. Where no supplementary and/or deviating regulations relative to certain parts of NEN 6720 are given, NEN 6720 shall remain valid in full. Where in NEN 6720 reference is made to another article in NEN 6720, the latter being supplemented and/or amended in this Recommendation, in case of reference the statement in the supplemented and/or amended article applies.

The standards NEN 5950: Regulations for concrete technology (VBT 1995): Requirements, production and inspection, and NEN 6722: Regulations for concrete: Construction (VBU 1998) are applicable.

1.2 Scope of application

This CUR-Recommendation applies to predominantly statically loaded BubbleDeck floors®, with a floor thickness from 230 mm up to and including 450 mm, fitted with reinforcement and not prestressed.

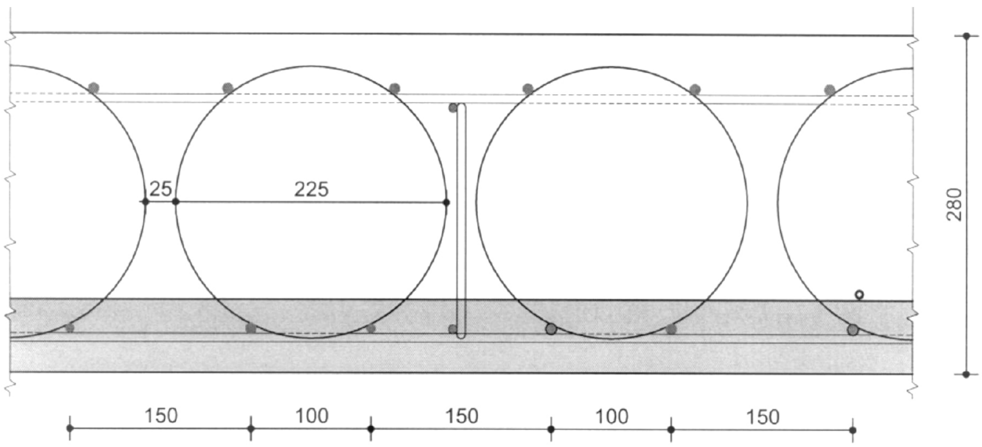
2. Terms and definitions

BubbleDeck floors®

A BubbleDeck floor® is a flat concrete slab composed of pre-fabricated reinforcement modules where between the lower and the upper reinforcement weight-saving hollow spherical elements are clamped. The pre-fabricated reinforcement modules can on the bottom be fitted with a concrete filigran slab or applied directly on the mould of the concrete floor. The reinforcement modules are connected by reinforcement bars and nets. The floor is poured on site. It is also possible to have a fully pre-fabricated BubbleDeck floor®.

Explanatory notes

Figure 1 is an example of a cross section of a BubbleDeck floor®.



BV-girder

Single leg girder for BubbleDeck floors®.

Gross concrete cross section

Area of the cross section without taking into consideration the presence of the spheres.

Net concrete cross section

Vertical cross section in the area of the middle of the spheres.

3. Units and quantities

The units and quantities used correspond with those in NEN 6720.

4. Requirements and determination methods

No supplementary regulations.

5. General conditions

No supplementary regulations.

6. Material properties

6.1 Concrete

6.1.5 Creep coefficient

For the determination of the creep coefficient and the shrinkage apply 2/3 of the fictive thickness of the gross concrete cross section as the fictitious thickness hm.

7. Schematization and distribution of sectional forces and moments

7.1 Schematization

7.1.4.2 Proportion of flexural stiffnesses

The calculated flexural stiffnesses EIvx and EIvy in this clause should be multiplied by the factor 0.8.

7.2 Theories

7.2.3 Principles of quasi-linear theory of elasticity

Method b2 can also be applied for BubbleDeck floors®. The value of I should be taken equal to the square area moment of the non-cracked gross concrete cross section. For the determination of the fictive modulus of elasticity Ef, the reinforcing percentage should be applied on the gross concrete cross section, so without taking the presence of spheres into consideration. The values of Ef following table 15 are not valid for flexure in combination with normal force. The values for flexure in combination with normal force should be multiplied by the factor 0.9.

8. Dimensioning and assessment

8.2 Shear force

8.2.1 Verification criterion

The value of t2 should be multiplied by the factor 2/3.

8.2.2 Design value of the shear resistance

In the formula for td the value of b should be 0.3 x the width of the gross concrete cross section.

8.2.3 Ultimate shear resistance

8.2.3.2 Cross sections loaded in flexure and normal force

For the determination of s'bmd the gross concrete cross section should be applied. The calculation of sbmd should be based on the net concrete cross section.

8.2.3.3 Cross sections with limited flexural tensile resistance

For the determination of s'bmd the gross concrete cross section should be applied.

8.2.4 Shear stress to be resisted by the reinforcement

Of the two diagonal legs of the BV-girder that form a triangle together, only one diagonal should be applied as shear force reinforcement. Of this diagonal only 75% of the cross section should be applied.
In the formula for ts the internal lever arm z should be maximized to the centre-to-centre distance of the upper and lower bar of the BV-girder. For the value of q the requirements in NEN 6720 are valid, provided that for q no bigger value than 45° should be applied.

Explanatory notes

The requirement in 8.2.4 of NEN 6720 that at least 50% of the total shear force reinforcement should be consist of stirrups if td is bigger than 2t1, is also valid for BubbleDeck floors®. Due to complaints about the practicality of applying stirrups it is generally recommended to omit the spheres in areas where td is bigger than 2t1, so that for these areas the requirements for shear stress resistance according to NEN 6720 are valid.

8.2.5 Shear joint surfaces of composite girders and slabs

For Bubble Deck floors® where pre-fabricated filigran slabs are applied, ks = 0.8 and kb = 0.3. If the shear force reinforcement consists of BV-girders the angle between the diagonals of the BV-girders and the shear joint surface of the filigran slab should be taken into consideration when determining tu. Asv in the formula tu should be multiplied by the factor (sin a + cos a), where a is the angle between the shear joint surface and the reinforcement bars that cross the shear joint surface. Of the two diagonal legs of the BV-girder that form a triangle together, only one leg can be taken into consideration.
On the surface of the shear joint surface the part that is taken by the spheres should be deducted.

8.2.6 Plates subjected to in-plane loading

This clause is not valid.

Explanatory notes

The clause concerned deals with the elementary calculation of plates subjected to in-plane loading by normal and shear forces. The fact that this clause is not applicable does not mean that BubbleDeck floors® cannot resist in-plane loading.

8.3 Punching shear

8.3.1 Verification criterion

In the formula for tu the contribution of ts should not be applied.
The value of t2 should to be multiplied by the factor 2/3.

Explanatory notes

There are no test results available to prove that the influence of punch reinforcement in BubbleDeck floors® could be determined in the same way as for solid floors. The contribution of punch reinforcement can therefore be left out of consideration. This is not a problem because punch reinforcement is impractical and anyway by leaving some spheres out the punch criterion can be satisfied. In this case the requirements for punch reinforcement according to NEN 6720 are valid for the area concerned.

8.3.2 Design value of the shear resistance

The values of the perimeter p from the formulaes should be multiplied by the factor 0.25.

Explanatory notes

The given factor is applicable for BubbleDeck floors® where there are spheres inside the periphery. It is generally recommended to exclude the spheres out of this periphery to achieve a locally solid floor where the requirements for punch according to NEN 6720 are valid.

8.3.3 Ultimate shear resistance

For the determination of the reinforcement percentages wox and woy the gross concrete cross section should be applied.

8.3.4 Shear stress to be resisted by the reinforcement

This clause is not valid.

8.6 Deflection

8.6.1 Verification criterion

Change the text by:

The calculation of the deflection should be carried out according to 8.6.2.

8.6.2 General verification

The given calculation method is applicable for BubbleDeck floors® under the condition that the values of the crack moments Mr and Mrt of the gross concrete cross section are multiplied by the factor 0.8. This reduction factor is not valid for the bends, so that these should be determined by the crack moments of the gross concrete cross section. In determining the bends it is allowed to consider the floor without spheres.

Explanatory notes

Figure 2 shows how to determine the M-_-diagrams.

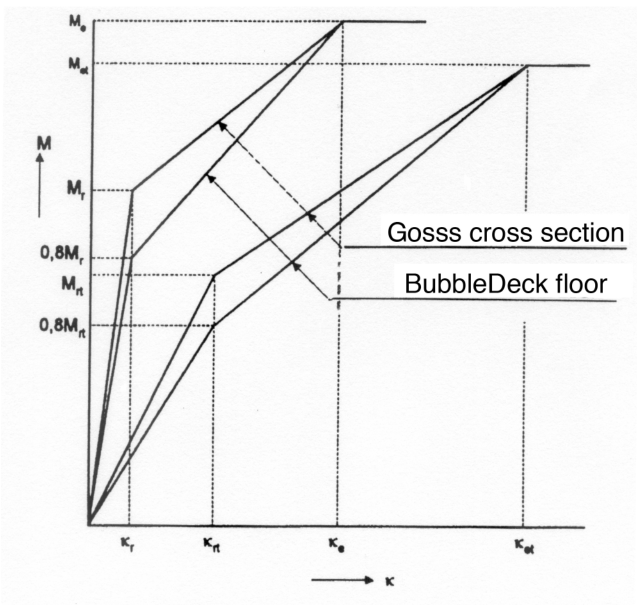


Figure 2 Determination of the M-_-diagrams of BubbleDeck floors®.

8.6.3. Flexural stiffness

This clause is not valid.

8.7 Cracking

For the determining of sb according to 8.7.1, ssr according to 8.7.3 and sb according to

8.7.4 of NEN 6720, the section factor should be equal to 75% of that of the gross concrete cross section.

9. Detailing

9.1 Minimum dimensions

Add to the clause:

9.1.7 BubbleDeck floors®

The minimum thickness of the concrete above, underneath and between the spheres should be at least 1/9 of the diameter of the spheres.

9.3 Fire resistance in relation to collapse

The requirements and the explanatory notes of 9.3 of NEN 6720 are not valid and have to be replaced by a complete new clause 9.3 with the same title: "Fire resistance in relation to collapse" and the following requirement text:
The fire resistance in relation to collapse of construction parts should be determined arithmetical according to chapter 5 of NEN 6071, or should be determined experimentally according to chapter 3 of NEN 6069.

Explanatory notes

Above adaptation on 9.3 will be included in the adaptation leaflet A2 of NEN 6720 to be published.

Add to this clause:

9.3.1 Arithmetical determination of the fire resistance

In the arithmetical determination of the fire resistance according to chapter 5 of NEN 6071 a distinction should be made for the temperature of the reinforcement bars next to the spheres and bars situated in the solid part. For bars in the solid part apply figure 12 of NEN 6071. For bars next to the spheres the temperature should be determined with figure 3. The correction factors belonging to these temperatures for the tensile strength of the reinforcement steel should be determined according to 8.2.1 of NEN 6071. For the total of the reinforcement, the tensile strength should be equal to the calculated average dependent on the determined design values of the tensile strengths and the amount of steel of the bars next to the spheres and those situated in the solid part.

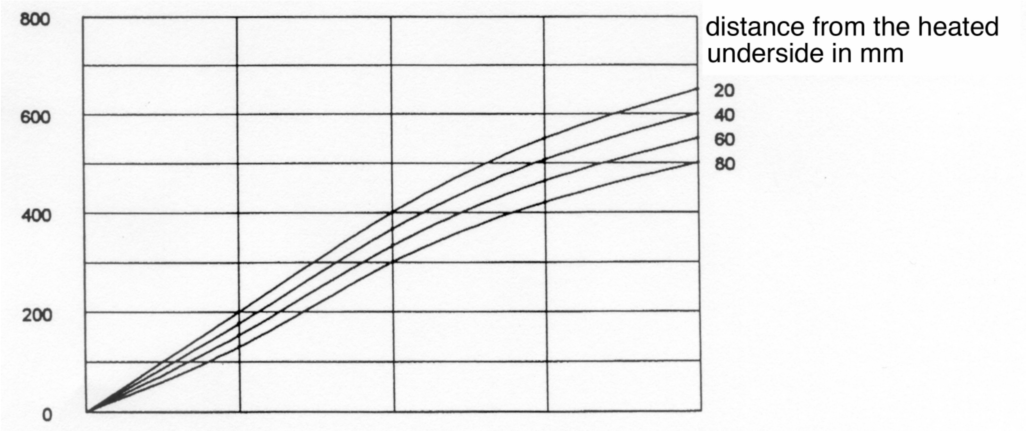


Figure 3 Temperature of the reinforcement next to the spheres in function of the fire time with different reinforcement distances
(Note: the reinforcement distance according to NEN 6720 is the distance from the surface of the concrete which is exposed to fire to the centre of the considered reinforcement bar).

Explanatory notes
Example: with a reinforcement distance of 40 mm, the temperature in the bars in the solid part after 90 minutes equals 440°C according to figure 12 of NEN 6071 and equals 500°C for the bars next to the spheres according to figure 3 of this CUR-Recommendation. The corresponding values for the tensile strength are respectively 344 N/mm2 and 278 N/mm2 according to figure 7 of NEN 6071. If 40% of the total reinforcement exists of bars next to the spheres than the calculated average equals 0.4 x 278 + 0.6 x 344 = 318 N/mm2.

9.3.2 Determination of the required reinforcement distance

If the reinforcement distances in table 1 are respected, then the arithmetical determination of the fire resistance is not necessary, except for the requirement in 9.3.3.

Table 1 Determination of the reinforcement distance in relation with the fire resistance.

Required fire resistance in minute	**Reinforcement distance for bars in the solid part in mm**	**Reinforcement distance for bars next to spheres in mm**
30	10	10
60	20	20
90	30	50
120	40	80

When determining the necessary reinforcement distance apply the calculated average of both reinforcement distances.

In seams between concrete filigran slabs, the slab thickness where the slabs lie directly against each other, should not be included in the determination of the reinforcement distance.

Explanatory notes
Example: for a required fire resistance of 120 minutes, the required reinforcement distance for bars in the solid part is 40 mm and for bars next to the spheres is 80 mm.

If 40% of the total reinforcement exists of bars next to the spheres, then the calculated average equals 0.4 x 80 + 0.6 x 40 = 56 mm. This is the required reinforcement distance of all bars if they were all situated on one level.

Application of large reinforcement distances can be difficult in practice. The reinforcement distances can be reduced by arithmetical determination according 9.3.1 of this Recommendation. In general this calculation will require in some areas of the floor more reinforcement than the reinforcement necessary at normal temperature. Research has proven that this 'overdimensioning' in general will be limited. In verification the method of redistribution of flexural moments can be used. In this case, it shows that 'overdimensioning' is even more limited or is not necessary at all.

In seams between concrete filigran slabs, it is assumed that the air can flow freely between the slabs, so that extra measurements are necessary to get acceptable reinforcement distances. The joining bars can be fixed on the required cover above the seam. Another possibility is the application of a triangle edge of the slab in which concrete is poured. Figure 4 shows both possibilities.

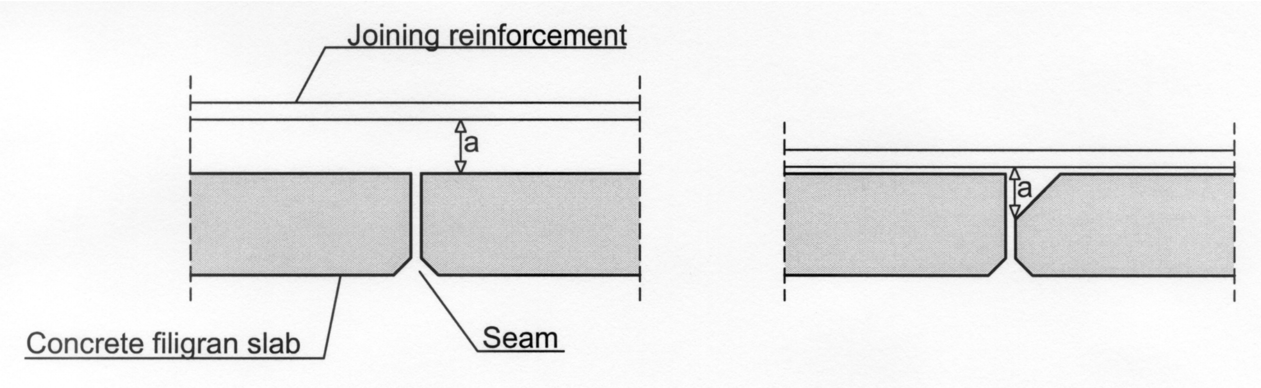


Figure 4 Reinforcement distances for joining bars.

9.3.3 Verification of the shear force resistance

If a fire resistance in relation to collapse of 60 minutes or more is required for the floor, a verification calculation should be executed on shear force resistance, under fire conditions according to NEN 6071. The contribution to the shear force resistance of the concrete should be applied to 50% of the value of t1 according 8.2.3.3 of NEN 6720.

Explanatory notes
In contrast to the verification of shear force resistance under normal circumstances, in case of fire possible collapse due to exceeding of the shear force tensile resistance has to be assumed. For BubbleDeck floors only 50% of this resistance should be taken into consideration.

9.6 Anchorage length of reinforcing bars

Add to this clause:

9.6.4 Anchorage of reinforcing bars in BubbleDeck floors®

The required anchorage length according to 9.6.1 up to and including 9.6.3 of NEN 6720 has to be increased by 10% for every sphere in contact with the bar in the anchoring area.

9.9 Minimum reinforcement

9.9.2.1 Minimum reinforcement

The section factor W should be determined for the net concrete cross section.

9.11 Detailing of the reinforcement

9.11.1 Plates

Add to this clause:

9.11.1.7 BV-girder

BV-girders that are applied as shear force reinforcement, have to meet the following requirements:

∑ • the centre-to-centre-distance of the BV-girder should be a maximum of twice the floor thickness;

∑ • the centre-to-centre-distance of two down running or up running diagonals should be a maximum of 2/3 of the floor thickness;

∑ • every pair of two diagonals, existing of one up running and one down running bar, should be welded with 2 welding points to both the lower and the upper longitudinal bar;

• the welding points with which the diagonals are attached to the lower and upper longitudinal bar should have a resistance per welding point of at least 25% of the flow strength of the diagonal;

∑ • the bend radius of bent bars should be minimal 2.5k according to 9.5 of NEN 6720;

∑ • the distance between the edge of the floor support and the connection of the first diagonal from the floor support with the upper longitudinal bar of the BV-girder should be maximal _ times the height of the BV-girder.

Titles of cited standards and CUR-Recommendations

NEN 5950: 1995
Regulations for concrete Technology (VBT 1995). Requirements, production and inspection, including amendment sheet A2: 1999

NEN 6069: 1991
Experimental determination of the fire resistance of building parts with correction sheet of March 1992

NEN 6071: 1991
Arithmetical determination of the fire resistance of building parts. Concrete constructions, including amendment sheet A1: 1997

NEN 6720: 1995
Technical principles for building constructions TGB 1990
Regulations for concrete: Structural requirements and calculation methods (VBC 1995), including amendment sheet A2: 2001 (in preparation)

NEN 6722: 1989
Regulations Concrete. Construction (VBU 1988), with correction sheet May 1989

CUR- Recommendation 37
High Strength Concrete. Additional requirements on NEN 6720 (VBC 1990), NEN 5950 (VBT 1986) and NEN 6722 (VBU 1988)

CUR- Recommendation 39
Concrete with rough light aggregates. Additional requitements on NEN 6720 (VBC 1990), NEN 5950 (VBT 1986) and NEN 6722 (VBU 1988).

Dutch standards are publications of the Dutch Standardization Institute (NEN), Vlinderweg 6, Postbus 5059, 2600 GB Delft (orders with NEN, sales and information department, Tel.nr.: 0031 15 269 03 91).

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Gouda, December 2001
The Board of CUR

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