# High performance lightweight noise barrier with carbon fibre reinforced concrete

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**Abstract**

High-strength concrete elements exhibiting low system weight and great slenderness can be created with a large degree of lightweight structure using textile-reinforced concrete (TRC) slab and a shell with very high level of sound absorption. The system was developed with the objective of lowering system weight, and then implemented operationally in construction. Arising from the specifications placed on the load-bearing concrete slab, the followings were developed: an adapted fine-grain concrete matrix was assembled, a carbon warp-knit fabric was modified and integrated into the fine concrete matrix, a formwork system at prototype scale was designed enabling noise barriers to be produced with an application-oriented approach and examined in practically investigations within the context of the project. Substantial decrease in weight of the load-bearing concrete slab's system was possible, which led to a decrease in transport and assembly costs.

Keywords: textile-reinforced concrete, noise barrier, high-performance concrete, durability

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## 1. Introduction

Noise is a consequence of increasing mobility and has a negative effect on both human beings and the environment. The continuous rise in traffic density, which grew by more than 70 percent on motorways between 1980 and 2012 [1], has led to greater noise emissions. Today, this makes sound protection measures more important than ever. It does not matter whether these noise barriers are for major roads, motorways or high-speed sections. Such systems are very complex and contain restrictions with regards to load-bearing capacity, serviceability and functionality. Alongside acoustic and mechanical specifications including durability, economic and ecological aspects additionally come to the fore. The objective is savings on resources not just based on optimizing weight and minimizing manufacturing costs but also leading to decreasing expenditure for transport and assembly.

In Germany, about 50 percent of noise barriers are made of concrete. They are mostly composed of a load-bearing layer made from steel reinforced concrete and a noise-absorbing facing concrete shell set up on one or both sides and made from lightweight concrete. The usual material thickness with the load-bearing concrete layer is about 12 to 15 cm due to the concrete coverage needed in terms of passive protection against corrosion. Utilising textile reinforced concrete in this case offers great potential in reducing weight and constructing in a resource-efficient and sustainable manner. Textile reinforced concrete is an innovative high-performance composite material consisting of fine concrete matrix and textile reinforcement [2, 3]. The development of this new type of composite material has made a construction method available which utilizes reinforcement that is generally not susceptible to corrosion due to environmental influences (e.g. air humidity and chloride) [4, 5]. The concrete cover needed in steel reinforced concrete construction can thus be substantially reduced by employing textile reinforced concrete [6, 7]. Just a few millimeters minimum concrete cover is necessary to safeguard the transfer of bonding forces between the fine concrete matrix and the textile reinforcement [8]. This means that thin-walled, free-formed surfaces can be created with a great degree of lightweight structure that feature low system weight and great slenderness.

This paper reports the development of a noise barrier, which consists of a load-bearing component made of textile reinforced concrete and a noise-absorbent component made of a lightweight concrete. An important part of this work is durability and so the lifespan of the noise barrier.

## 2. Materials and methods

### 2.1 Components for load- bearing and noise-absorbent concretes

*Table 1* illustrates the qualitative and quantitative composition of the load-bearing concrete and the noise-absorbent concrete. The load-bearing concrete contains, besides type CEM I 52.5 R Portland cement according to EN 206, pozzolanic fly ash and silica fume as binding agents (*Table 1*), which have a positive action on both fresh and hardened concrete characteristics in respect of sedimentation stability, durability and mechanical strength. Two quartz sands and dolomite powder were utilized as aggregate or filler. The alkali resistant (AR) glass fibres, which lower the propensity to shrinkage cracking and can enhance first crack tensile strength in the concrete, are 12 mm long and have a length mass of 45 tex. The high-performance superplasticiser employed has a 30 percent by weight proportion of polycarboxylate ether (PCE). The noise-absorbent concrete has a monodisperse (single particle) aggregate made of round expanded clay in a fraction of 0 to 2 mm.

| Component | Load-bearing (kg/m³) | Absorber (kg/m³) |
|---|---|---|
| **White cement 52.5 R** | 495 | 250 |
| **Amorphous alumosilicate** | 150 | - |
| **Quartz sand 0/2** | 310 | - |
| **Quartz sand 0/1** | 900 | - |
| **Expanded clay** | - | 970 |
| **Dolomite powder ($x_{5ß}$= 70 µm)** | 190 | - |
| **Water** | 210 | 150 |
| **AR-glass fibres (12 mm, integral)** | 14 | - |
| **superplasticizers** | 15 | - |
| **Water-binder-ratio** | 0.38 | 0.60 |

*Table 1. Composition of the fine grained concrete mix*
*1. táblázat A vizsgált finomszemű betonok összetétele*

## 2.2 Textile for textile reinforced concrete

Two layers of a two-dimensional bidirectional warp-knit fabric of carbon were used for the reinforcement of TRC (*Fig. 1*). The warp and weft yarn had a length weight of 3300 g/km (≙ 3300 tex) and a tensile strength of 1576 MPa. The mesh size of the 15 mass percent impregnated warp-knit fabric (measured by thermogravimetry) was 10.8×18.0 mm². The warp and weft yarn consisted of 50000 carbon filaments with a diameter of 7 µm. The degree of reinforcement in concrete was approximately 1.1% by volume.

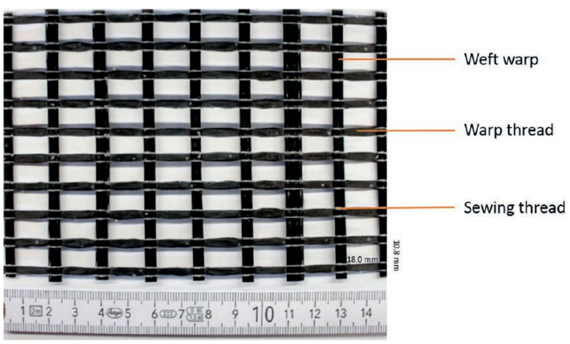



*Fig. 1. Schematic of the bidirectional warp-knit fabric of carbon fibres*
*1. ábra. A kétirányban teherhordó szénszálas szövet sémája*

| | component | mixing technology | mixing power in % | mixing time in s |
|---|---|---|---|---|
| **1st** | binders + aggregates | concurrent | 15 | 60 |
| **2nd** | 75% of water | sequence | 35 | 90 |
| **3rd** | super plasticizer | sequence | 35 | 60 |
| **4th** | residual water | sequence | 40 | 30 |
| **5th** | AR-glass fibres | sequence | 40 | 30 |

*Table 2. Mixing parameters for fine grained concrete*
*2. táblázat A finomszemű betonok keverési paraméterei*

## 2.3 Test Specimens

Several plates (50×50 cm²) were prepared for the test specimens. In a first step, the absorber concrete was mixed. Thereafter, the fresh absorber concrete was poured into the mold. After this, the fine grained concrete was mixed with the intensive mixer R05T by Erich. The mixing parameters are shown in *Table 2*. Subsequently, the fresh fine grained concrete was applied on the absorber concrete (*Fig. 2.a*). Finally, the test plates were demolded after 24h (*Fig. 2.b*).

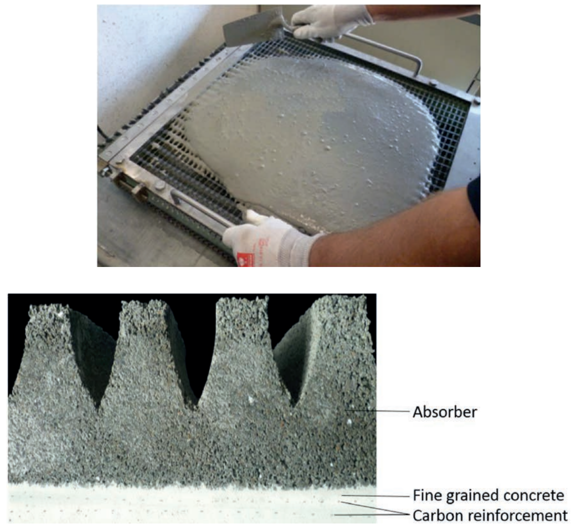



*Fig. 2. Application of fine grained concrete (a) and demolded test plate (b)*
*2. ábra. A finomszemű beton alkalmazása (a) és a kizsaluzott elem képe (b)*

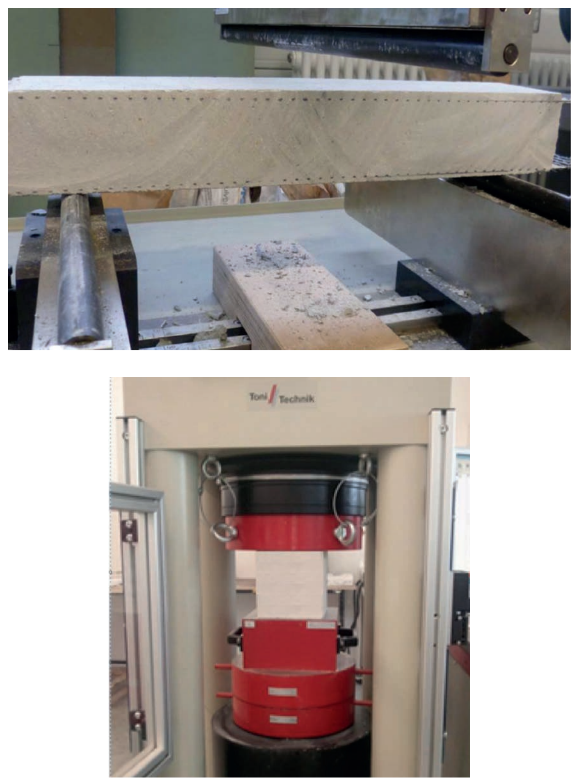



*Fig. 3. Determination of 3-point bending tensile strength (a) and compressive strength (b)*
*3. ábra. Harmadpontos hajlítóvizsgálat elrendezése (a) és nyomószilárdság vizsgálat (b)*

## 2.3 Test Specimens Test set-up for TRC and absorber

The samples for the tests to be performed on the hardened concrete were stored dry, according to EN 12390-2. The 3-point bending tensile strength (*Fig. 3.a*) was determined by means of the Toni Technik ToniNorm with samples which measured 225×50×15 mm³ (length × width × height), based on EN 12390-5. The span width set was 200 mm and the load speed 100 N/s constant. The compressive strength was determined by means of the Toni Technik ToniNorm (load frame 3000 kN) following EN 12390-3, with cubes having an edge length of 150 mm (*Fig. 3.b*). The pre-load was 18 kN.

To validate the durability of the fine grained concrete, the capillary suction of de-icing solution and freeze thaw test (CDF-Test) was measured by the Schleibinger Freeze-Thaw-Tester with standard agent solution according to the recommendations of RILEM TC 117-FDC (*Fig. 4*).

*Fig. 4. Determination of the capillary suction of de-icing solution and freeze thaw test*
*4. ábra. Kapilláris sóoldat felszívás és fagyhámlás vizsgálata*

## 3. Results

### 3.1 Properties of fresh and hardened TRC

*Table 3* shows the fresh and hardened concrete characteristics after 28 days. The fresh fine grained concrete possessed great flowability (flow spread 640 mm) and corresponded to flow class F6 according to EN 12350-5. Using an air content tester, air content of 2.7 volume percent and a gross geometric density of 2.31 g/cm³ were determined in the fresh concrete. A shrinkage channel was utilized to determine the total shrinkage deformation at 0.68 mm/m. The reason for this high total shrinkage was the high binding agent content and the great chemical and autogenic strength of the hardened concrete at 28 days (gross density: 2.31 g/cm³) was 83.7 MPa; it was 25 MPa after 24 hours. The 3-point bending tensile strength of the unreinforced concrete was 11.73 MPa after 28 days.

| characteristic | fresh concrete | hardened concrete |
|---|---|---|
| geometric bulk density | 2.37 g/cm³ | 2.31 g/cm³ |
| flow spread | 640 mm | - |
| air content | 2.7 Vol.-% | - |
| linear shrinkage | 0.91 mm/m | |
| compressive strength | - | 83.7 MPa |
| 3-point bending tensile strength | - | 11.73 MPa |

*Table 3. Properties of fresh and hardened fine grained concrete*
*3. táblázat Frissbeton és szilárd beton jellemzők (finomszemű beton)*

In addition, the fine concrete exhibited great durability, which was verified through a successful CDF test with an average scaling of 912 g/m² and a relative dynamic modulus of elasticity of 100 percent after 28 freeze-thaw cycles (*Table 4*).

| test method | test value |
|---|---|
| CDF test | $m_{28}$ = 113 g/m³ |
| | $R_{u,28}$ = 100% |
| water penetration depth | 11 mm |

*Table 4. Examinations of the durability of fine grained concrete*
*4. táblázat Tartóssági vizsgálatok a finomszemű betonon*

Building in 2 layers of carbon meshes in with the flow of forces enabled the 3 point flexural strength to be enhanced to 24.51 MPa (*Fig. 5*). In this case, the first crack tensile strength was 11.21 MPa (*Fig. 5*). By utilizing short fibres with a critical fibre volume content (fibres have a strengthening effect on the matrix) and prestressing the textile reinforcement, an increase in tension without slippage was observed in the concrete after macro-crack formation (see blue shading in *Fig. 5*), i.e. the bending tensile stress was transferred without loss of force from the concrete into the textile reinforcement. Integrating short fibres in the concrete generated a fine crack pattern with a positive action on durability.

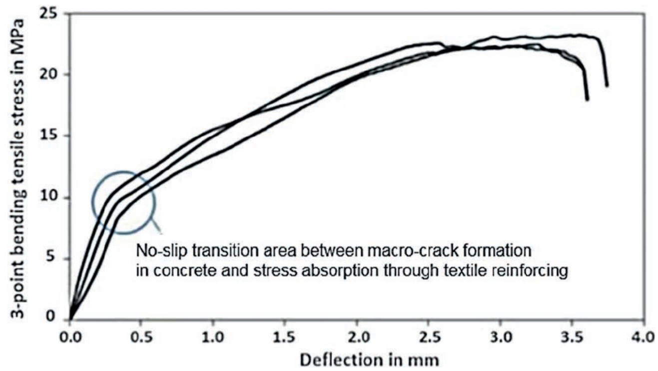


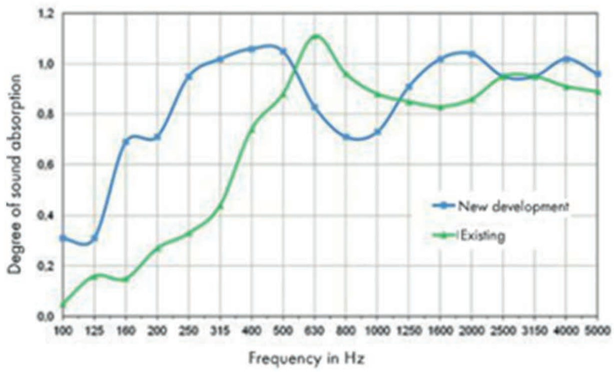

*Fig. 5. Stress-deflection diagram*
*5. ábra. Feszültség-lehajlás diagram*

### 3.2 Noise-absorbent concrete

The noise-absorbent concrete had a gross density of 1.31 g/cm³ and a compressive strength of 16.0 MPa (*Table 5*). Dynamic modulus of elasticity of 17 GPa was determined from the speed of sound using an ultrasonic measurement device. The degree of sound absorption was ascertained by means of the reverberation time procedure according to EN ISO 354:2003 with structured test specimens (*Fig. 6.b*). The results of this test showed that the degree of sound absorption is more than 0.7 at a frequency of 160 Hz (*Fig. 6.a*). The first local maximum sound absorption ($\alpha = 1$) was found at a frequency of 350 Hz. The decrease in sound absorption between 600 and 1000 Hz after 800 Hz means that great sound particle velocity prevails in this area. These types of curve progressions occur comparatively often with mono-modular and porous aggregate materials. They are indicative of insufficient flow resistance adaptation. The result is that the noise absorber acts like a resonator. Based on these measurements, the noise absorbent shell met the conditions for sound group 4 (highly absorbent).

| characteristic | fresh concrete | hardened concrete |
|---|---|---|
| geometric bulk density | 1.53 g/cm³ | 1.43 g/cm³ |
| flow spread | 650 mm | - |
| air content | 11.5 Vol.-% | 10.4 |
| compressive strength | - | 16.9 MPa |
| 3-point bending tensile strength | - | 2.0 MPa |

*Table 5. Properties of fresh and hardened noise-absorbent concrete*
*5. táblázat Frissbeton és szilárd beton jellemzők (hangelnyelő beton)*



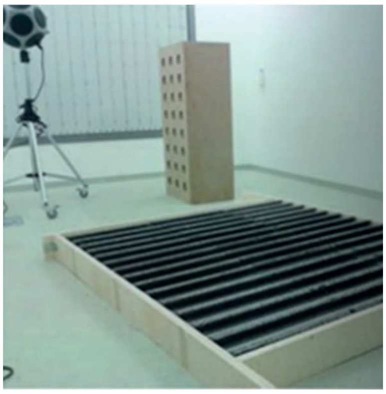



*Fig. 6. Degree of sound absorption according to EN ISO 354*
*(a) Degree of sound absorption*
*(b) Measurement in echo chamber*
*6. ábra. Hangelnyelés vizsgálata az EN ISO 354 szabvány szerint*
*(a) Hangelnyelés mértéke*
*(b) Mérés visszhang kamrában*

## 4. Conclusions

At the completion of this project, a noise barrier was able to be implemented using textile-reinforced lightweight construction method under construction conditions. In the context of the present research and development project, a scientific basis was created for developing the materials: it was technically implemented in production, tested in numerous test series, adopted and practically investigated in the form of a prototype.

Integrating short fibres in the concrete generated a fine crack pattern with a positive action on durability, amongst other things. Taking the first crack computations into account, proof was furnished in mechanical investigations that the thickness of the textile-reinforced, load-bearing concrete slab can be reduced from 12 cm (steel reinforced concrete) to 5 cm (carbon reinforced concrete). Proof was also given of good post-cracking strength, low creep and shrinkage deformation, low susceptibility to cracking and excellent resistance to frost/de-icing salt (exposure class XF4).

This new type of textile-reinforced noise barrier meets requirements as regards resource efficiency, cost reduction, sustainability, minimization of the system slab weight and a decrease in transport and assembly expenses in practice under construction conditions. The marginal conditions for manufacturing such noise barriers on an industrial scale in large quantities with high demands on equality are currently being created in preparation for its mass production and market launch. Beyond this, a key priority is obtaining general building authority approval or product approval.

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**Nagy teljesítőképességű könnyűbeton zajvédő fal szénszál erősítésű betonból**
Nagy szilárdságú, kis önsúllyal rendelkező, nagy karcsúságú textil-erősítésű könnyűbeton lemez és nagy hangelnyelő-képességű könnyűbeton héj kombinációját vizsgálja a cikk. A kutatás során kifejlesztésre került a finomszemű beton összetétele, a szénszál-erősítésű szövet, a hangelnyelő héj zsaluzata. A fejlesztés eredményeként jelentős önsúly csökkenést lehetett elérni, amely gazdaságos beépítést tesz lehetővé.
Kulcsszavak: textil-erősítésű beton, könnyűbeton, zajvédő fal, tartósság