Measurement of acoustic emission at fibre reinforcement concrete slab with subsoil

O Sucharda¹, L Pazdera², Z Marcalikova³, L Topolar², M Kozielova³ and V Bilek¹

¹ Department of Building Materials and Diagnostics of Structures, VSB-Technical University of Ostrava, Ludvíka Poděště 1875/17, 708 33 Ostrava-Poruba, Czech Republic
² Institute of Physics, Faculty of Civil Engineering, Technical University of Brno, Veveří 331/95, 602 00 Brno, Czech Republic
³ Department of Structures, Faculty of Civil Engineering, VSB-Technical University of Ostrava, Ludvíka Poděště 1875/17, 708 33 Ostrava-Poruba, Czech Republic

E-mail: oldrich.sucharda@vsb.cz

Abstract. The paper deals with the possibility of using the acoustic emission (AE) measurement for the identification of cracks and failure in fibre concrete slabs in interaction with subsoil. In this specific task it is not possible to check visually cracking on the slab bottom surface. The research task included an experimental load test of a slab and supplemented laboratory testing to determine the mechanical properties of fibre concrete. The concrete used has a dosage of 25 kg/m³ fibres. Laboratory tests included cube and cylindrical compressive strength, flexural strength and split tensile strength. Homogeneity of the concrete mixture, i.e. uniform distribution of the fibres, was proven with testing of the split tensile strength both evenly and perpendicularly to the direction of filling the concrete mixture into the form. Experimental load test of slab on subsoil was performed on fibre concrete slab with plan dimensions 2000 x 2000 mm and thickness 150 mm. Concrete slab was loaded in the middle with force load step 75 kN. AE measurements were provided using track sensors.

1. Introduction
Diagnostics of buildings and identification of failure are important areas of research, especially in case of quasi-brittle materials [1, 2], where the diagnostic methods can be combined with advanced structural analysis. Using new materials and advanced structural design structures are more subtle and the intensity of internal forces is closer to material failure. New mixtures of concrete and composites as quasi-brittle materials may have different behavior or character of failure in the structure then common concrete [3, 4]. The group of quasi-brittle composites includes also fibre concrete [5-7]. Fibre concrete exists in a number of variations with a variety of mechanical properties [8-12].

Great attention is paid to concrete structures [13-16] and structural health monitoring using non-destructive methods. These include ultrasound, computed tomography or acoustic emission (AE) measurements since the 1970s [17, 18]. The advantages of AE method are that, depending on the measurement configuration, it enables identification of the occurrence of the disorder, its quantification and its continuous monitoring [19-21]. A number of recommendations and standards can be found [22-29]. It should be noted, however, that in view of the universality of the measurement
method and the very principle of acoustic emission, it is always necessary to find an appropriate method of evaluation that takes into account specific boundary conditions of the solved task [30-34].

In the paper slab in interaction with the subsoil [35-36] is analyzed. With this structural type it is not possible visually identify the crack occurrence on the bottom surface. The crack formation itself does not necessarily endanger the safety of the construction, but it will affect the structural service life. Especially in the case of complicated geological conditions (groundwater level, aggressiveness of the environment), accelerated degradation of materials can occur at the point of crack formation.

The very possibility of identifying cracking in concrete and fiber reinforcement concrete in a solved task is illustrated on a set of experiments [37]. Taking into account the measurements so far and the number of tests, the present research has focused on further verifying possibility used acoustic emission and the possibility / form of presentation of measurement results.

2. Acoustic emission

Acoustic emission is a non-destructive testing method (NDT). It belongs to passive methods and allows not only identification and localization of crack formation. The acoustic emission itself can be interpreted by means of a number of parameters. They are AE counts, duration, amplitude, rise time, and the measured area under the corrected signal envelope that is also called relative energy. Basic parameters of acoustic emission are the change of ring down counting which can be recorded:

$$\frac{dn}{dt} = \alpha \times \Delta K^m_i$$  \hspace{1cm} (1)

where $\Delta K_i$ is the change of the stress intensity, $\alpha$ and $m$ constitute material constants. The AE measurements made within load test of slab were provided with acoustics sensors type MTPA-15 with an integrated 35 dB pre-amplifier (type) attached to the surface of the sample with beeswax. DAKEL-XEDO© universal measuring and diagnostic system developed by ZD Rpety-Dakel was used for the processing and recording of AE signals and the XEDO-AE unit was used for the assessment of acoustic emission parameters.

3. Laboratory tests

Knowledge of the mechanical properties of the fibre concrete is necessary for a wider evaluation and analysis of the concrete slab testing. Testing of mechanical properties was conducted in the laboratories of the Faculty of Civil Engineering, VŠB-TU Ostrava. The used concrete had a dosage of 25 kg/m³ of Dramix® 3D 65/60 BG fibre. Basic properties of fibres are shown in Table 1 and the fibres shape is in Figure 1.

| Table 1. Basic characteristics of the Dramix® 3D 65/60 BG fibre. |
|---------------------------------------------------------------|
| Fibre shape          | curved ends |
| Length [mm]          | 60          |
| Diameter [mm]        | 0.9         |
| Aspect ratio         | 67          |
| Tensile strength [N/mm²] | 1160       |
| Effect on consistency [s] | 8           |
| Effect on concrete strength [kg/m³] | 15           |
| Elastic modulus [GPa] | 200         |

![Figure 1. Fibres Dramix® 3D 65/60 BG.](image)

The concrete recipe is presented in Table 2. Concrete compressive strength was tested on 6 cubes and 6 cylinders. Another sample series of cubes 150 × 150 × 150 mm was tested for split tensile strength. There were 12 cube samples in total, 6 samples were used to determine the split tensile strength perpendicular to the filling direction and 6 samples to determine the split tensile strength.
parallel to the filling direction. This way also homogeneity of the fibres in the concrete mixture was verified. Another series of samples were beams with dimension $150 \times 150 \times 600$ mm, for determining the flexural strength. Two types of tests were performed, i.e. a three-point bending tensile test with a force in the middle of the beam and with a span between the supports 500 mm and a four-point bending test with forces 175 mm from support, where the span between supports was 500 mm. Test results are shown in Table 3.

**Table 2.** Material composition of concrete.

| Description               | Type/Quantity     |
|---------------------------|-------------------|
| Consistency               | S3                |
| Cement                    | CEM I 42.5 R      |
| Minimal cement content    | 300 kg            |
| Water cement ratio        | 0.6               |
| Aggregates 0/4 (mined)    | 870 kg            |
| Aggregates 4/8 (mined)    | 150 kg            |
| Aggregates 8/16 (mined)   | 820 kg            |
| Water                     | 189 l             |
| Plasticizer               | 2.9 l (Stacheplast)|

**Table 3.** Fibre concrete strengths determined from laboratory tests.

| Type of test                              | Number of samples | Average [MPa] | Standard deviation [MPa] |
|-------------------------------------------|-------------------|---------------|--------------------------|
| Compressive strength (Cube $150 \times 150 \times 150$ mm) | 6                 | 26.49         | 1.292                    |
| Compressive strength (Cylindrical $150 \times 300$ mm) | 6                 | 21.88         | 0.692                    |
| Split tensile strength - perpendicular to filling direction | 6                 | 2.26          | 0.158                    |
| Split tensile strength - parallel to the filling direction | 6                 | 1.73          | 0.237                    |
| Three-point bending tensile test          | 2                 | 4.26          | -                        |
| Four-point bending tensile test           | 1                 | 3.99          | -                        |

4. **Experimental measurement on slab on subsoil**
A special testing device for testing concrete slabs in interaction with the subsoil (Figure 2), is located in the campus of the Faculty of Civil Engineering.
Tested concrete slab was with plan dimensions 2000 × 2000 mm with thickness 150 mm. Load was applied in steps of 75 kN until it was completely damaged, i.e. until slab bearing capacity was reached. Time step of each load step was 30 min.

Figure 3 shows the load - time diagram of the concrete slab test. The maximum achieved load value was 499.2 kN, when the slab was damaged. Measurement was terminated after significant pressure drop in the hydraulic press and the slab was pressed into the subsoil. The deformations were measured by the net of 24 track sensors - potentiometers. 8 AE sensors were installed on the slab. The scheme diagram of the track sensors and AE sensors position is in the Figure 4. The maximum deformation 26.72 mm was measured in section A-A´, corresponding to middle part of slab pushed into subsoil. The maximum negative deformation -13.06 mm was measured at lifted up corners. Selected deformations are shown in Figure 5. Description the x-axis is the coordinates of plane in the FRC slab.
The $x = 0$ coordinate is the centre of the slab. Coordinates $y$-axis are the vertical deflection of the slab. Based on polynomial approximation maximum slab deformation 29.65 mm was calculated.

**Figure 5.** Deformation corresponding to track sensors – section A-A'.

For section B-B‘ the maximum deformation 26.72 mm was measured, corresponding to middle part of slab pushed into subsoil and the maximum negative deformation -13.93 mm was measured, corresponding to slab border part with lifted up corners. The deformation sections are shown in Figure 6. The course of the test and the deformation evaluation shows that deformations up to the load 225 kN are very small. The size of acoustic emission parameters measured is also very low. For increasing load, the deformation increases more significantly and the size of the acoustic emission parameters also increases. At a load of 450 kN, the deformation in the middle of the slab is around 15 mm. The
slab is damaged with cracks but is still entire. With the next load step, which ends with 499.2 kN, the deformation grows very fast and cracks are very distinct. This is evident also in the measurement of acoustic emission. Failure of the fibre concrete slab is shown in the Figure 7.

![Failure of the fibre concrete slab](image)

**Figure 7.** Failure of the fibre concrete slab with sensors.

The details of the AE measurements are in the Figure 8. The first higher AE values are visible for the load value 150 kN. For the load of 75 kN the AE count can be considered as a measurement noise. The highest AE intensity is for the load 375 kN and 450 kN for sensor 3, 4, 6, 8. This is consistent with deformation measurements where rapid growth occurs at the same load step. As for the sensor 7, the AE values are very high during the whole experiment and the values from this sensor are not taken into consideration.

![Acoustic emission measurement](image)

**Figure 8.** Acoustic emission measurement - AE count / Sensors / Load.

### 5. Conclusion

The paper was focused on the possibility of measuring acoustic emission in slab interacting with the subsoil. Acoustic emission measurement proved that it is possible to identify the crack occurrence in fiber concrete slab. Acoustic emission measurements have also confirmed the results of previous
research in the project of focus on the possibility of identification crack in concrete [37]. The first cracks were formed on the bottom surface of the slab, which is in contact with the subsoil. Final break of tested slab and the exhausting of the load capacity is also very obvious in the AE graphs. Size of acoustic emission and the growth of the deformations is similar. Acoustic emission measurements contributed to a better understanding of damage mechanism and slab structure collapse and can be used to identify cracking. Wider range of conclusion requires more types of tested slabs and wider material variations. This is the aim of further research together with using AE measurement for crack localization.

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