Importance of dowels in transversal joints in concrete pavements

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Abstract. Concrete pavements are designed for heavy loaded road structures. Their usage brings a number of specific issues. It is necessary to solve them all to ensure that concrete pavements will fulfil their function along the whole design period. One of these issues concerns dowels, which are located in transversal joints. Modelling of load, caused by heavy vehicles, with the use of the finite element method, provides valuable information about the stress condition of concrete pavement. The results of modelling can be verified by measurements or experiments in practice. Dowels and tie bars in jointed unreinforced concrete pavements and the importance of their correct placement, dimensions and material quality on pavement behaviour and lifespan were studied as a part of R&D projects of Technology Agency of the Czech Republic Nos. TA02031195 and TE01020168. The paper presents the experience from the modelling and performed experiments and makes conclusions which are important for the use in practice.

1. Introduction

Dowels are placed in transversal contraction or construction joints of concrete pavements and help to transfer loading between individual slabs. Dowels allow horizontal movement of slabs during contraction in the time period after laying the concrete pavement and at temperature changes. In addition, they prevent different vertical slab movements and occurrence of so-called “steps” during the concrete pavement life span. Transversal joints are critical spots in the structure, when dowels and concrete itself are loaded by the combination of overrunning heavy vehicles and temperature gradient on the slab. Modelling of concrete pavement road structures brings valuable knowledge on structure loading, which is subsequently tested by measurements on testing road segments.

In the Czech Republic, just one steel dowel type with the diameter of 25 mm and length of 500 mm with anti-corrosion coating is used. This dimension of dowels is used for the construction of motorways, where the thickness of the road pavement is 220-300 mm, as well as for the construction of airports, where the thickness of road pavement reaches 400 mm. The existing requirements for dowels in the Czech Republic are specified by standards ČSN EN 13 877-1, ČSN EN 13877-2, ČSN EN 13 877-3 and ČSN 73 6123-1.

National annex ČSN EN 13877-3: 2006 states that dowels used for concrete road pavements CB I must have the minimum diameter of 25 mm and minimum length of 500 mm. The whole length of dowels must be coated with a thin 0.3 mm plastic film, which provides anti-corrosion protection and allow slipping of the dowel in concrete.
ČSN 73 6123-1 Road building – concrete pavements – Part 1: Construction and conformity assessment states that dowels must be installed in such way that the dowel axis is at the height h/2 minus dowel diameter (where h is concrete pavement thickness), in a single axis, parallel to the surface of the concrete pavement and with the longitudinal axis of the installed traffic lane typically at the distance of 250 mm, or potentially 500 mm. The necessary amount, profile, deployment, and distance of dowels is specified by construction documentation based on the amount of loading of the traffic lane and the merging lane. Unless the construction documentation states otherwise, the distance of dowels on loaded traffic lanes is 250 mm. The distance can be doubled on lightly loaded traffic lanes and hard shoulders.

The following Table 1 contains a list of required dimensions of dowels and horizontal distances for their installation in transversal joints in individual countries where the concrete pavements with cut joints are used.

Table 1. Required dimensions and horizontal distance of dowels.

| Country     | Dowel diameter (mm) | Dowel length (mm) | Distance (mm) | Pavement thickness (mm) |
|-------------|---------------------|-------------------|---------------|------------------------|
| Czech       | 25                  | 500               | 250           | -                      |
| Germany     | 25                  | 500               | 250           | -                      |
| Austria     | 25                  | 500               | 250           | -                      |
| USA         | 25                  | 450               | 300           | <200                   |
|             | 32                  | 450               | 300           | 200-250                |
|             | 38                  | 450               | 300           | >250                   |
| France      | 20                  | 400               | 300           | 130-150                |
|             | 25                  | 450               | 300           | 160-200                |
|             | 30                  | 450               | 300           | 210-280                |
|             | 40                  | 500               | 400           | 290-400                |
|             | 45                  | 550               | 450           | 410-500                |
| Poland      | 32                  | 520               | 300-500       | 260-300                |
|             | 40                  | 640               | 300-500       | 300-400                |
|             | 45                  | 800               | 300-500       | >400                   |
| Belgium     | 25                  | 600               | 300           | -                      |
| Slovakia    | 25                  | 500               | 250-500       | ≤ 250                  |
|             | 30                  | 500               | 250-500       | > 250                  |

Only few studies focus on examining the contact stress between dowels and the surrounding concrete in jointed concrete pavement. A study performed in West Virginia University confirmed an occurrence of high tensile stress in concrete around dowels and the fact that their size influences the dowel diameter [3]. Another two studies state that serious stress concentration in the surrounding concrete caused by the small diameter and high strength dowel will lead to crush and spall at the edge of the concrete and becomes the main reason for a failure. Based on the multiple diameter analysis, the contact stress at the dowel-concrete interface decreases with the increase of dowel diameter [4, 5]. Therefore, the method of finite elements was selected for the modelling and a testing segment was created, which was to verify the foreign experience.

2. Modelling by finite element method
The calculations were performed at Brno University of Technology, Faculty of Civil Engineering, Institute of Structural Mechanics. The aim of the calculations was to find whether an incorrect position of a dowel in a concrete slab has an effect on tensile stress at the bottom of the concrete slab and on potential occurrence of cracks around the dowel (diameter: 25 mm, length: 500 mm). The calculation took into account 5 variants of “defective” dowel positions (Table 2).
Table 2. Considered variants of defective dowel positions.

| Variant | Vertical Translation (mm) | Vertical Tilt (mm) | Description               |
|---------|---------------------------|-------------------|---------------------------|
| (V1)    | -                         | -                 | Basic variant             |
| (V6)    | -20                       | -                 | Vertical Translation (downwards) |
| (V7)    | -40                       | -                 | Vertical Translation (downwards) |
| (V12)   | -                         | -20               | Vertical Tilt             |
| (V13)   | -                         | -40               | Vertical Tilt             |

The calculations were performed with the use of the finite element method in ANSYS software using detailed 3D calculation models. The global calculation model includes the area of road pavement formed by 3x3 slabs (thickness 240 mm). The detailed more accurate model includes the area of transversal joint with five dowels. The global calculation model provides a global field of displacement, field of stress, and boundary conditions for the detailed model. The detailed calculation model provides a local field of displacement and stress around the examined dowel.

Apart from the loading by its own weight and thermal deformation, external loading by a dual-wheel of the total force of 50 kN was inserted into the calculation model. The axis of one wheel crosses the axis of a “defective” dowel. The axis of the other wheel is 344 mm distant in transversal direction. The diameter of contact areas of forces is 240 mm. The wheel contact areas are placed close to the edge of one of the concrete slabs. The axes of forces are 120 mm distant in longitudinal direction from the edge of the contraction joint.

An uneven thermal field was applied to the model of concrete slabs and dowels and tie bars. Linear change in temperature along the slab height was set so that the temperature of the bottom of the concrete slab was 0 °C and the temperature of the top was -7°C. The reference temperature was set to 0 °C. The average axis expansion/shrinking, reference temperature and thermal field correspond with a 3 mm geometric clearance between concrete slabs.

Figure 1. Main tensile stress of concrete around dowel – (V12) variant of defective dowel position.
The obtained maximum values of tensile stress in concrete slab in close vicinity to defective dowels ($\sigma_3 = 8.0$ to $12.0$ MPa) make it obvious that the tensile strength of material is significantly exceeded (approximate $f_{ct} = 2.3$ MPa – derived from the conversion from standard compressive strength) and cracks will occur. Tensile strength was exceeded at all variants of positioning of “defective” dowels. The highest values of tensile stress were found at variants (V12) and (V13), where the dowel is vertical tilted (Figure 1). The results of tensile strength $\sigma_y$ at the bottom slab edge under defective dowels are influenced by defective dowel positions very little and virtually in all cases the 240 mm slabs range from 1.3 to 1.5 MPa.

3. Measurements in practice on testing field

In order to verify deformations in real concrete slabs, a testing field with concrete pavement was built in Brno. A slab of thickness of 230 mm was laid on a sub-base layer from lean concrete. Dowels on baskets were placed in transversal joints. Their placement on baskets allowed for a setting of different defective position of dowels (vertical and horizontal translation in comparison with the designed position, including vertical tilt). In its premises in Modřice, FIRESTA – Fišer, s.r.o. built a testing site, whose main aim was to construct a single span bridge and an incoming concrete pavement road. The sensors were installed in two transversal joints to the edge of the bottom part of concrete pavement and near dowels with cables running to a green strip of land at the side, where they could be connected to the control measurement unit (Figures 2, 3).

The road construction was designed with a subbase from porous cement concrete, onto which separation woven geotextile was placed. This is to prevent the cement milk from leaking to the porous cement concrete during the concrete pavement installation, which would lead to clogging of this subbase layer with overall drainage effect. The installation of concrete pavement was performed manually, which allowed the installation of baskets with dowels in the area of transversal joints in accurate distance and position. The compacting of concrete pavement was chosen while taking into account the baskets with dowels and sensors as a combination of a hand held concrete immersion vibrator and a vibrating beam on the surface. The concrete on the segment was laid in two longitudinal stripes (Figurer 4, 5).
Performed tests:

- Measurement of deflection and load transfer efficiency by Falling Weight Deflectometer (FWD) – measurement of deflection under loading in selected points, which simulates a heavy vehicle overrun;
- Measurement of strain in concrete by gauges of PMFL type 50-2LT (with active length of 50 mm) with the aim to study stress around different defectively positioned dowels;
- Measurement of tensile stress at the bottom of slabs – by FWD.

An overview of stress measured in December on 30-day old concrete is shown in Table 4. The average temperature of concrete during the measurements in December was 3.1 °C and negative thermal gradient ranged between -0.01 and -0.29 °C/cm.

Table 3. Measured deformations of concrete loaded by FWD of 115 kN on a 230-mm-thick slab leading to the following stress values (elastic modulus of concrete = 37500 MPa).

| Dowel position          | Principal tensile stress at the slab bottom (MPa) | Max. tensile stress around dowel (MPa) | Compressive stress around dowel (MPa) |
|-------------------------|--------------------------------------------------|--------------------------------------|--------------------------------------|
| Correct fit             | 1.23                                             | 0.29                                 | -0.77                                |
| Vertical Translation (downwards) 20 mm | 1.61                                             | 0.75                                 | -                                    |

The first informative results of the measurement proved suitability of the inbuilt system to monitor stress in the vicinity of dowels. The tests in practice show conformity with theoretical calculations when evaluating tensile stress at the bottom part of the slab. The tests confirm the assumption that stress at the bottom part of the slab under defective dowels is influenced very little by defective position of dowels.

The strain gauges placed around dowels show low values of tensile and compression stress and fail to correspond with theoretical calculations. This discrepancy is caused by the strain gauge length, which exceeds the stress concentration.

4. Recommendations
The development in the field of dowels tends to apply bigger diameters in relation to concrete pavement thickness and their traffic loading. In addition, it is possible to increase horizontal distance
of dowels in less busy traffic lanes (fast lane, hard shoulder). Steel dowels must be located in the center of the slab thickness in the same axis, parallel to the road pavement surface and perpendicular to the joint in a tolerance specified by ČSN EN 13877-3.

The recommendations for the use of the numbers of dowels and tie bars of different diameters are mentioned below. The recommendations are based on the experience from abroad, from performed tests, and from modelling. The axial distance of dowels is 250 mm. The distance can be increased, but maximally doubled, (Tables 4 and 5) on less busy traffic lanes (without heavy vehicle traffic) and on hard shoulders. The distance of dowels from slab edges may not be lower than 250 mm. The scheme of this recommendation for the construction of motorway pavements is shown in Figures 6, 7.

Table 4. Recommended dimensions and distance of dowels in transversal joints in concrete pavement.

| Dowel diameter (mm) | Dowel length (mm) | Distance (mm) | Pavement thickness (mm) |
|--------------------|-------------------|---------------|------------------------|
| 25                 | 500               | 250           | ≤ 200                  |
| 25                 | 200-250           |               | 200-250                |
| 30                 | 250               | 250           | 250-350                |
| 35                 | ≥350              |               | ≥350                   |

Table 5. Recommended dimensions and distance of tie bars in longitudinal joints in concrete pavement.

| Tie bar diameter (mm) | Tie bar length (mm) | Distance (mm) | Pavement thickness (mm) |
|----------------------|---------------------|---------------|------------------------|
| 14-16                | 800                 | min. 3 pcs (single carriageway) | ≤250 mm |
| 16-18                |                     | min. 5 pcs (dual carriageway) | >250 mm |

Figure 6. Example of a potential deployment of dowels and tie bars in transversal joints in dual carriageway.
Figure 7. Example of a potential deployment of dowels and tie bars in transversal joints in dual carriageway.

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