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DOWEL BARS – REINFORCING ELEMENTS OF CEMENT CONCRETE PAVEMENTS

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Abstract. Our aim is to analyze the function of reinforcement elements (dowel bars) in cement concrete pavement to highlight the influence of these elements on the service life of the pavement as a whole and to find possible alternatives to existing products that are freely available on the Czech market. That is, how these elements in the form of dowel bars should work properly so that the function meets the design assumptions of a rigid pavement. We describe the procedure for inserting dowel bars during paving, which is directly related to the possibilities of using different dowel bars. Finally, we summarize the possibilities of using alternative materials, shapes, or sizes of dowel bars and the possibilities of their use in the Czech Republic.

Keywords: Dowel bar, concrete pavement, reinforcing, material, shape, position.

1. Introduction

As reinforcing elements in cement concrete pavement (CCP), which are placed in transverse shrinkage, expansion and contraction joints, dowel bars in the form of short steel bars of circular cross-section coated with epoxy are used as standard in the Czech Republic. They are embedded in the concrete pavement and provide a mechanical connection that limits the vertical movement of the slabs while allowing their horizontal movement due to shrinkage and temperature changes in the cement concrete pavement. At the same time, these reinforcing elements ensure a reduction in deflection of the joint and stresses on the approach and departure slabs by increasing the efficiency of load transfer between the slabs. Dowel bars were used on Czech motorways in the 1990s during the construction of the D5 motorway, which was implemented according to German regulations and experience of that time. The previous motorway constructed, i.e. D1 motorway, was built without reinforcement of transverse and longitudinal joints, which led to sliding of the slabs in all directions and the formation of a step during use. Dowel bars are used in jointed unreinforced and jointed reinforced cement concrete pavement Figure 1 [1] . In both cases they have the same function.

Figure 1. Jointed reinforced concrete pavement [1].

2. Basic requirements for dowel bars and design of their location

Dowel bars are used in the transverse joints of CCP motorways and airport surfaces. For surfaces that are run in an omnidirectional direction, dowel bars can be used in both transverse and longitudinal joints. On other roads, the interaction of the plates in the longitudinal joints can be ensured by a so-called tooth (tongue and groove) [2]. Dowel bars shall comply with the provisions set out in EN 13877-3 [3], EN 13877-2 [4] and EN 73 6123-1 [2] for the design and construction of the roadway. Here it is specified that the minimum diameter of the dowel bars shall be 25 mm and the minimum length 500 mm for motorways and airfields. For other roads a minimum diameter of 16 mm may be designed.

In the Czech Republic, steel bars with a diameter of 25 mm and a length of 500 mm with a coating along the entire length are used as standard. The minimum requirements for the design of the placement of the dowel bars are defined in the standard [4] as follows:

- the distance between the dowel bars must not be greater than 12 times their diameter (i.e., in the Czech Republic $25 \times 12 = 300$ mm),
- the distance between the dowel bars can be doubled for lanes with light traffic loads, e.g., overtaking lanes,

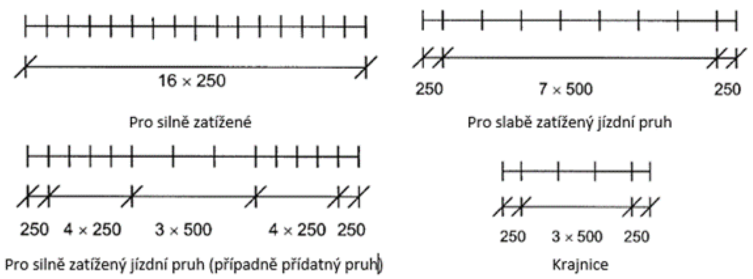

Figure 2. Examples of the possible arrangement of dowel bars in transverse joints according to [2], chap. 5.3.7.1.

- the distance between the outer dowel bars must not be less than 250 mm.

Czech technical standard [2] already recommends the arrangement according to Figure 2.

3. Basic materials of dowel bars and requirements for their properties

During the construction of CCP, dowel bars have been manufactured from a variety of materials. Nowadays, mainly steel and various types of composite materials (FRP – Fiber Reinforced Polymer) are used for the production of dowel bars in the world. In the Czech Republic, the regulations [3] so far allow us to use only steel bars made of plain coated steel. The steel for the bars is not specified by steel grade, only the tensile strength, which must be equal to or greater than 250 MPa according to EN ISO 15630-1. The manufacturers [5], [6] state in the documents for this product that the dowel bars are made of S235JR steel. In addition to the material of the bars itself, the coating is very important and has two functions. The first function is to protect the steel bar from corrosion due to moisture and the action of chemical de-icing agents and the second function is to allow easy horizontal movement of the concrete slabs (slip in concrete). According to the regulations [3], the average thickness of the coating should not exceed 1.25 mm. However, this value is very high from our point of view. Due to the properties of the standard epoxy coatings used and the amount of deformation, such a high coating thickness can adversely affect the load transfer between the slabs. Furthermore, the Czech regulations [2] specify a minimum coating thickness of 0.3 mm of plastic, which must be factory applied. For CB II and CB III a different type of coating may be used [2].

As mentioned above, dowel bars for CCP can be made from materials other than steel. As an alternative, FRP is offered. FRP material consists of two parts, a reinforcing component and a binder (matrix). By combining these components, the resulting properties are achieved. The resulting properties depend on the relative proportions and types of the input components. The most commonly used fibres for the production of FRP reinforcement are glass fibre reinforcement (GFRP), carbon fibre reinforcement (CFRP), aramid fibre reinforcement (AFRP), basalt fibre reinforcement (BFRP) or a combination of these. The binder or matrix provides cohesion and binds the individual fibres together. The matrix transfers the external stresses to the fibres and at the same time has a protective function against environmental influences. Basic binders include epoxies, vinylesters and polyesters.

According to available evidence from manufacturers, the tensile strength of glass fibre composite reinforcement can be found in a wide range from 550 MPa to 1 300 MPa. Carbon fibre composite reinforcement can also reach tensile strengths of around 2 000 MPa. For example, the findings of research [7], which compared the LTE (load transfer efficiency) betweEN steel and FRP dowel bars, stated that FRP dowel bars would result in significantly lower LTE than steel specimens of the same cross section. To give an idea, Figure 3 compares the load transfer efficiency between different shapes, diameters and materials. This shows that in the case of using FRP for CCP in the Czech Republic, we would have to consider larger dowel bars estimated at around 30 mm.

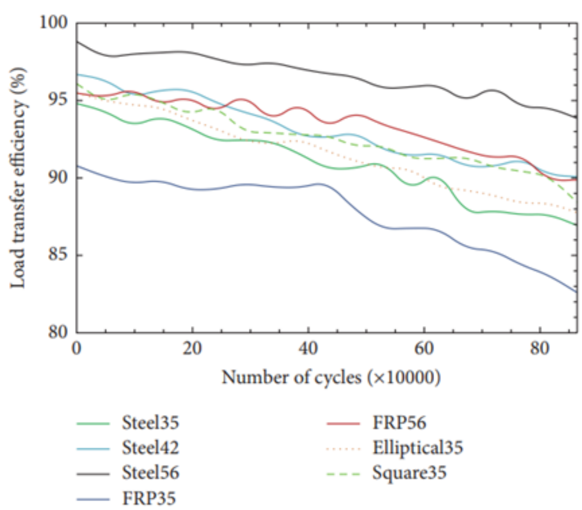

Figure 3. Load transfer efficiency during load cycles for different materials and diameters of dowel bars [7].

Due to the differences in the properties of the input materials and the associated resulting properties, it is not possible to use this type of material outside of, for example, experimental sections without a technical regulation setting out the minimum requirements. A comparison of the basic material properties of FRP and steel is given in Table 1. The individual properties of FRP materials may vary according to the choice of fibres (combination), matrix and manufacturing.

An important parameter for the correct and long-term function of the dowel bars is the shear strength. Dowel bars are shear stressed and we do not currently have long-term experience from which all the necessary parameters can be determined. Research carried out in the Czech Republic in earlier years has shown that if FRP is used it could lead to failures at CCP joints. The lower resistance of some types of FRP to repeated shear stresses has been demonstrated. Already after a few thousand cycles of laboratory testing, deformation of the dowel bars occurred [9]. Results and comparisons of tested materials (steel/FRP) including different dimensions (diameter) are also reported in foreign research, indicating that some properties of FRP material can be compensated by increasing the diameter of the dowel bars [10].

In the case of combinations of steel and composite materials, there are experiments with a steel core covered with composite material. However, there is a question as to what the price of the product will be compared to existing available products.

Given the need to find alternative sources to the standard ones that have been proven for many years, it is imperative that such a regulation be established as soon as possible [11].

4. Shapes of dowel bars

The most common shape of dowel bars is a cylinder see Figure 4 [6] and will probably remain so. Especially for CCP in the Czech Republic, where two-layer laying is carried out and bars are inserted by machine. In addition, the production of other rolled steel types, e.g. oval diameters, is significantly more expensive and less available or other shapes of dowel bars such as, e.g. diamond see Figure 5 [12].

In the case of inserting dowel bars into baskets (or other attachment methods), other shapes can be used that cannot be used in machine insertion to ensure the correct position of the dowel bars and its correct function. The dowel bars on shorter sections are fixed in the baskets before the concrete mix is placed in the desired position so that the optimum function of the bars is fulfilled.

The next most common shapes of dowel bars are bars with oval or square or tubular cross-sections. For large areas, diamond-shaped or disc-shaped bars are also used to reduce tensile stresses and allow movement parallel to the joint.

If we are thinking about saving materials, a tubular dowel bar filled with, e.g., a composite material is a suitable alternative. All the proposed shapes of dowel bars have been designed with the intention of reducing the tensile stresses at the joints and preventing cracking or damage at shrinkage or expansion joints, while increasing load transfer.

Figure 4. Standard dowel bars with a diameter of 25 mm and a length of 500 mm coated with polyolefin powder [6].

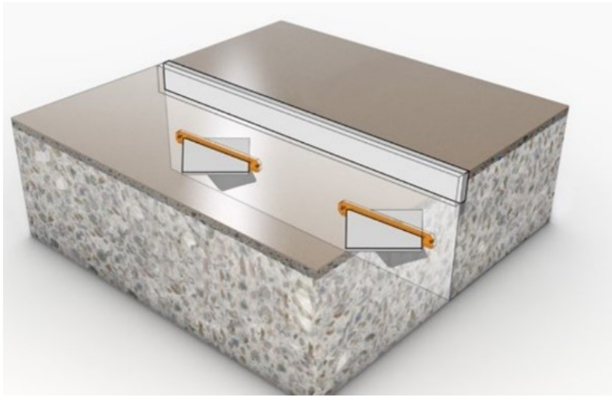

Figure 5. Diamond-shaped dowel bars [12].

5. Inserting dowel bars

The dowel bars are usually inserted halfway through the thickness of the slab (ideally parallel to the road surface) parallel to the direction of travel.

- Machine placement into fresh mixture – dowel bars are inserted by means of a vibrating device which is part of a concrete paver or one of a set of pavers (usually the first one, designed for the lower concrete). Machine placement is used for two-layer paving. The concrete is placed in two layers, with a layer of top concrete on top of the fresh bottom layer, see Figure 6.
- With the help of support baskets – dowel bars are prepared and fixed in the desired position, usually in steel baskets before machine laying or hand concreting.
- Additional insertion of reinforcement elements into hardened concrete. In the case of dowel bars, this

Feature	Material		
	Steel	GFRP	CFRP
Modulus in longitudinal direction [GPa]	200	35 to 60	90 to 580
Modulus in transverse direction [GPa]	200	about 8 to 9	about 10 to 12
Tensile strength in fibre direction [MPa]	300 to 600	450 to 1 600	600 to 3 500
Compressive strength in fibre direction [MPa]	300 to 600	approx. 1/2 of the tensile strength	approx. 1/2 of the tensile strength
Transverse tensile strength [MPa]	300 to 600	30 to 40	30 to 40
Volume weight [$\mathrm{kg\,m^{-3}}$]	7 850	about 2 100	about 1 700

Table 1. Comparison of the properties of steel and composite materials [8]

is done by drilling or cutting holes of the required size.

- By pre-installing the dowel bars (or bars to create holes) in the formwork, see Figure 7 [13].

Figure 6. Finisher set for two-layer cement concrete pavement, construction D1 (STRABAG).

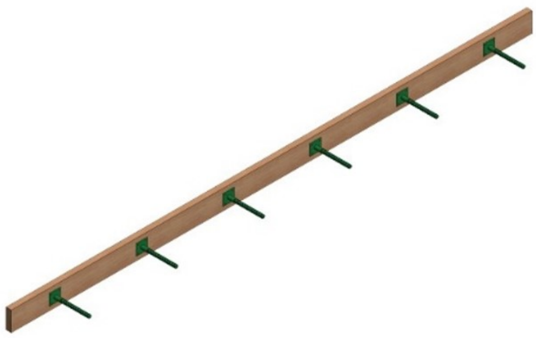

Figure 7. Mould with bars for subsequent insertion of dowel bars into the joint [13].

The choice of the technology for the CCP is crucial when deciding (from the point of view of implementation) what shape of the bars can be designed.

6. Position of dowel bars

The basic distribution of dowel bars deviations is illustrated in Figure 8 [11]. Faulty fit of the dowel bars reduces its efficiency and its ability to provide adequate load transfer. Vertical or horizontal tilt (especially vertical skew) can limit movements due to thermal expansion or contraction, which is the most serious problem in relation to CCP life see Figure 9. These constraints increase the tensile stresses of the plates and can be the cause of failures (most commonly manifested by the formation of cracks). These constraints can also induce an additional increase in local concrete stresses around the dowel bar, which then leads to failures at the transverse joints.

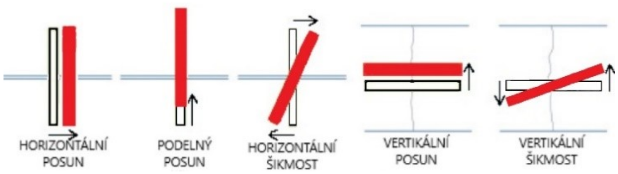

Figure 8. Basic distribution of deviations from the prescribed dowel bars fit [11].

Figure 9. Damage to the cement concrete pavement at the transverse joint of the D5 motorway.

It is obvious that the friction of the dowel bars in the concrete creates a resistive force that must be overcome both when closing and opening the joint (for this reason, the coating of dowel bars is also tested). It should be noted here that the frictional force is significantly increased by the angular deviation between the axis of the bars and the axis of the road (i.e. horizontal and vertical tilt). Already an average angular deviation of 5° can induce a stress of approximately 1 MPa in the cross-section of the plate [6]. Since a perfect fit of the dowel bars cannot generally be achieved, it can be assumed that considerable normal forces must be overcome regularly when opening and closing the joints.

On the other hand, the friction of the concrete slab against the base layer no longer plays a significant role at this point. A detailed representation of the temperature curve and the associated joint opening for one day is given in Figure 10. The temperature waveform of the concrete slab during the day shows the joint closure/opening.

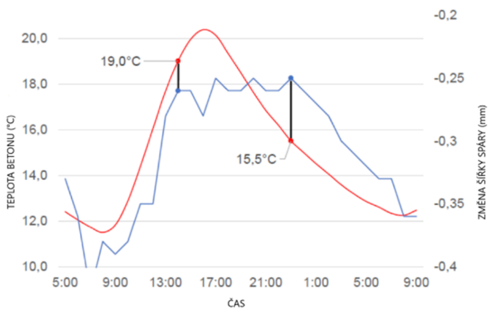

FIGURE 10. Daily curve of concrete temperature (red) and joint opening (blue) near zero stress [10].

In the Czech Republic, since 2014, changes in the accepted tolerances for individual categories of dowel bars misplacement are given in [2] in chapter 5.3.7.2:

- the inclined position of the dowel bar relative to the dowel bar length of 500 mm (difference of the dowel barends in the horizontal and vertical direction) may be up to 25 mm, but this value must be met for 75 % of the dowel bars in the joint and the remaining maximum 25 % of the dowel bars in the joint may have an inclination of up to 40 mm;
- the deviation of the fit relative to the top surface of the plate must be observed for at least 75 % of the dowel bars in the joint and for the remaining maximum 25 % of the dowel bars in the joint this deviation may be up to 50 mm;
- the deviation with respect to the transverse joint (longitudinal displacement) may be up to 75 mm, this value must be observed for a minimum of 75 % of the dowel bars and for the remaining maximum 25 % of the dowel bars in the joint it may be up to 120 mm.

I recommend checking the fit of the dowel bars using non-destructive equipment such as Ground Penetrating Radar (GPR) or MIT Scan. These devices already produce very accurate results in the hands of an experienced surveyor and results processor. To calibrate and verify the results, it is recommended that the results be verified on a bore with a dowel bar made on an untraveled portion of the roadway (e.g. paved shoulder). Ferrous minerals in the aggregate, moisture in the concrete or other steel elements in the CCP (e.g. surface reinforcement) may affect the measurement results. Detecting the position of slip-rods in fresh concrete by exposing the slip-rods is not recommended due to imperfect subsequent compaction and repair of the cement concrete pavement. Failures may subsequently occur at these locations. In addition, on uncured concrete, the propagation speed of the electromagnetic signal varies, leading to inaccuracies in the determination of the layer thickness and therefore the correct position of the dowel bar.

A general problem in evaluating the performance of the entire CCP is the evaluation of the performance of the individual parts separately (fresh hardened concrete, base layers, dowel bars, etc.). If "mistakes" are made in the design and then in the implementation, the individual deficiencies are cumulative. The result is a shortened service life of the CCP, even though we have complied with all the prescribed parameters. The same is true for the assessment of the faulty fit of the dowel bars. The evaluation considers individual dowel bars variations at the measured transverse joint, but does not consider the overall effect of the misfit on the roadway behavior, or whether it is a single joint or several transverse joints in a row, or whether the deficiency is in the staging or slow lane, etc. However, these deviations from the correct fit have different effects on the behaviour of individual, interlocking slabs.

When checking the dowel bars and their functionality, we must also consider the influence of the dowel bars on the formation of shrinkage cracks (autogenous shrinkage during hydration, etc.) and the subsequent correct functioning of the transverse joints.

To give you an idea, if we consider a concrete shrinkage of 0.1–0.25 $\mu\mathrm{m\,m^{-1}}$ (depending on the mix) [14] at an approximate stress of 1 MPa, it is likely that deformations due to tensile stresses will occur at the contact between the dowel bars and the concrete already in the first days after concreting, especially for dowel bars placed in an inclined position. This subsequently reduces the efficiency of load transfer between the slabs. It is therefore important not to underestimate the importance of the correct position of this reinforcement element during implementation.

7. Errors in the implementation of cement concrete pavement

The main cause of errors in the use of dowel bars is the human factor. Whether the error is conscious or unconscious, it is often behind the subsequent costly corrective measures. The following are individual errors by technology that occur on construction sites regardless of the contractor.

In the case of machine laying, the insertion of the dowel bars is secured mechanically. Either the machine automatically inserts the dowel bars into holder with the vibrator, or the bars are inserted manually by an authorized employee and then vibrated into the underlying concrete layer by the machine. The correct positioning of the dowel bars is mainly influenced by the characteristics of the machine (paver, whole assembly), the characteristics of the underlying fresh concrete mixture, etc.

Leaving aside machine error, which we have to take into account, the most common shortcomings are:

- Insufficiently trained employees (at least they are not aware of the consequences of their omissions);
- not adding dowel bars to the machine (dowel bars are not in the transverse joints);
- incorrectly set height of vibrating dowel bars;
- the fit of the dowel bar to the position of the transverse joint (horizontal displacement) is not checked.

Other deficiencies that affect the position of the bars, such as the consistency of the fresh concrete, the vibration effect of the paver, the speed of paving; nighttime concreting, or frequent stoppages, must also be technologically addressed by the contractor's responsible persons.

When installing dowel bars using baskets, it is always necessary to:

- choose the material and thickness of the wire of the basket so that it is not deformed during laying (covering with dense concrete mix and vibrating equipment);
- check the height of the basket, which must correspond to the desired position of the dowel bar, i.e. h/2 – the radius of the dowel bar (check the height of the treasury layer);
- fix the steel basket in such a way that it does not shift during concrete pouring;
- fix the dowel bars in the basket so that they do not fall out of the basket or shift relative to the position of the planned contraction joint when the concrete mix is included.

When preparing for concrete pouring, we must be aware that heavy equipment is used during the execution (various excavators to stretch the concrete mixture), or the concrete mix is dumped from a truck or pumped from a mixer truck. All these procedures are carried out at a certain frequency, where everything has a temporal coincidence. Therefore, if any damage occurs, for example due to an imperfectly prepared bin, there may be a delay if the paving workers notice the problem [11, 15].

8. Conslusion

Cement concrete covers have the advantage of resisting higher loads and therefore have a longer service life compared to asphalt pavements. However, this advantage becomes a disadvantage when you are trying to find information on the implementation of the road after twenty or more years of operation. The documentation is often incomplete and the implementers do not remember the details, are retired, etc. Yet one of the most important bases for diagnosis is information that is usually never passed on by the contractor to the client, that there was a problem with the concrete plant, aggregate, cement, air temperature and we could go on. So we can divide the failures caused by the placement of slipforms into two groups:

Figure 11. Non-functioning grout on cement concrete roadway.

- failures that occur within a relatively short period of time after commissioning 0–5 years – these failures are caused by e.g. insufficient concrete cover or the sliding spikes are in an inclined vertical position and one of the ends is close to the road surface;
- faults that occur after more than 10 years of operation – for these faults, it is often important to have sufficient documentation to enable diagnostics to be properly evaluated and the cause of the faults to be identified [11, 15].

In the field of CCP, reinforcement elements are one area that deserves more attention, in particular [11, 15]:

- allow the use of FRP composite reinforcement elements or other possible variants by developing a regulation (standard) to allow this;
- to consider other possible shape options of dowel bars, e.g. oval or tubular shapes, within the developed regulation;
- for major and highly loaded roads, recommend designing larger diameter dowel bars, thereby reducing the magnitude of tensile stresses between the mandrel and the concrete (e.g. for airport carriageways or highly loaded storage areas).

A well-maintained and functional joints or rubber seal also contributes to the proper function of the transverse joint. If the condition of the pavement is not regularly checked and corrected immediately if necessary, the cost of repairing cement concrete pavements will be high regardless of the quality of the work carried out, see Figure 11.

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