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# Structural maintenance of concrete roads: replacement of concrete slabs on the A1 West Motorway – a Case Study

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ABSTRACT

Common problems on motorways with concrete pavements include edge chipping along the edges of the concrete slabs, damaged pavement transitions (joint damage), reduced skid resistance, cracking and concrete slab migration or subsidence. To effectively repair these damages, concrete pavement rehabilitation works are carried out during periods of low usage, such as weekends and/or during night hours. During these periods, the concrete pavement will be rehabilitated in sections on individual lanes while traffic is routed on the remaining lanes.

## 1. Introduction

On behalf of the Austrian ASFINAG (germ. "*Autobahnen- und Schnellstrassen Finanzierungs-Aktiengesellschaft*") - motorway and expressway financing joint-stock company, the rehabilitation of various damages to joints, edges and concrete fields on both directional carriageways of the A1 west motorway was carried out. The specific case study dealt with in this work relates to the area of the St. George motorway junction. In order to disrupt traffic as little as possible, rapid concrete was used throughout the work, which was always carried out at weekends and during the night. The author spent an entire night on this construction site, and it paid off handsomely.

## 2. The Damages to concrete pavements

### 2.1. General

Cracks, unevenness, migration or subsidence of slabs, surface damage, reduced skid resistance across the slab cross-section, edge damage, corner break-offs and defective joint filling are all possible damage that can occur to concrete pavements. Particularly important and problematic are the continuous longitudinal and transverse cracks, as these can lead to the concrete slabs being destroyed over time and under high traffic loads.

Adequate maintenance and timely repair are therefore crucial to ensure the safety and longevity of concrete pavements and to avoid costly and extensive repairs or replacements. Appropriate measures can extend the service life of concrete pavements and improve road safety. This includes regular inspections, targeted repair measures and the use of suitable materials such as early strength road concrete or rapid concrete when needed.

### 2.2. Types of Damage to concrete pavements

Continuous cracks in concrete pavements can occur when the breaking strain of the concrete is exceeded. This can occur in the following cases, among others (Ehrlich & Hersel, 2010):

#### 2.2.1 Concrete slabs with too large joint spacing

If the distances between the joints in the concrete slabs are chosen too large, the concrete cannot sufficiently compensate for the volume changes that occur with temperature fluctuations. The resulting stresses in the concrete can exceed the breaking strain limit and lead to continuous cracks. In concrete road construction, a joint spacing of 4 to 6 m is usually used.

At these distances, the occurring flexural tensile stresses in the concrete due to temperature gradients and traffic loads are usually safe and provide sufficient safety against the breaking of the concrete slabs. This is especially true considering the slab thicknesses and concrete strengths used today. A larger joint spacing would result in the concrete slabs having longer uninterrupted sections, which could lead to greater stresses during temperature fluctuations. This increases the risk of cracks and damage to the concrete slabs.

### 2.2.2 Under-dimensioning of the concrete slabs

If the concrete slabs are not sufficiently dimensioned to withstand the traffic loads that occur, high stresses can develop in the concrete, leading to cracks.

### 2.2.3 Changing the support conditions of the concrete slabs

Changes in the support conditions of the concrete slabs, such as settlement in the subgrade or uneven load distribution, can lead to additional stresses in the concrete and cause cracking. If surface water cannot be effectively drained from the concrete pavement due to defective joints or other defects, it can penetrate into the underlying base. This penetrating water can then degrade and loosen the base under traffic loads. This problem can be particularly severe in the joint area. With each wheel transition (load/unload), a pumping process occurs, during which the water is sucked into the loose underlay and dissolved fine particles can be carried away. This causes the concrete slabs in the area of the joints to "*pump*" [Fig.1], i.e. move up and down, as traffic passes over them. This pumping process can cause the slabs to become hollow at the points of water penetration. Over time and due to repeated loads, this can lead to overloading and the concrete slabs can crack at the penetration points. This damage can further propagate and compromise the integrity of the pavement, leading to an increased risk of accidents and a shortened life of the concrete pavement.

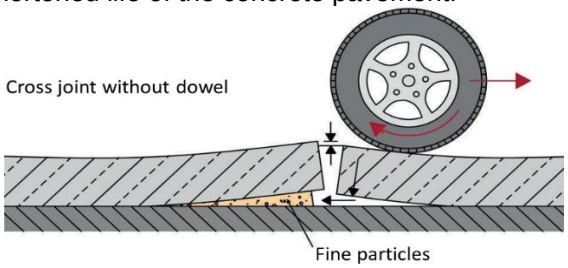


**Figure 1.** Pumping of the concrete slabs
*Source: Hoffmann M. et al. 2012*

## 2.3 Changing the support conditions of the concrete slabs

In order to minimise the development of continuous cracks in concrete pavements, careful design and construction of the pavement is of great importance. This includes consideration of appropriate joint spacing, correct dimensioning of the concrete slabs and adequate consideration of the bearing conditions. In addition, regular inspections and early repair measures are important to detect and repair damage at an early stage. This can increase the service life and safety of the concrete pavements.

(Ehrlich & Hersel, 2010) found that in addition to the causes already mentioned, other factors can lead to cracks in concrete slabs. These causes include:

- *Cracks in the sub-base/base layer*: If the base or sub-base on which the concrete slabs rest has cracks or deformations, these can transfer to the concrete slabs and lead to cracks.
- *Cutting too late or cutting depth of the dummy joints too shallow*: Cutting dummy joints, also called predetermined crack joints, is important to allow planned cracks to form in a controlled manner. If cutting is done too late or the depth of cut is insufficient, uncontrolled cracks can form in the concrete slabs.
- *Insufficient concrete strength*: Insufficient strength of the concrete can lead to the concrete slabs not being able to withstand the loads that occur and to cracks forming.
- *Unsuitable concrete composition*: The composition of the concrete, including the use of aggregates and admixtures, can affect the properties of the concrete. An unsuitable concrete composition can lead to cracks.
- *Defective ceiling manufacture (e.g. installation, built-in appliance)*: Errors during the production of the concrete slab, such as improper installation or the use of unsuitable installation equipment, can lead to quality problems and cracks.
- *Overloading of the concrete slab due to insufficient support of the concrete slab (heavy transports)*: If the concrete slabs are overloaded due to insufficient support, for example by heavy transport, cracks can occur.
- *Unsuitable panel shape (unfavourable length-to-width ratio, gusset)*: An unfavourable panel shape, such as an unfavourable length-to-width ratio or the presence of gussets (triangular panel areas), can lead to stresses that can cause cracking.

## 2.4. Migration of concrete slabs

Migration of concrete slabs may have occurred if the longitudinal joints were not anchored adequately or if the anchors used were uncoated and consequently rusted through. Anchoring of the longitudinal joints is critical to hold the concrete slabs securely in place and prevent migration. If the longitudinal joints are not properly anchored, the slabs can shift or migrate due to traffic loading and other forces, which can cause damage to the joints and the pavement.

Furthermore, the anchors used play an important role in securing the concrete slabs. If the anchors are uncoated and exposed to corrosion, this can lead to a reduction in their strength and durability. As a result, the anchors can no longer fulfil their function as fastening elements for the concrete slabs, which can also promote the migration of the slabs.

### 2.5. Stepping and settlement of the concrete slabs

*Stepping* and *settlement* of the concrete slabs can also be due to various causes other than overloading, including (Ehrlich & Hersel, 2010):

- *Deformation, erosion or destruction of the base*: If the base on which the concrete slabs rest shows deformation, erosion or destruction, these can be transferred to the concrete slabs and lead to step formations and settlements. Lack of or ineffective dowelling or anchoring: Inadequate dowelling or anchoring of the concrete slabs can result in the slabs not being able to be adequately fixed to the substrate. This can lead to movements and uneven settlements.
- "*Pumping*": The "*pumping*" of the slabs, mentioned earlier, is an essential factor. Since the amount of material discharged at the joint flanks varies in the direction of travel, this leads to different settlements between the beginning and the end of the slabs. This creates steps and unevenness on the road surface.

### 2.6. Spalling and removal of the mortar layer of the concrete slabs

Surface damage to concrete pavements can occur when parts of the pavement surface become detached due to spalling or when the top layer of mortar is removed by traffic or weather, exposing the coarse aggregate. As typical surface damage, (Ehrlich & Hersel, 2010) state the following phenomena:

- *Spalling*: Due to various impacts such as erosion, chemical attack, freeze-thaw cycles, traffic loads or other mechanical stresses, parts of the concrete surface may spall or detach.
- *Removal of the mortar layer*: The upper mortar layer of the concrete can be removed by traffic, especially heavy goods traffic, or by weather influences such as frost, snow or salts. This exposes the underlying coarse grain. This surface damage can not only impair the aesthetic appearance of the roadway, but also negatively affect the function and safety of the road. Exposed coarse aggregate, for example, increases the risk of slipping for vehicles, especially in wet conditions.

### 2.7. Causes for surface damage of the concrete slabs

Ehrlich and Hersel (2010) gave the following causes for surface damage:

- *Insufficient concrete strength*: can be caused by various factors, such as too high a water content in the concrete when it is placed or a lack of curing. If the concrete does not have the required strength, the surface may be more susceptible to damage.
- *Unsuitable concrete composition*: Incorrect mixing of the concrete can lead to problems. Too high a sand content, too low or no air content in the fresh concrete or the alkali-silica reaction can affect the properties of the concrete and lead to surface damage.
- *Impurities in the aggregates or the concrete*: Impurities such as wood particles or aluminium abrasion can affect the quality of the concrete and cause damage to the surface.
- *Segregation during concrete placement*: If the concrete is not properly compacted during placement or segregation occurs, this can lead to unevenness and damage to the surface.
- *Insufficient curing*: Adequate curing of the concrete is important to ensure optimum strength and durability. If the curing is insufficient, this can lead to surface damage.
- *Mechanical impacts or fire exposure*: External impacts such as mechanical stress or fire exposure can also cause damage to the surface.

Edge damages on concrete pavements are break-offs at the joints, cracks and the outer edges of the concrete slabs. They are mainly caused by insufficient concrete strength in the edge area and possibly adversely changed bearing conditions. Insufficient concrete strength in the edge area can have various causes, such as insufficient compaction of the concrete at the edges during placement, incorrect concrete composition or insufficient curing.

If the concrete in the edge area does not have the required strength, it is more susceptible to fractures and break-offs. In addition, the support conditions in the edge area may change, e.g. due to subsidence in the substrate or uneven load distribution. Such changes can lead to additional stresses in the concrete and increase the likelihood of edge damage.

### 2.8. The rules and regulations for the new construction of traffic areas made of concrete

#### 2.8.1 General

For the structural maintenance of traffic areas made of concrete, the following guidelines apply in addition to the rules and regulations for the new construction of traffic areas made of concrete ((ZTV Beton-StB 07, 2007), (TL Beton-StB 07, 2007), (TP B-StB, 2023)) (Heidelberg Materials, 2023):

- (ZTV BEB-StB, 2015): Supplementary technical conditions of contract and guidelines for the structural maintenance of traffic surfaces - Concrete construction methods & amendments 2018-11. This guideline contains supplementary technical

conditions of contract and regulations for the maintenance of traffic surfaces made of concrete. It refers to specific construction methods and procedures to be considered in the maintenance of concrete surfaces.
- (TL BEB-StB, 2015): Technical delivery conditions for building materials and mixtures for the structural maintenance of traffic surfaces - concrete construction methods & amendments 2018-11. These technical delivery conditions specify the requirements for the procurement and delivery of building materials and mixtures used in the structural maintenance of traffic surfaces made of concrete. They contain specifications for the material quality and composition to ensure the necessary durability and functionality of the concrete surfaces.

These additional guidelines are specifically designed to ensure the long-term maintenance and functionality of concrete traffic surfaces and are an important supplement to the general codes for new construction.
The (ZTV BEB-StB, 2015) describe measures for the structural maintenance of existing concrete traffic surfaces, i.e. maintenance, repair and rehabilitation of concrete traffic surfaces depending on the condition and maintenance objective.

1. *Repair*: Small-scale structural maintenance measures for localised damage that can be carried out manually or mechanically with little effort, e.g. repairing for numbered lists.
2. *Maintenance*: Structural measures to maintain the substance or improve the surface properties of traffic areas, such as replacement of joint fillings, slabs and slab parts, replacement of concrete pavements in strips, surface treatment and coating with reactive resin or reactive resin mortar.
3. *Rehabilitation*: Structural measures for the complete restoration of the surface properties and substance of traffic areas or parts thereof, such as the application of a new road surface or the replacement of individual layers.

(Heidelberg Materials, 2023) distinguish for the repair (replacement) of slabs or slab parts on concrete paved traffic areas, depending on the specific requirements, the early strength road concrete and rapid hardening concrete:

- *Early strength road concrete*: Early strength road concrete hardens quickly in the initial phase and reaches the required strength for traffic release faster than conventional road concrete, but slower than rapid concrete. The requirements for the use of early strength road concrete are defined by the TL BEB-StB in addition to the TL Beton-StB. Early strength road concrete is mainly used for the replacement of slabs and slab parts as well as for the rehabilitation of lane strips. The execution is carried out according to the specifications of the ZTV Beton-StB.
- *Rapid concrete*: Rapid concrete is characterised by a very rapid strength development in the initial phase, which means that a traffic release can be possible after only 3 to 5 hours under favourable conditions.

The choice between early strength road concrete and rapid concrete depends on the urgency of the repair and the time requirements for traffic clearance. It is important to observe the respective regulations and recommendations of the ZTV Beton-StB and the TL BEB-StB in order to ensure that the repair work is carried out professionally.

### 2.8.2 Replacement of concrete slabs according to M BEB (Fact sheet for the structural maintenance of concrete traffic areas)

The replacement measures for damaged slabs or slab parts are specified in the contractual regulations of (ZTV BEB-StB, 2015). According to the (M BEB, 2009), whole slabs can be replaced if crack patterns 1 and 2 (Fig.2) or crack clusters, larger steps or sagging of slabs and slab parts are present. For crack patterns 3 to 6, it is probably sufficient to replace only slab parts. For crack patterns 7 to 10, no replacement of slabs or slab parts is necessary, provided there are no steps or sagging. In such cases, subsequent dowelling or anchoring can usually suffice.

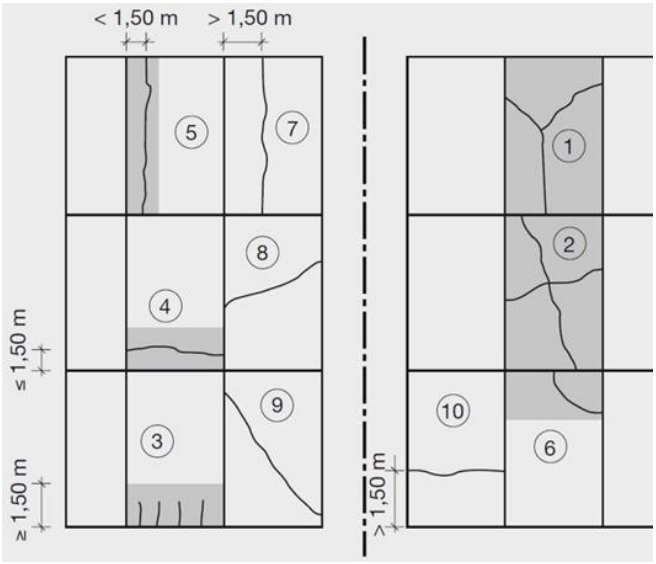


**Figure 2.** Crack pattern scheme
*Source: M BEB, 2009*

## 3. Replacement of concrete slabs on the A1 west motorway in the area of the St. Georg motorway junction

Concrete - small area renovations (approx. 40 – 80 m$^2$ per day of work): The work was usually weather-dependent and therefore there were also postponements. Afterwards, the joints were cut and grouted. Most of the work was done during the night - usually from 08:00 pm - 04:00 am with traffic clearance

and 04:00 am in the morning. In the following illustrations, this small-scale renovation was depicted, for which the author spent the whole night on this motorway construction site.

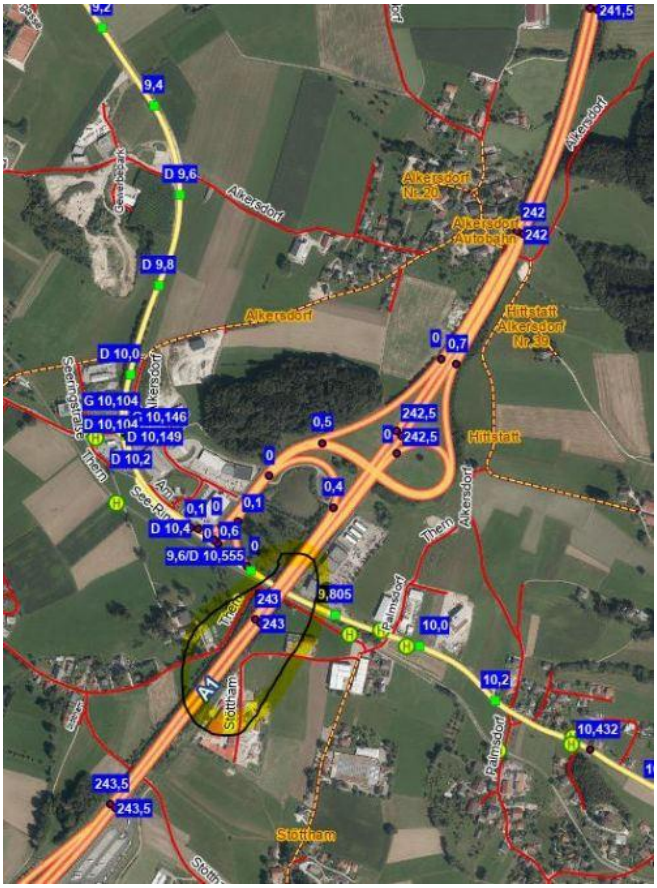


**Figure 3.** Weekly schedule of the rehabilitation work in the area of the St. Georg motorway junction
*Source: Reisinger 2021*

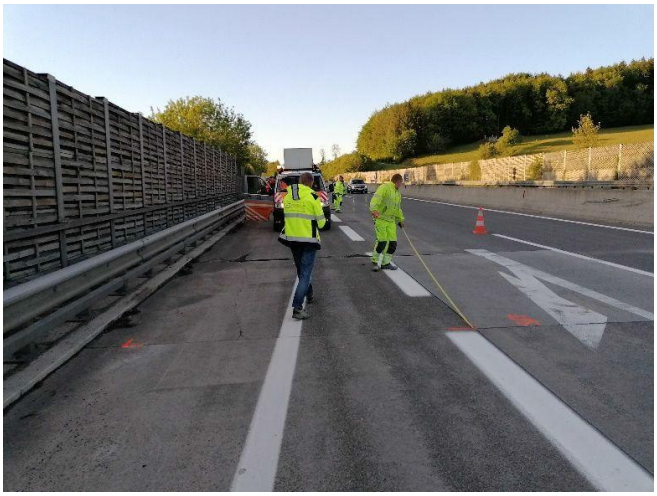

**Figure 4.** Measuring the area to be renovated
*Source: Author 2021*

**Figure 5.** Damaged areas: Cracks
*Source: Author 2021*

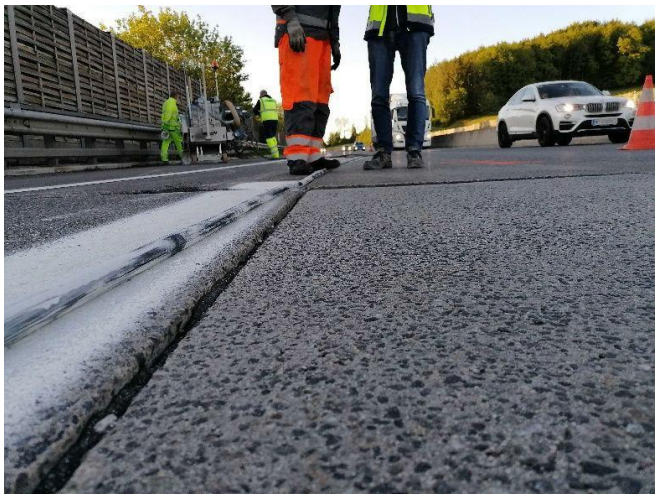

**Figure 6.** Stepping and settlement of the concrete slab as well as reduced skid resistance of the concrete slab surface
*Source: Author 2021*

**Figure 7.** Step formation and settlement of the concrete slab as well as corner and edge breaks filled with cold asphalt
*Source: Author 2021*

**Figure 8.** Cracks and damaged surface filled with cold asphalt
*Source: Author 2021*

**Figure 9.** Cutting the area to be renovated
*Source: Author 2021*

**Figure 10.** Milling the area to be renovated
*Source: Author 2021*

**Figure 11.** Milling area
*Source: Author 2021*

**Figure 12.** Breaking the remains after milling by means of a pile hammer
*Source: Author 2021*

**Figure 13.** Removal of the remains by means of an excavator bucket
*Source: Author 2021*

**Figure 14.** Marking for drilling for the adhesive anchors
*Source: Author 2021*

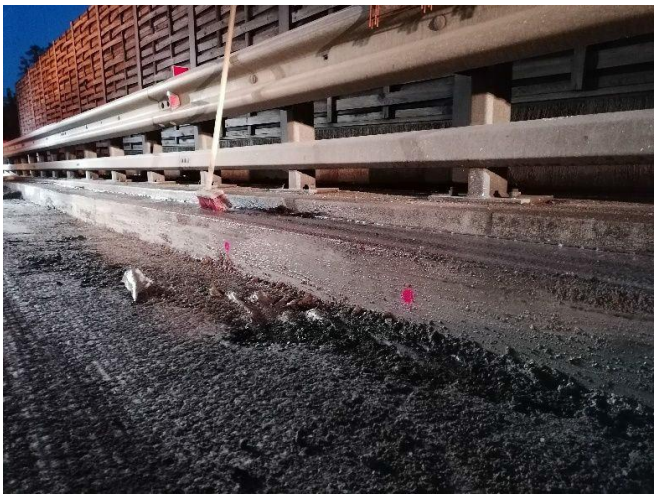

**Figure 15.** Marking for drilling for the adhesive anchors
*Source: Author 2021*

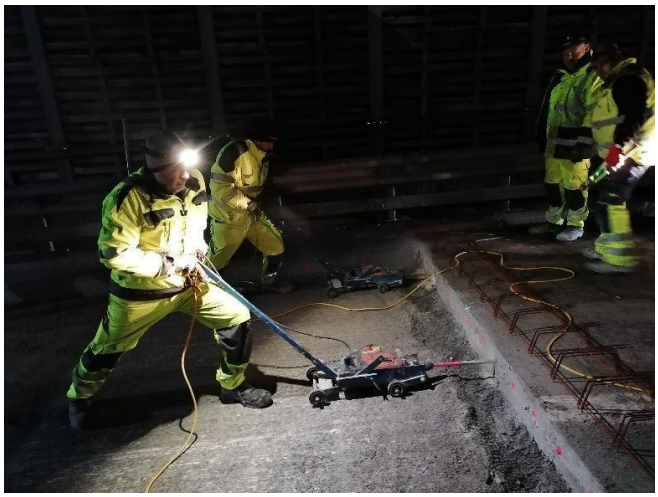

**Figure 16.** Drilling the holes for the adhesive anchors
*Source: Author 2021*

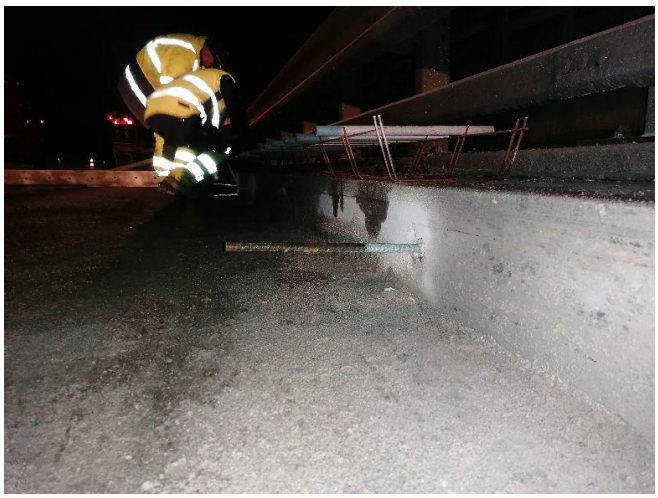

**Figure 17.** Drilled-in adhesive anchor
*Source: Author 2021*

**Figure 18.** Dowels laid on baskets in the area of the dummy joints
*Source: Author 2021*

**Figure 19.** Dowels laid on baskets in the area of the dummy joints
*Source: Author 2021*


**Figure 20.** Accelerating agent for rapid concrete
*Source: Author 2021*

**Figure 21.** Concrete test: Spreading dimension F (F = Flow Table Test)
*Source: Author 2021*

**Figure 22.** Concrete testing: Production of a cube- shaped test specimen for subsequent laboratory testing of the cube compressive strength fc of the concrete
*Source: Author 2021*

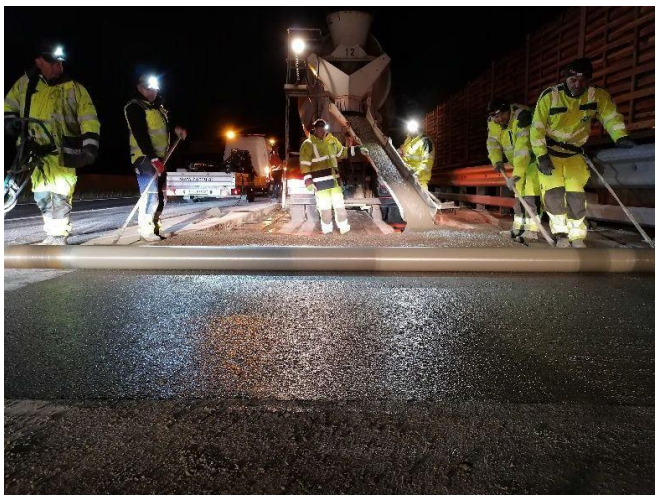

**Figure 23.** Installation and compacting vibration of the rapid concrete
*Source: Author 2021*

**Figure 24.** Finished concrete slab after traffic clearance the next morning after a long night
*Source: Author 2021*

## 4. Conclusion

Some sections of the A1 west motorway are heavily affected by high traffic volumes, which leads to intensive annual stress on the concrete slabs. As a result, cracks, subsidence and edge break-offs occur. To ensure safety on the motorway and prevent further damage, the damaged areas that occurred were repaired. The focus was on keeping the closure times as short as possible to minimize traffic obstructions. Therefore, it was crucial that the concrete used had an extremely fast strength development. The repair work was carried out at night between 08:00 pm and 04:00 pm. Thanks to the efficient cooperation of all parties involved, the concrete carriageway slabs to be rehabilitated were successfully renewed overnight within short closure times. I would like to congratulate the supervisor, engineer Reisinger Thomas, for the great organization of these construction sites and at the same time thank him very much for making it possible for me to visit this challenging construction site and to take valuable photos and videos.

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