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Sustainability in road construction – Two case studies

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Research Paper

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Sustainability in road construction – Two case studies

Sustainability in the field of traffic route construction should be considered against the background of intelligent resource conservation. A holistic assessment of sustainability, including life cycle considerations and assessments, is essential. In the first case study, the pavement structure at the heavily loaded Daimler intersection was constructed using concrete in the direct intersection area and using both concrete and asphalt in the connecting areas of all four axes. A 31 cm thick unbound frost protection layer with a grain size of 0/45 mm was placed over the existing road surface. This was followed by an 8 cm thick asphalt base course (AC 32), applied using an asphalt paver. Finally, a 26 cm thick concrete layer was placed over the asphalt base course. In the second case study, a horizontal hybrid construction method is presented using the German motorway BAB A61 in the Koblenz area as an example. Horizontal hybrid construction combines the advantages of asphalt and concrete to create a durable and resistant pavement surface capable of withstanding high traffic loads. This innovative construction method enables the optimum use of different materials and ensures efficient rehabilitation and improvement of motorway infrastructure.

Key words:
road construction, pavement, sustainability, asphalt, concrete, deformation resistance, horizontal hybrid construction, service life, polypropylene fibres

Prethodno priopćenje

Kerim Hrapović

Održivost u gradnji cesta – Dvije studije slučaja

Razmatranje održivosti u području izgradnje prometnica treba se odvijati u kontekstu inteligentne zaštite resursa. Holistička procjena održivosti, uključujući razmatranje i procjenu životnog ciklusa, ovdje je od ključne važnosti. U prvom slučaju, kolnička konstrukcija na značajno opterećenom prometnom raskrižju Daimler izvedena je od betona u neposrednom području raskrižja te od betona i asfalta u području sva četiri privoza. Preko postojećeg završnog sloja ceste izveden je nevezani sloj za zaštitu od smrzavanja s granulacijom zrna 0/45 mm, u debljini od 31 cm. Slijedilo je postavljanje asfaltnog nosivog sloja (AC 32) u debljini od 8 cm, koji je ugrađen pomoću asfaltnog finišera. Na kraju se preko asfaltnog nosivog sloja izveo sloj betona debljine 26 cm. U drugom slučaju, prikazana je horizontalna hibridna metoda gradnje na primjeru njemačke autoceste BAB A61 u području Koblenz-a. Horizontalna hibridna metoda gradnje kombinira prednosti asfalta i betona kako bi se stvorila trajna i otporna površina kolnika koja može podnijeti velika prometna opterećenja. Ova inovativna metoda izgradnje omogućuje optimalno korištenje različitih materijala i osigurava učinkovitu rekonstrukciju i poboljšanje infrastrukture autocesta.

Ključne riječi:
izgradnja cesta, kolnik , održivost, asfalt, beton, otpornost na deformacije, horizontalna hibridna izgradnja, vijek trajanja, polipropilenska vlakna

1. Introduction

Sustainability in road construction: Not a contradiction. The importance of sustainability in road construction has steadily increased. It is no longer just about creating roads for traffic; instead, we must prioritize sealed surfaces made of concrete, asphalt, and incorporate new drainage concepts. Particularly, asphalt can reach extreme temperatures of over 60 to 70 °C on hot days, posing health risks to vulnerable populations and contributing to global warming.
According to the Federal Environment Agency of Austria, in 2021, an additional 10 ha of land were consumed daily. Over three years, the average daily consumption was 11.3 ha, equivalent to approximately 12 large football fields. This land was primarily required for construction activities, transport infrastructure, and commercial areas [1].
The German Federal Environmental Agency reports that settlement and transport areas increased by an average of 129 ha per day between 1997 and 2000. This significant increase corresponded to approximately 180 football pitches. However, from 2018 to 2021, the average daily expansion decreased to 55 ha, albeit with a recent slight increase in the trend curve [2].
Sustainable road construction involves choosing the appropriate building material for each location to ensure the longest possible service life. For example, concrete can be a practical choice in heavily loaded areas with high traffic volumes. The use of concrete in these locations offers advantages in terms of the longevity and durability of traffic routes, owing to its high resistance to deformation. By leveraging the strengths of various building materials, infrastructure sustainability can be enhanced, leading to reduced costs for repairs and renewals.

Figure 1. Ruts and deformations in the asphalt by overloading from braking, stopping, and starting at intersections and bus stops [author, 2020]

The situation where ruts and deformations occur in asphalt owing to the overload caused by braking, stopping, and starting at intersections is familiar to many people. This scenario is often observed on busy roads and results from the continuous stress that the road surface experiences from traffic, particularly in areas where vehicles frequently brake or accelerate. This phenomenon illustrates the effect of constant stress on the road surface over time. To minimize such damage and ensure the safety and durability of traffic routes, regular road maintenance is essential (Figure1).
In everyday life and in the field of traffic route construction, each building material presents its own set of advantages and disadvantages. Asphalt is known for its elasticity, while concrete is rigid. Concrete, being a rigid material, exhibits high resistance to deformation, especially under heavy vehicle loads. Consequently, concrete road surfaces generally do not develop deep ruts that accumulate water.
However, each construction material offers specific advantages. The selection between asphalt and concrete for road construction depends on factors such as traffic load, environmental conditions, weather, and desired roadway properties. Therefore, meticulous planning and material selection are crucial to determine the most suitable solution for the specific requirements of roads or highways (Figure2).

Figure 2. A concrete road surface showing no ruts with significant water accumulation [author, 2016]

The structure at the Daimler intersections exemplifies the combination of asphalt and concrete to create a durable and resilient road surface capable of withstanding high traffic loads. Concrete, serving as the final layer, provides stability and durability against heavy traffic. By combining asphalt and concrete, a road surface resistant to high traffic loads and temperature fluctuations is achieved. This significantly extends the lifespan of motorways and reduces long-term maintenance costs.

2. Junction in concrete construction

2.1. General

The Daimler intersection in Boeblingen serves as a busy traffic junction connecting the four-lane district road K 1073 between Boeblingen and Dagersheim (Boeblinger Strasse) to Gottlieb-Daimler-Straße in the north and Dornierstrasse in the south. Recent analysis of traffic loads for the superstructure measurement revealed particularly high volumes for Gottlieb-Daimler-Strasse North. Approximately 28,000 motor vehicles and 3,640 trucks weighing more than 3.5 tonnes (heavy goods vehicles) were identified per day. These figures illustrate the immense traffic load that roads must handle daily. In view of such loads, meticulous planning and dimensioning of road surfaces are crucial to ensure the long-term and usability of traffic routes.

Due to the high load of heavy goods traffic, the former Daimler intersection experienced severe rutting caused by the asphalt construction. In planning for a significantly large intersection, and considering the projected increase in traffic volume to up to 37,700 motor vehicles per day and 4,310 heavy goods vehicles per day, To address this, the intersection was reconstructed by adding a concrete layer to the asphalt base course. This reconstruction resulted in a resilient road surface capable of better withstanding future traffic loads. In addition, maintaining traffic flow during construction is crucial to avoid disrupting road user mobility. Such a decision requires thorough planning and coordination to ensure smooth construction operations while considering the safety of all road users [3] (Figure3).

Figure 3. Concrete construction junction: Daimler Junction, Boeblingen District [3]

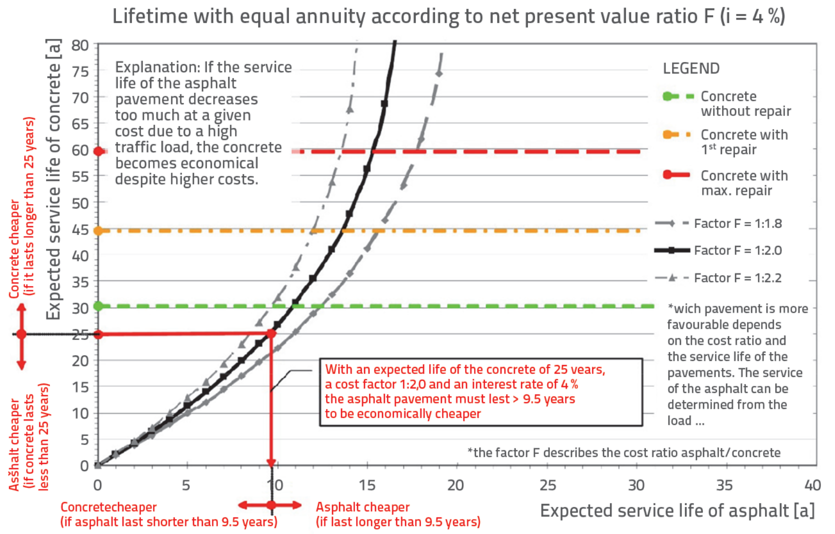

Figure 4. Economic pavement use in roundabouts considering load, service life, and cost ratio [4] (edited by author)

Figure 4 shows a diagram of the economic efficiency of road pavement, illustrating the economic pavement use in roundabout CIPs according to load, service life, and cost ratio [4].

Based on the given data and cost factor F, which is the ratio of the cost of asphalt to that of concrete, a simple method can be used to determine the economically optimal pavement. Annuity formulas were applied to determine the lifespan of asphalt and concrete for a given cost ratio, ensuring the same annual cost was incurred. For example, if concrete has an expected lifespan of 25 years, with a cost factor F of 1:2.0, and an interest rate is 4%, the asphalt pavement must last longer than 9.5 years to be economically cheaper than concrete. This means that if the asphalt pavement lasts less than 9.5 years, concrete pavement is the more economical choice. However, if the asphalt pavement lasts longer than 9.5 years, it becomes economically more advantageous than concrete pavement, given the specified cost factors and interest rates. This method provides a quick estimate of the economic viability of a pavement and can be helpful in making decisions regarding the optimal pavement type in certain situations [4].

2.2. Pavement structure of the Daimler intersection

Figure 5 shows the pavement structure at the Daimler intersection. A 31 cm thick unbound frost protection layer with a grain size of 0/45 mm was placed over the existing road surface. This was followed by an 8 cm thick asphalt base course (AC 32), applied using an asphalt paver. Finally, a 26 cm thick concrete layer was placed over the asphalt base course. The concrete specifications were C 30/37 XM2, XF4, and WS, with a maximum grain size of 16 mm. It is an lightweight prestressed concrete with fibres, which are placed in a concrete paver [3].

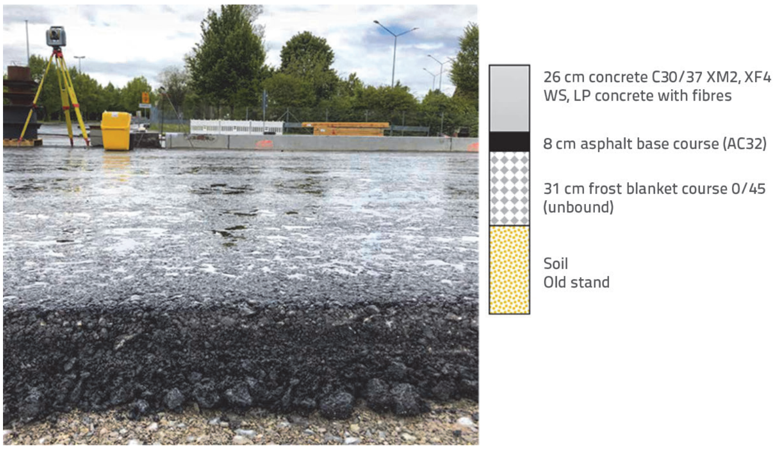

Figure 5. Concrete construction junction: asphalt base course, total superstructure cross section, Daimler junction [3] (edited by author)

Dowels and anchors play an important role in connecting and stabilising concrete slabs in the slab system of the Daimler crossing:

- *Dowels*: These were placed in holders (baskets) at the centre of each concrete slab, with a spacing of 25 cm, before concreting. Their main function is to prevent vertical displacement (slab misalignment) within the slab system, which may occur due to transverse forces and moments. These displacements often happen when vehicles traverse over the joints or edges of concrete slabs.

This structure combines the advantages of both asphalt and concrete to create a durable and resilient road surface capable of withstanding high traffic loads at Daimler intersections. The unbound frost protection layer prevents frost from penetrating the road surface, whereas the asphalt base layer ensures even load distribution. Concrete, as the final layer, provides stability and durability against traffic loads, especially heavy traffic. Thus, this layered structure ensures the required strength and resilience of the road to accommodate future traffic loads at the Daimler intersection.

Paving the 8 cm thick asphalt base course using a wire-guided asphalt paver proceeded smoothly. This provided an ideal basis for the subsequent concrete pavement owing to the relatively high EV2 modulus (modulus of elasticity), good evenness, and precise height leveling. Consequently, the asphalt base layer performs several important functions:

- Perfect base for concrete pavement: The asphalt base layer serves as an excellent foundation for the subsequent concrete pavement, owing to its properties.
- Accommodating construction site and delivery traffic: During the construction phase, the asphalt base course effectively accommodated traffic and allowed access for construction vehicles and deliveries.
- Fixing the edge formwork: The stable substrate provided by the asphalt base layer facilitates the installation of edge formwork required for the concrete slab.

The combination of a high-quality asphalt base course and precise workmanship has created a solid foundation, streamlining the construction of the concrete pavement. This approach ensures that the Daimler intersection receives a robust and durable road surface capable of withstanding traffic [3] (Figure6).

- *Anchors*: These provided reliable anchorage, preventing uncontrolled drifting of the slabs.The anchors were evenly spaced along the travel direction, with three anchors per slab. Their main function is to hold the concrete slabs together and prevent lateral drift. These anchors ensured the overall stability of the slab system and maintained the positions of the concrete slabs.
- *Reinforcement for unfavourable slabs*: Concrete slabs with an unfavourable length-to-width ratio or unavoidable acute angles required the use of a single layer of reinforcing steel mesh on top. This reinforcement increases the strength and stability of these special concrete slabs, minimizing the risk of cracking or deformation.

Figure 6. Concrete construction junction: asphalt base-course, Daimler junction [3]

The combination of dowels, anchors, and additional reinforcement, when necessary, plays a decisive role in effectively connecting and stabilizing concrete slabs at the Daimler intersection. This layered structure and meticulous incorporation of these elements ensure a durable and resistant road surface that meets the high demands of traffic and loads at this busy intersection [3] (Figure7).

Figure 7. Preparation of concrete layer with reinforced, geometrically critical field; pre-laying of dowels in baskets below the later transverse join [3]

The dowels (Figure8) are made of smooth round steel (S 235 JR) with a standard diameter of Ø 25 mm (with limit dimensions of +/- 0.5 mm) and a length of 500 mm (with limit dimensions of +/- 5 mm). They were sawn on both sides, almost free of burrs, without any change in cross-section, and were polyethylene-plastic-coated (resistant to alkalis) over their entire length, including one end face. The coating thickness should be at least 0.3 mm. One end of the face was painted to protect it against rust. Dowels were then inserted into the middle of the slab (Figure9).

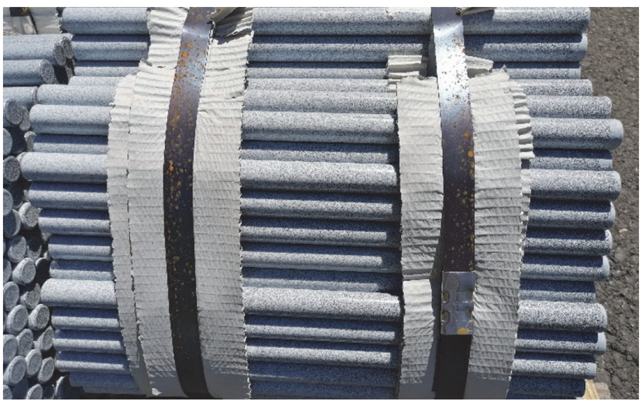

Figure 8. Smooth round steel dowels [Author, 2023]

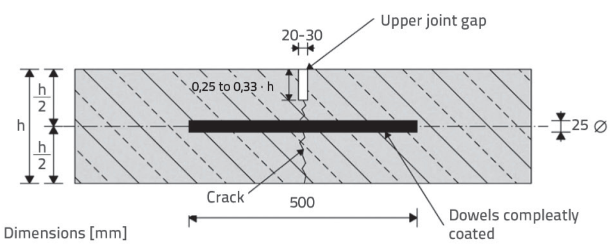

Figure 9. Unsealed dowelled dummy joint (dimensions mm) [5] (edited by author)

The anchors for longitudinal dummy joints (standard anchors) (Figure10) are made of ribbed reinforcing steel B500B, with a standard diameter of Ø 20 mm and a length of 800 mm (with limit dimensions of +/- 15 mm). They were cut on both sides with reinforcing steel shears and were plyethylene-plastic-coated (resistant to alkalis) in the middle section over a length of approximately 200 mm. The coating thickness was at least 0.3 mm. The ribbed steel anchors at the compression joints were placed at the centre of the concrete slab (see Figure 11) [6].

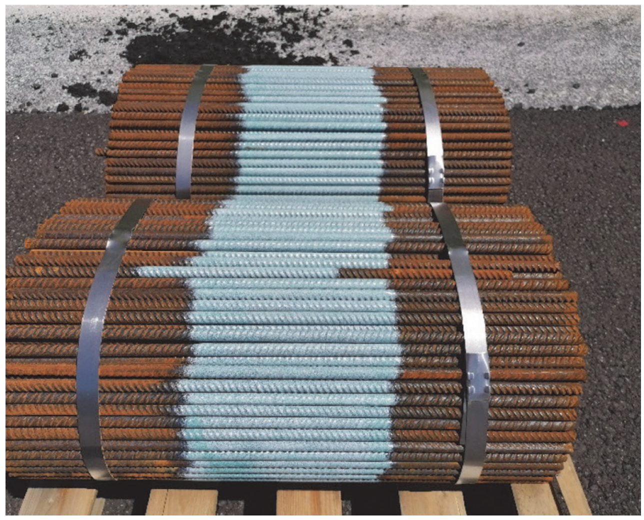

Figure 10. Anchors for longitudnal dummy joints [Author 2023]

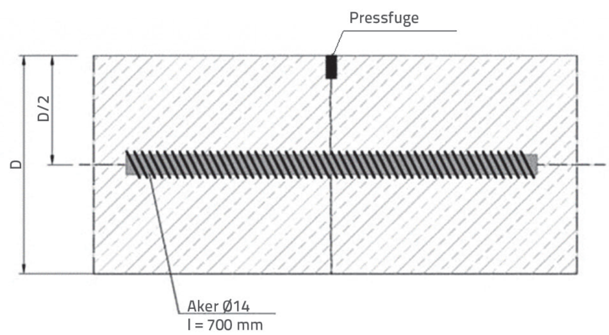

Figure 11. Anchors at the compression joints [6]

The concrete for paver paving at the Daimler intersection has a consistency class of C1, indicating a certain level of workability and consistency. The supplied concrete, C30/37 XM2, XF4, WS, with fibres and a maximum grain size of 16 mm, was placed by means of a concrete finisher. The designation "XF4" signifies an air-entrained concrete with an average of 5.5 % artificially introduced air voids in the fresh concrete. While these air voids are not visible to the naked eye, they serve an important function: ensuring that water penetrating the concrete (owing to capillary action) has sufficient space to expand when it freezes. This prevented the concrete surface from being damaged by ice formation and the associated increase in volume. The decision to use air-entrained concrete with the XF4 designation is important to ensure the frost-resistant properties of the concrete and minimize damage from freeze-thaw cycles.

This is particularly important because the Daimler crossing is exposed to varying weather conditions, emphasizing the need to ensure the durability and resistance of the concrete surface.
The use of concrete with these specific properties, coupled with precise installation methods using pavers, ensures that concrete slabs form a robust and durable road surface capable of withstanding the demands of traffic and external influences [3] (Figure12).

Figure 12. Initial "start-up" during the road paver production [3]

The exposure class XM2 requires special surface treatment, typically achieved in municipal concrete road construction through a method known as a broom finish. This finish involves applying a broom perpendicular to the direction of travel on the concrete surface. The application of the broom finish has several important effects.

- *Surface finish*: The broom finish creates the necessary texture on the concrete surface, providing protection against environmental influences.
- *Improved skid resistance*: Texturing the concrete surface with a broom improves skid resistance for vehicles, enhancing road safety, particularly in wet and slippery conditions.
- *Drainage of rainwater*: The broom finish channels rainwater laterally, preventing the formation of puddles on the pavement and ensuring effective drainage.

The broom finish method is a proven technique for enhancing the safety and resilience of concrete surfaces to road traffic. It meets the requirements of exposure class XM2, which requires special surface treatment measures. This approach ensures that the Daimler intersection has a road surface that is safe for traffic and well-drained, capable of withstanding various weather conditions and traffic loads (Figure13) [3].
The construction schedule was characterized by the definition of two construction phases to avoid full closure. The first phase (western side) commenced in March and concluded in July 2019, whereas the second phase ran in reverse from mid-July to mid-September 2019, with traffic opening on 25 September 2019.

Figure 13. Application of broom finish [3]

Joints play a crucial role in this unreinforced construction method for concrete slabs. They prevent uncontrolled cracking within the slab system, allow the concrete structure to relax along specific crack lines, and enable technically flawless joint sealing.
The joints were prepared using primers to ensure good flank adhesion. Subsequently, they were sealed with a two-

Figure 14. Joint cut: Haunch milling (chamfering) in the foreground. In the background, the ride-on cutting machine for the previously created first and second joint cut (1st joint notch, 2nd joint gap) [3]

component cold-joint grout to prevent dirt and water ingress. Proper sealing of the joints is particularly important to prevent water ingress, as moisture can lead to freeze-thaw cycles that may damage the concrete surface. Figure 14 shows two aspects of the joints [3].

- *Joint cut*: In the foreground, the milling of the haunch, also known as chamfering, can be observed. This preparation of the joints is important for specifying the crack line and ensuring the joint is technically clean. In the background, one can see the ride-on cutting machine that has performed the previously created first and second joint cut (1st joint notch and 2nd joint gap).
- *Dummy joint*: A dummy joint is a visible line or separator placed on the surface of a concrete slab to create the impression of a joint. These dummy joints can serve an aesthetic function or divide concrete paving into different areas or sections.

Figure 15. Cycle planning for paver runs and joint layouts [3]

Overall, joints are an essential part of the design to ensure the durability and resistance of the slab system at the Daimler intersection and to create a safe and technically sound road surface. The joint plan includes the arrangement of dummy joints, expansion joints/space joints, compression joints, and end-of-day joints as compression joints is shown in detail. In addition, cycle planning of the paver runs was performed according to this plan [3] (Figure15).

The 26 cm thick concrete slab at the Daimler intersection was reinforced with polypropylene fibres, known as "micro-reinforcement". These fibres, approximately 6 cm in length, were mixed into the concrete at a quantity of 3 kg/m³. Although not statistically relevant, they fulfil important functions (Figure16).

The addition of fibres resulted in the following:

Reduction of shrinkage cracking: Polypropylene fibres significantly reduce the likelihood of shrinkage cracking during the exothermic setting process of concrete. This process refers to an increase in the temperature of the concrete when the binder reacts with water, and the cracking of the fibres was minimised during this process.

- *Improvement of material cohesion*: Fibres strengthen the material cohesion of concrete, especially under mechanical loads,thereby increasing the resistance of the concrete.
- *Increase in post-crack tensile strength and elongation at break*: Polypropylene fibres improve the ability of the concrete to absorb tensile stresses after a crack and increase the elongation capacity of the material.
- *Internal curing*: The adhesion of water to the fibre surface creates a form of "internal curing" aiding in the curing of concrete and promoting the development of optimal strength and durability.

The use of polypropylene fibres as microreinforcements is an effective way to improve concrete properties and increase its durability and performance at Daimler intersections. This measure helps concrete to better withstand high traffic loads,

Figure 16. a) polypropylene fibre "AWP Forta Ferro"; b) concrete with fibres [3]

temperature fluctuations, and other stresses, thereby extending the service life of the road surface [3] (Figure16).

3. Horizontal hybrid construction

3.1. General

The second example of sustainability in road construction is the horizontal hybrid road construction. The best building material does not help if it is installed incorrectly or in the wrong location. Asphalt or concrete? Intrestingly, the construction company where I began my career in 1994 and stayed for 17 years, the original company of Strabag boss Dr. Hans-Peter Haselsteiner, was named "Asphalt and Concrete" ("ASPHALT UND BETON"). This aligns perfectly with the theme, so why not combine both asphalt and concrete?

3.2. Horizontal-hybrid construction method

Figure 17 illustrates the implementation of the "*horizontal-hybrid construction method*" in the rehabilitation of the busy A61 motorway. During the summer of 2019, the worn asphalt pavement was replaced with a concrete pavement in the hard shoulder and right-hand lane. The federal state of Rhineland-Palatinate, in particular, has embraced this concept and recognized its potential in road construction. The statement regarding the successful realization of over 12 km of motorways in the Koblenz area since 2017 is concise and clear [7]. The construction method consisted of pavements made of two different materials:

- *Asphalt pavement*: The asphalt pavement consists of an asphalt base layer, an asphalt binder course, and a top layer of mastic asphalt. Mastic asphalt, a special form of asphalt, offers high skid resistance and smoothness owing to its homogeneous surface. This layer was used for one lane of traffic.
- *Concrete pavement*: The concrete pavement is constructed as a two-layer system, with an exposed aggregate concrete surface. Exposed aggregate concrete is a type of concrete surface where the binder is washed out to create a textured finish. This concrete surface is used in the other lane, hard shoulder, or additional lanes.

The decision to use mastic asphalt as the surface course for the asphalt side was probably made due to its special properties, such as high durability, good skid resistance, and sound absorption, all of which are advantageous for busy motorways.

The horizontal hybrid construction method combines the advantages of both asphalt and concrete to create a durable and resistant road surface capable of withstanding heavy traffic. This innovative construction method allows the optimal use of various materials and ensures the efficient rehabilitation and improvement of motorway infrastructure [7].

Figure 17. Horizontal-hybrid construction method for the rehabilitation of the heavily traveled A 61 motorway in Germany [7]

Water seepage from the joint between asphalt and concrete presents a challenge that may arise during horizontal hybrid construction. In this construction method, where asphalt and concrete meet, a joint line is formed, which could potentially be susceptible to water penetration (Figures18 and 19).

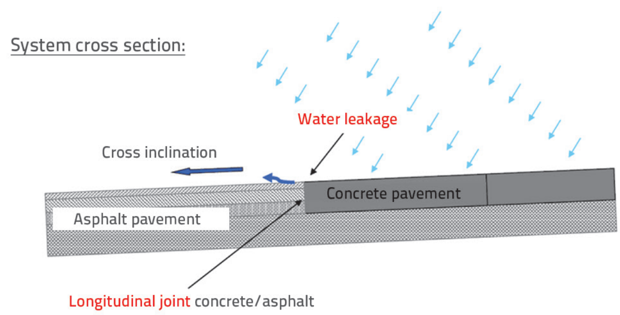

Figure 18. Illustration of water leakage from asphalt-concrete joints [8]

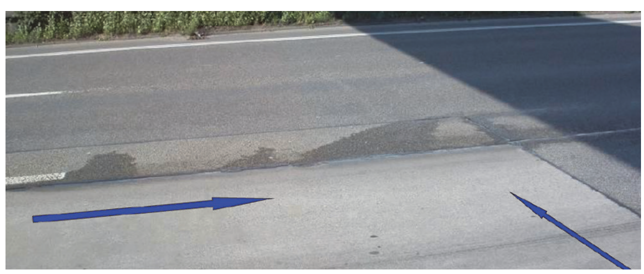

Figure 19. Visual representation showcasing the issue of water leakage from asphalt-concrete joints [8]

Water leakage from the joints can have various causes.

- *Different expansion properties*: Asphalt and concrete exhibit distinct thermal expansion coefficients, indicating that they respond differently to temperature changes.

These differences can result in differential expansion or contraction under hot or cold conditions, potentially leading to cracks or fissures along the joints.

- *Insufficient sealing*: Inadequately sealed joints can allow water to penetrate the interface between asphalt and concrete, particularly after rainfall or in adverse weather conditions, causing potential issues.
- *Movement of traffic*: Constant exposure to traffic, especially heavy vehicles like trucks, can induce pavement movement and deformation. This movement can compromise the integrity of the joints, making them susceptible to water ingress.

The design and workmanship of joints between different types of fixtures are critical for the durability of the hybrid system. Attention to detail during planning and construction is paramount, with the joint requiring particular focus. Detailed information regarding the joints can be found in Figure 20, with reference to the paper "H BaA" published by FGSV in 2017. Notably, the use of bituminous welded sheet is highlighted. To facilitate drainage in case water penetrates the joint, a drainage slot must be incorporated, extending down to the unbound layers. This drainage slot was created as a recess through groove milling, cutting, or edge formation of the underlay in a 2:1 ratio. Subsequently, it must be completely backfilled with a suitable drainage-capable building material mixture, such as grain groups of 2/5 or 5/8 mm [9] (Figure20).

Notably, following the paving of the asphalt base course and asphalt binder course in the left and centre lanes, the position of the later right-edge joint was precisely measured. This meticulous measurement ensured the accurate placement of the joint, optimizing the design of the contact surface between the asphalt and concrete. The drainage slot, filled with a building material mixture (e.g. grain groups of 2/5 mm or 5/8 mm), serves a crucial role in horizontal hybrid construction. This slot facilitates the drainage of penetrating water along the joint, ensuring effective pavement drainage. Drainage is of great importance as it prevents the accumulation of standing water in the joint, thus reducing the risk of frost damage and other moisture-related issues.

The use of differently coloured or grained materials for the asphalt base course, asphalt binder course, and construction material mixture in the drainage slot offers clear visibility of the different layers and functions of the road surface. This visibility is important not only for practical purposes but also for enhancing the overall aesthetic impression of the finished motorway. The exact measurement of the joint position, careful design of the drainage system, and distinct differentiation of the layers were instrumental in the successful implementation of the horizontal hybrid construction method. These measures not only enhanced the functionality and resilience of the road surface but also elevated its aesthetic appeal. Such measures are crucial for extending the lifespan of motorways and providing safe and reliable transport infrastructure [7] (Figure21).

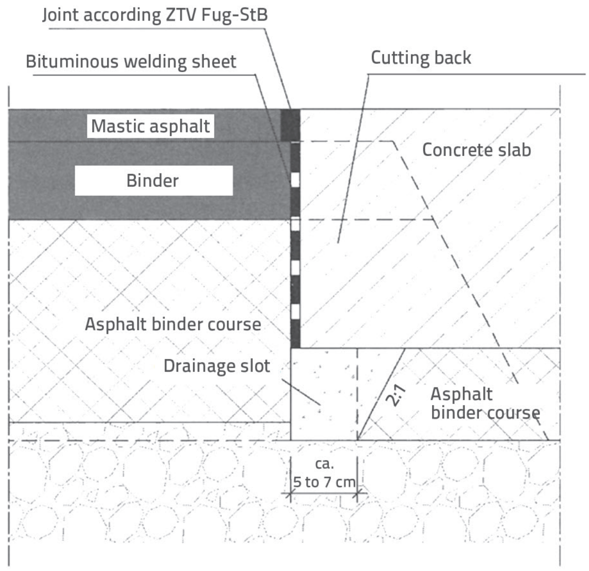

Figure 20. Details of the joint [9]

The exact bonding of the bituminous membrane to the asphalt cut edge plays a crucial role in ensuring the effectiveness of the joint in horizontal hybrid construction. This measure considers the different expansion behaviours of the construction materials, concrete, and asphalt.

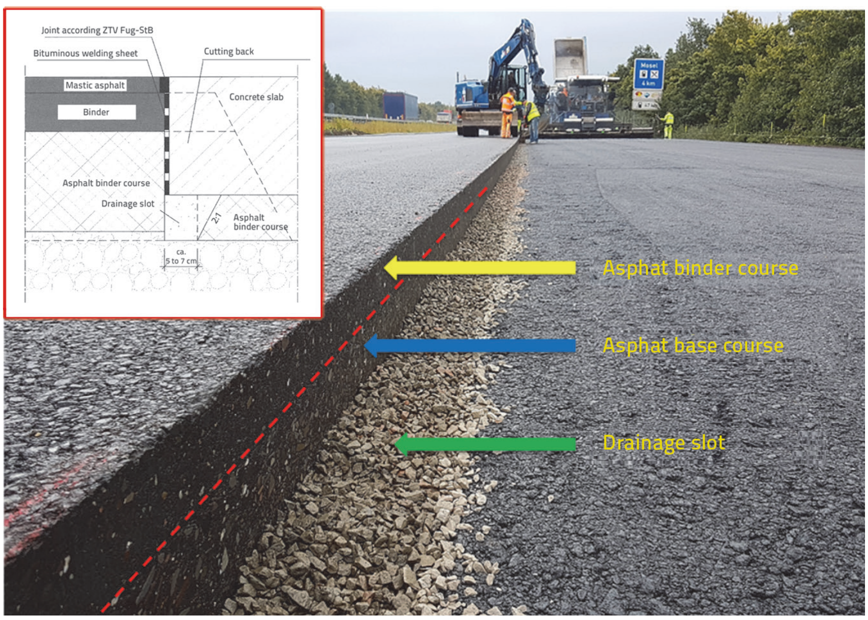

Figure 21. Right edge of the asphalt roadway or precise measurement of the joint as indicated in [7] (edited by the author)

Concrete and asphalt exhibit different thermal expansion properties. Although concrete tends to expand with heat, asphalt expands to a greater extent at high temperatures. Conversely, at low temperatures, concrete contracts more than asphalt. These different expansion properties can induce stresses and deformations at the joint line if the construction materials are not properly matched. By accurately and firmly bonding the bituminous membrane to the asphalt cut edge, an effective bond was established between the concrete and asphalt. The bituminous membrane acts as an elastic separating and connecting layer capable of accommodating the movement of the two materials under different temperature conditions. This bonding ensures that the joint between the concrete and asphalt remains watertight, thereby minimizing damage from water penetration and freeze-thaw cycles.
Therefore, the proper handling and installation of bituminous sheets are crucial to ensure the functionality and durability of the horizontal hybrid construction method. This precise implementation can ensure that, despite the different expansion properties of the construction materials, the motorway pavement maintains a stable and durable bond, capable of withstanding both traffic loads and weather conditions (Figure22).

Figure 22. Precise bonding of bituminous sheets to asphalt cut edges [7]

The horizontal-hybrid constructed section of A61, completed in the winter of 2017/18, stands as a striking and functional example of sustainability in road construction. The implementation of this innovative construction method undoubtedly presents an effective solution for improving the longevity and resilience of motorway pavements, all while satisfying sustainability requirements. Some of the sustainability features and advantages of this construction method are as follows:

- *Durability*: The combination of asphalt and concrete provides a resistant road surface capable of withstanding heavy traffic loads and temperature fluctuations. This significantly extends the lifespan of motorways and reduces long-term maintenance costs.
- *Resource protection*: The selection of suitable materials and the careful planning and execution of construction methods contribute to resource conservation. Utilizing concrete and asphalt in certain sections of roadways allows for the efficient utilization of the respective advantages of these materials.
- *Water drainage*: Effective drainage and sealing of joints reduce the risk of moisture ingress and protect road surfaces from frost damage, thereby further improving the motorway longevity.
- *Energy efficiency*: Designing and selecting materials adapted to the specific requirements of horizontal hybrid construction can help optimize energy consumption during both construction and subsequent operation of the motorway.

Reduction of environmental impacts: Using sustainable construction methods and materials reduces the environmental impact of transport infrastructure construction, resulting in a positive effect, particularly in terms of CO_2 emissions and resource consumption.

The successful implementation of such a project demonstrates that sustainable solutions for road construction are possible and offer both economic and ecological benefits (Figure23). Such examples are inspiring and show that road construction in the future can increasingly rely on sustainable principles to create future-proof infrastructure. A classic example of a concrete-asphalt connection is also found on the A10 Tauern freeway at the Wengen-Pongau junction in Austria (Figure24).

Figure 23. Horizontal-hybrid construction section of A 61 [10]

Figure 24. A10 Tauern Freeway at Wengen–Pongau Junction, Austria [author, 2021]

4. Conclusion

According to the Federal Environment Agency of Austria, in 2021, an additional 10 ha of land were being taken up daily. Over a three-year period, the daily average was 11.3 hectares (equivalent to approximately 12 large football fields), primarily for construction activities, transport infrastructure, and commercial areas. According to the German Federal Environmental Agency, settlement and transport areas increased by an average of 129 ha per day between 1997 and 2000, corresponding to approximately 180 football pitches. Sustainable road construction also involves choosing the appropriate building material for each location to ensure the longest possible service life.

In the two examples shown here, the junction in concrete construction and the horizontal hybrid construction method, the influence on sustainability in road construction through the selection of the right building material (in this case, concrete) for the right location or correct use was highlighted. If the service life of the asphalt pavement significantly decreases due to high traffic load (Figure4), concrete becomes economically viable despite its higher initial costs, even though it is approximately half as expensive as asphalt.

In the first case study, the structure combines the advantages of both asphalt and concrete to create a durable and resilient road surface capable of withstanding high traffic loads at the Daimler intersection. The unbound frost protection layer prevents frost from penetrating the road surface, whereas the asphalt base layer ensures even load distribution. Concrete, serving as the final layer, provides stability and durability against traffic loads, especially heavy traffic. Thus, this layered structure ensures the required strength and resilience of the road to accommodate future traffic loads at the Daimler intersection. In the second case study, the horizontal hybrid construction method combines the advantages of asphalt and concrete to create a durable and resistant road surface capable of withstanding heavy traffic loads. This innovative construction method allows for optimal use of different materials and ensures efficient rehabilitation and improvement of motorway infrastructure.

The widespread and appropriate application of these two methods in road construction projects is the author's great wish, as they hold great potential for enhancing the sustainability of road construction in the future.

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