Evaluation of Utility Cut Patching on Pavement Structure

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Abstract. Utility Cut Patching (UCP) typically involves cutting road pavement, often with subsurface excavation, and patching works related to utility pipeline maintenance. UCPs disrupt the static behavior of pavements, causing cracking and altering their impermeability and adherence. Generally, there is poor quality control of UCPs, leading to rapid degradation of pavements within a few years, which has severe impacts on traffic quality and safety. This paper presents a case study of a bidirectional urban road where a water pipeline has been constructed in one of the two lanes. The rapid deterioration of the lane was investigated using in-situ nondestructive FWD deflectometric testing, comparing its structural quality with the adjacent pavement not affected by the works. A total of 312 tests were conducted at 80 locations, 40 for each lane, with a 20.0 m pitch by repeating the measurements for 3 stress levels. The analysis results show how the pavement subjected to UCP increases its deformability by about 25%, with less homogeneous and highly variable values. The coefficient of variation is 40% for all layers of the pavement without UCP, while in the one with UCP it is increased by 116% in the HMA, 73% in the foundation, and 58% in the subbase. Further analysis was performed using FE simulations to investigate the effect of the load position with respect to the UCP. Similar maximum deflection values occur in a large range of position while highest horizontal tensile stress peaks occur in the granular foundation when the load is located outside the UCP.

Keywords: Utility Cut Patching · pavement · FWD · maintenance · superstructures evaluation

1 Introduction

The influence of Utility Cut Patching (UCP) on pavement is a complex issue with significant implications for pavement integrity and performance. Maintaining the pavements structural integrity is essential for ensuring safe and efficient traffic flow.

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However, routine maintenance and repair activities, such as UCP, can significantly influence pavement structure and its performance. UCP involves cutting road pavements to facilitate subsurface excavation for utility pipeline maintenance, followed by patching to restore the pavement surface. These activities disrupt the static behavior of pavements, leading to cracking and alterations in impermeability and adherence [1].

Despite the importance of UCPs in utility infrastructure maintenance, several studies report lack of quality control in their execution [55–58]. These studies highlight that often the frequency and type of inspections are inadequate, especially regarding the material compaction. This deficiency often results in rapid degradation of pavements within a few years, with adverse consequences for traffic quality and safety [2]. The UCPs can accelerate pavement deterioration in urban area, increasing maintenance costs for municipalities [3]. Some researchers highlighted the need for a management system to address this problem [4]. Jensen in 2005 identified factors contributing to settlement in and around utility cuts, including fill material and construction practices.

Recommendations include the need for greater control of the moisture content of the remnant material, which should be similar to the natural material to avoid the phenomena of swelling and shrinkage. It is also indicated that the material should be compacted with the relative density greater than 65%. In addition, compaction should be done with a vibrating plate, both in the excavated and cut area [5]. Some studies using FWD (Falling Weight Deflectometer) have analysed pavement deterioration, finding that the deflection value at the patch centre is critical, resulting $\approx$ 1.8 times the average deflection at existing pavement. Moreover, the deflection depends on trench geometry and pavement condition and, as the width increases, the deflection decreases at a diminishing rate [6]. This effect's magnitude depended on climate, traffic loadings, pavement patching procedure, and pavement condition at the time of patching [7]. Others investigation pointed out how a way of reducing the negative impact on traffic networks can be achieved harmonization design, development and operations for attaining sustainable improved movement and safety, for easier maintenance and minimize relocation cost of users and road authorities [8]. These reasons many road authorities have investigate how control and reduce the UCPs impact on pavements [9, 11–13].The systematic literature review, conducted according to PRISMA [59] methodology, returns 260 relevant studies on UCP of pavement. The Fig. 1 summarizes the results of the most pertinent studies.

The 63 most relevant ones were analyzed in detail [1–58]. The review identifies key factors influencing UCPs, evaluates its impact on pavement performance, examines assessment methods, explores mitigation strategies, and highlights directions for future research. In a recent paper [14], the finite element method (FEM) has been employed to analyze the mechanical response of superficial asphalt pavements patched with different shapes of patches (rectangular, stair, and trapezoidal). Pavement with rectangular patches was found to be the most vulnerable to Top-Down and Bottom-Up crack propagation, while stepped and trapezoidal patches can effectively mitigate stress-induced cracking of the asphalt surface layer. Opposite behavior concerns thermal FEM simulation where cracking is less critical for rectangular patching. The study remains limited to the surface bituminous layers, and it would be interesting to extend it to the lower layers (base, foundation and subgrade) as well.

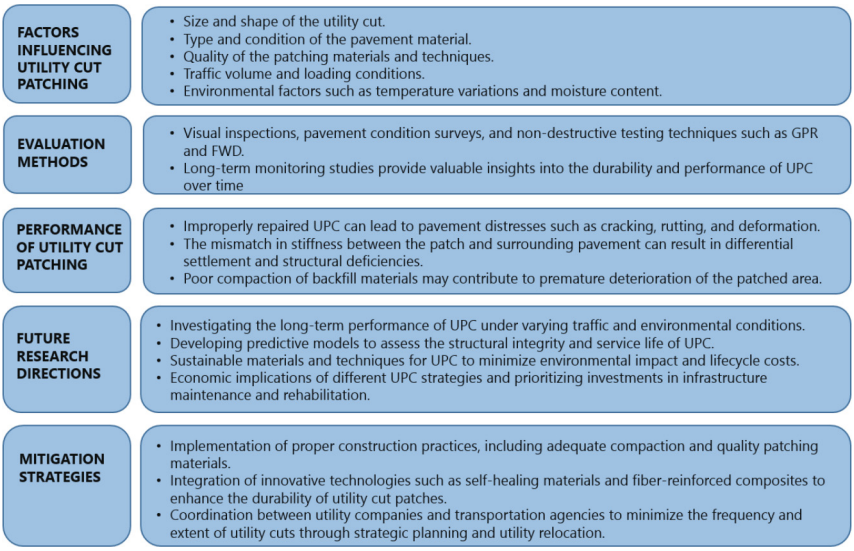


Fig. 1. The findings of the PRISMA systematic literature review

This paper present a case study of an evaluation method of before/after UCP on pavement structure through a FEM simulation and FWD tests in situ. The research was conducted under the specific geographic, climatic, and traffic conditions of the site but can be easily implemented in other contexts. An extensive campaign in a variety of other situations would be highly beneficial for network managers in defining thresholds and parameters of acceptability in quality control procedures. In this perspective, the FHWA (Federal Highway Administration USA) developed a comprehensive manual in 2018 [9] addressing UCP issues in an integrated manner. The document was created to provide information to managing entities aiming to protect and control their infrastructures. On the policy side, various types of policies and regulations are presented, along with case studies and standard regulations. The technological part of the manual offers a brief overview of various trenchless technology methods, their advantages and disadvantages, and other relevant information on implementing this technology in UCP construction. The FHWA views the manual as a starting point for a comprehensive investigation into the types of policies and technologies available to control and reduce UCP-related issues, encouraging researchers and professionals to implement, experiment with, and develop their own policies, regulations, and specifications.

2 Case Study

In the year 2019, a 3.8 km segment of the provincial road SP17 was subject to construction activities for the installation of a water pipeline (Fig. 2).

At a depth of 140 cm within the excavation, a 15 cm layer of sand bedding was laid, serving as a foundation upon which a pressurized pipeline with a diameter of 25 cm was positioned. The excavation, measuring approximately 70 cm in width, was reinstated in

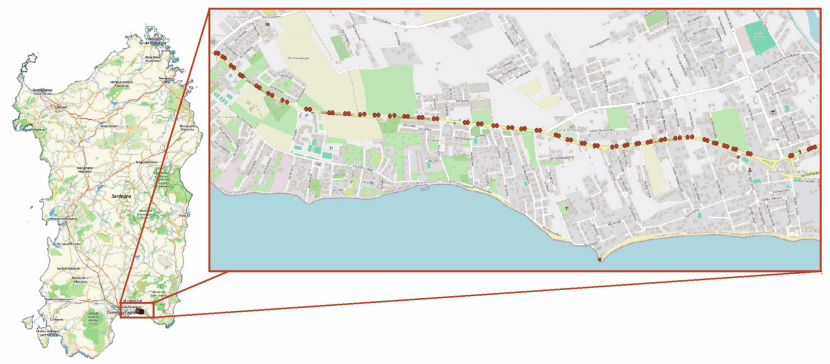


Fig. 2. Provincial road SP17 in Sardinia (Italy) subject to UCP for the installation of a water pipeline

the subgrade using the same material as that excavated. Simultaneously, the pavement underwent reconstruction employing identical thicknesses and materials as the original structure detected during excavations: 20 cm of unbound granular mix and 20 cm of Hot Mix Asphalt (HMA), consisting of a 10 cm base layer and 10 cm surface layers.

Compaction of both the subgrade and granular layers was achieved through the use of a vibrating plate, while the asphalt conglomerates were compacted using a small roller weighing 600 kg and with a width of 60 cm. Figure 3 depicts the cross-sectional view of the excavation and FWD position tests over and outside of the UCP.

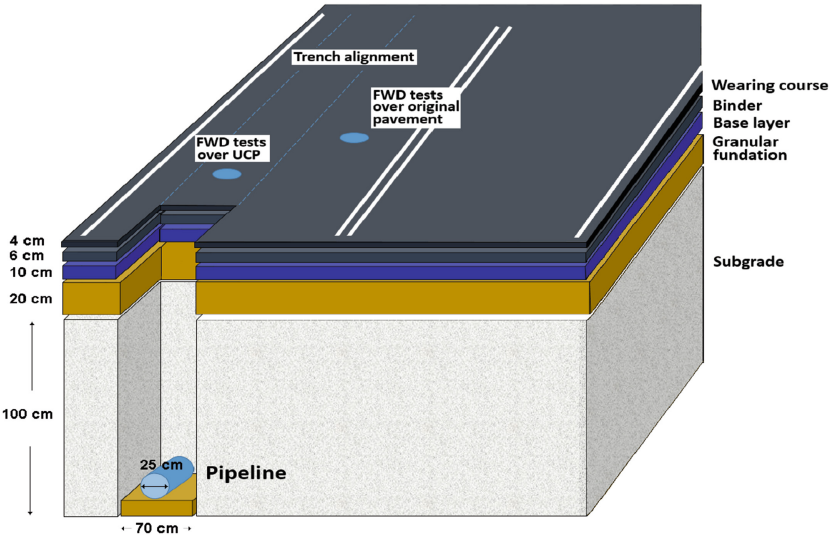


Fig. 3. The cross-sectional view of the excavation and FWD position tests over and outside of the UCP.

3 Research Methodology

First, a series of tests were conducted using the Falling Weight Deflectometer (FWD) to evaluate whether and how a pavement loses structural capacity following the construction of a road cut. The same tests have been used to validate a finite element simulation. The model was subsequently modified to verify the effect of the transversal position of the wheel path respect to UCP.

FWD deflection tests.
The Falling Weight Deflectometer (FWD) is commonly utilized for the investigation of road and airport pavement structures (see Fig. 4). It consists of a falling mass that can be adjusted within the range of 50 to 350 kg, imparting a load impulse spanning from 40 to 120 kN. This load impulse is transmitted through a circular steel plate, measuring 300 mm in diameter, which is strategically divided into four circular sectors to ensure optimal conformity with the pavement surface. Ten geophones are positioned in a line over the pavement, automatically preceding the mass drop, to measure the deflection basin. The impulse duration is 30 ms, while the geophones record within a range of 60 ms with an accuracy of 0.05 μm. The measurements, repeated at 900, 1200 and 1500 kPa, are very fast since the procedure requires about 1 min for a single station point. The shape and slope of the deflection basin are well correlated with the stiffness of the material in each single layer, and numerous parameters have been proposed and investigated to understand pavement response. For these reasons, many road and airport authorities adopt specific techniques and deflection parameters in the process of quality assurance (QA) of the pavements construction and maintenance.

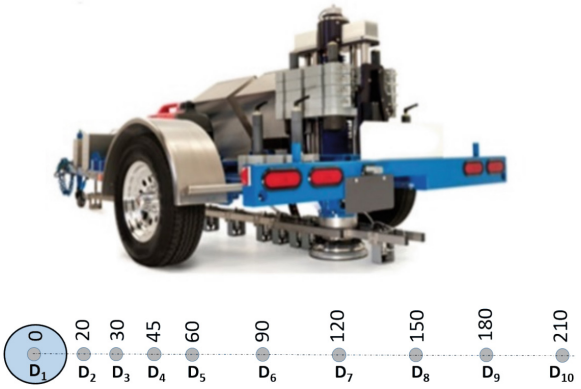


Fig. 4. The fast-FWD and the ten geophones positions

The measurements were analyzed using ELMOD6 software for inverse backcalculation analysis, estimating pavement layer stiffness and thickness from deflection data obtained from FWD testing. Initially, deflection basin data, pavement temperature, and loading conditions are input into the software. It iteratively adjusts pavement layer properties until calculated deflection closely matches measured deflection, employing algorithms like layered elastic theory or finite element analysis.

Output includes estimates of layer stiffness, thickness, and other pavement properties crucial for design, rehabilitation, and management decisions. Backcalculation provides a non-destructive, cost-effective method for accurately assessing pavement structural condition in pavement engineering. In particular, through backcalculation, the elastic moduli of materials were evaluated. For this purpose, the pavement was schematized as composed of three layers: 20 cm of HMA, 20 cm of granular mixture foundation, and subgrade. In addition, from the raw FWD data acquired, it is possible to obtain particular indices, called Basin Indexes, which are well correlated with the stiffness of the layers. Those considered relevant for the trials were:

- Base Layer Index BLI = D_0 –D_{300} correlated with bituminous layer stiffness
- Middle Layer Index MLI = D_{300} –D_{600} correlated with granular fundation stiffness
- Lower Layer Index LLI = D600 –D900 correlated with subgrade stiffness

The measured and backcalculated data allowed for the validation of a 2D finite element model in the elasto-plastic field.

FEM simulations

The Finite Element Method (FEM) is a widely employed numerical technique for intricately evaluating the mechanical response of structures. Initially, the system is discretized into small and simple elements. This is followed by solving the corresponding partial differential equations and connecting them through common nodes. This approach, coupled with graphical modelling of results, effectively visualizes the mechanical behaviour within materials. Consequently, FEM is universally acknowledged as an effective tool in pavement design, facilitating detailed analyses without excessive labour or high costs. The predictive quality of simulations hinges on the accuracy of the model, particularly the size of finite elements, which exponentially increases computational cost. Furthermore, accurately describing the constitutive behaviour of the materials is crucial. Considering elastic road materials may suffice only if material stress levels remain far from plasticity and load application times are rapid. The Drucker-Prager constitutional model was used in order to simulate the non-linear behaviour of the granular and cohesive soil of the foundation. For these reasons, the Drucker-Prager constitutive model was used to simulate the nonlinear behaviour of the granular and cohesive soil materials. The simulation process proceeds step by step, verifying at each iteration the attainment of an equivalent stress value, equal to:

$$\sigma_t = 3\beta\sigma_m + \left[\frac{1}{2}\{s\}^T[M]\{s\}\right]^{\frac{1}{2}} \tag{1}$$

with:

$$\sigma_m = \tfrac{\sigma_1+\sigma_2+\sigma_3}{3},\ \{s\} = \{\sigma\} - \sigma_m[1\ 1\ 1\ 0\ 0\ 0]^T \text{ and } [M] = \begin{bmatrix} 1&0&0&0&0&0\\ 0&1&0&0&0&0\\ 0&0&1&0&0&0\\ 0&0&0&2&0&0\\ 0&0&0&0&2&0\\ 0&0&0&0&0&2 \end{bmatrix}.$$

Knowing the values of the angle of friction (ϕ) and of cohesion (c), it is possible to estimate the parameter β and the value of the ultimate tensile strength:

$$\beta = \frac{2\sin\varphi}{\sqrt{3}(3-\sin\varphi)} \tag{2}$$

$$\sigma_y = 3c\beta\text{cotg}\varphi \tag{3}$$

Figure 5 show the conical shape of the breaking surface defined in the Drucker-Prager model, which coincides with the hexagonal breaking surface of Mohr-Coulomb.

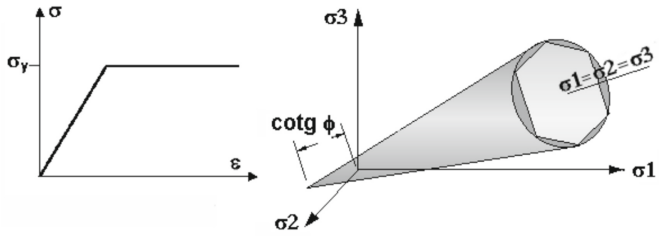


Fig. 5. Breaking surface of Drucker-Prager model

Once the plastic state is reached, the material flows, incapable of assuming ulterior stress states. Thus the stress is transferred to the adjacent zones that, depending on both the stress level and mechanical characteristics, can get plasticized. Therefore, it forms a plasticized volume that grows until reaching equilibrium that, in case of excessive stress levels, could not be achieved. On Table 1 are reported the values used for the FE simulation.

Table 1. Material parameters used for finite element model

Layer	Modulus Elasticity MPa	Coefficient of Poisson	Angle friction °	Cohesion MPa	Bulk weight KN/m^3	Drucker-Pragerσy MPa
HMA	3000	0.35	45	1.2	20	3.600
Foundation	300	0.4	35	0.04	19	0.1714
Subgrade	40	0.42	30	0.02	18	0.1039

The rectangular shapes of the asphalt pavement patching and pavement without UCP were simulated using FE analysis, implemented with ANSYS/Mechanical APDL 18.1 software, to evaluate the effect of the load position with respect to the UCP. Figure 6 shows details of the FE mesh and model dimensions. Contact materials have been introduced on the cutting interface to simulate the loss of mechanical characteristics of the materials introduced during roughening: 50% for the HMA and 30% for the granular foundation material. A 15% reduction in characteristics was considered for the subbase.

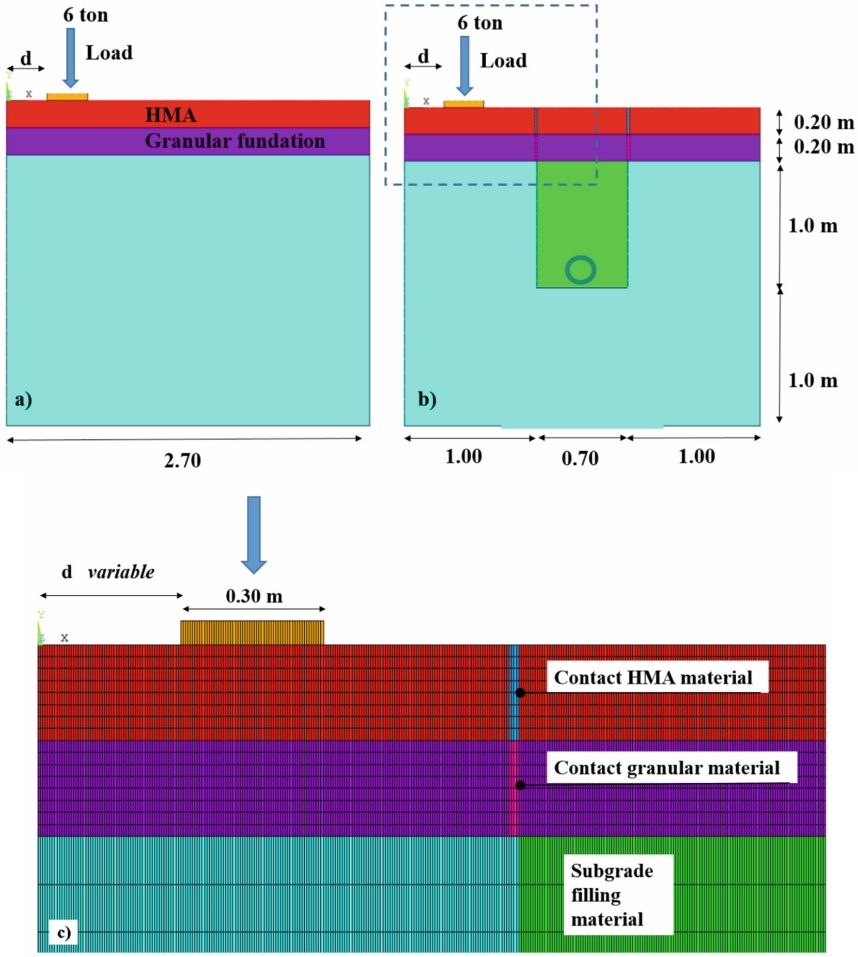


Fig. 6. Details of the FE mesh and model dimension: a) Original pavement without UCP; b) Pavement with UCP; c) contact materials are introduced in the cutting interfaces

4 Results

FWD deflection tests.

The results of the FWD test analyses are shown in Fig. 7. The two alignments tested with and without UCP were compared along the lane progression in terms of maximum deflections and deflection basin regularity. A greater variability is evident in the tests involving pavement with UCP compared to those where it is absent.

The average value of maximum deflection is 507 μstrain in the pavement without UCP, while in the one with UCP, the value increases to 633 μstrain, with a 24.9% increase. The mean BLI, correlated with the stiffness of the HMA, increases from 149 μstrain to 172 μstrain, with a 16% increase in deformability. Similarly, the deformability of the granular foundation and subbase increases. Mean MLI increases from 125 μstrain

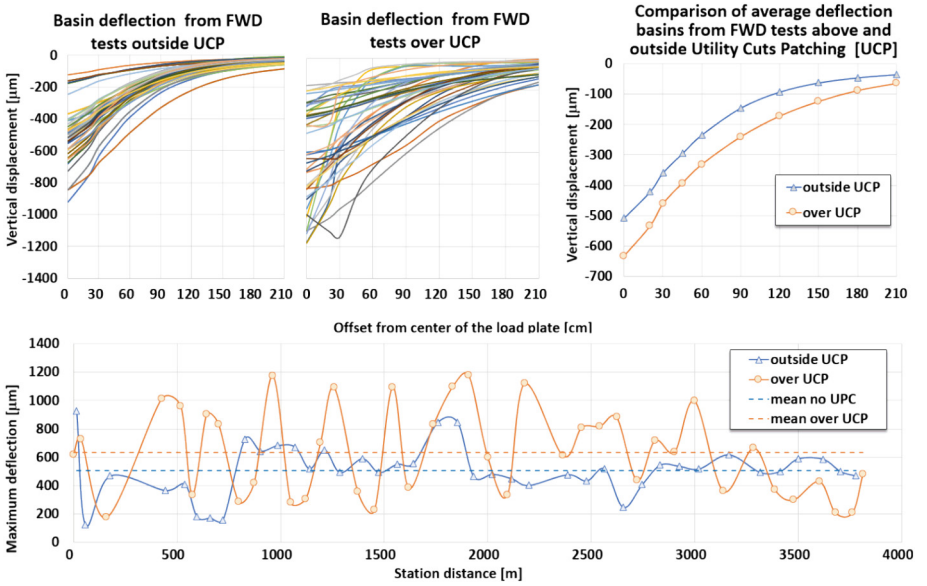


Fig. 7. FWD test results. **On the top**: The set of all deflection basins of the pavement with and without UCP, and the comparison of the mean deflection basins. **On the bottom**: the maximum deflections along the FWD tests alignments

to 129 µstrain, and mean LLI from 89 µstrain to 91 µstrain, with increases of 4% and 2% in deformability, respectively.

The increased variability in the response of the pavement with UCP is also evident in the results of the BLI, MLI, and LLI indices (Fig. 8). The coefficient of variation increases from 40% to 116%, from 40% to 73%, and from 37 to 58%, respectively. The high variability affected the backcalculation of the pavement with UCP, which resulted unreliable. The values of the moduli obtained for the pavement without UCP were 6227 MPa for HMA (T_{ref} 14 °C), 798 MPa for the foundation, and 148 MPa for the subbase.

FEM simulations

The simulation of the pavement without UCP was validated by introducing the values of the average modulus of the materials obtained from backcalculation of FWD deflection tests in situ, reproducing the deflection basin most similar to the average one found in the tests. Subsequently, the FE model was modified to introduce a rectangular cut filled with the same layers and thicknesses of the materials. The interface between the materials present on the edge of the excavation and those of the new filling materials was modelled considering the inability to fully restore the monolithic nature of the structure during filling.

To account for the reduced capacity of the filling materials and those at the interface of the cut, the modulus values were appropriately reduced, based on the fraction obtained in the deflection basin indexes.

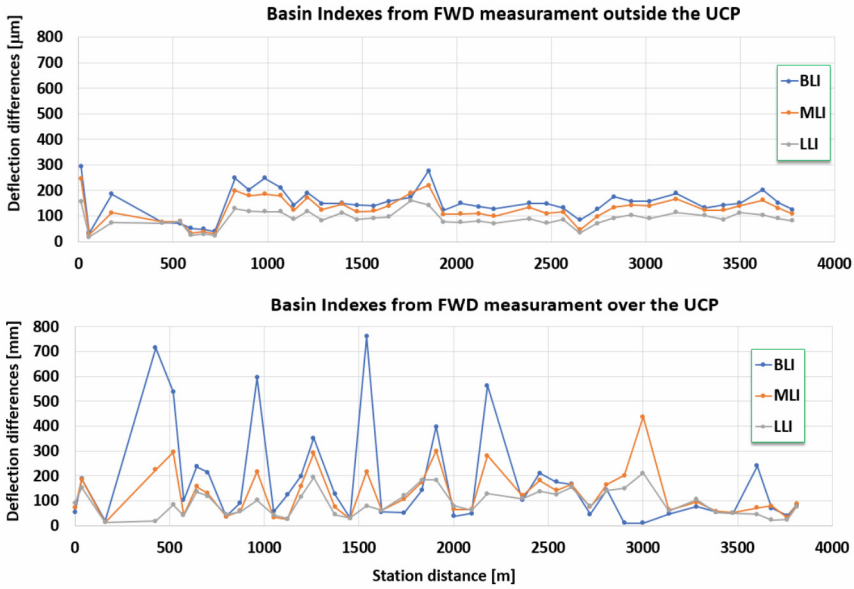


Fig. 8. BLI, MLI and LLI deflection index along the FWD tests alignments

Figure 9 illustrates the distribution of stress and deformation components in the modified model assuming a load positioned above the left joint of the UCP.

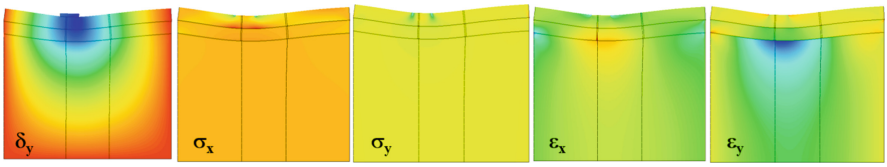


Fig. 9. The distribution of tensile and deformation components δ_y, σ_x, σ_y, δ_x, δ_y

The aim of the FE simulation was to assess the effect of the load position relative to the UCP. For this reason, the load, represented by a circular plate of 0.30 m loaded with 6 tons, was positioned at varying distances from the UCP, deriving the profile below the load axis of displacement components, horizontal stress, and horizontal and vertical deformations (Fig. 9).

The maximum deflection values occur when the load is positioned at the center of the UCP, at 0.49 mm. Values very close to this are also observed for load positions outside the UCP, within a wide range around the UCP. The maximum values of horizontal tensile stress of approximately 0.14 MPa occur in the granular foundation when the load is positioned outside the UCP. Horizontal deformations generally result in tension at the base of the HMA with maximum values when the load is placed at the side of the UCP (157 µstrain). Lower values are obtained when the load is positioned at the center of the

UCP. Finally, vertical deformations reach maximum values (350 μstrain) when the load is positioned above the road cut.

5 Conclusion

UCP is a critical aspect affecting pavement structure, with implications for integrity and performance, especially in terms of traffic safety and efficiency. Lack of quality control in UCP execution often results in rapid pavement degradation, increasing maintenance costs and posing safety risks.

The paper emphasize the need for management systems to address UCP-related issues, by employing FWD deflection tests and Finite Element simulation.

A systematic literature review identifies key factors influencing UCP, its impact on pavement performance, assessment methods, mitigation strategies, and future research directions. Results indicate increased pavement deformability and variability due to UCP, affecting pavement performance and reliability.

FEM simulations illustrate the effect of load position relative to UCP on pavement stress, deformation, and deflection. Maximum horizontal tensile stress occurs in the granular foundation when the load is positioned outside the UCP, while horizontal deformations result in tension at the base of the HMA, with variations depending on load position.

The main specific results of the study are:

- the FWD tests show greater variability in pavement performance with UCP compared to those without it;
- the maximum deflection in pavement without UCP averaged at 507 μstrain, while with UCP, it increased to 633 μstrain, marking a 24.9% increase;
- BLI, MLI, and LLI, correlated to the deformability of HMA, foundation, and subgrade, respectively increased with UCP by 18.3%, 3.5%, and 2.4%;
- the higher variability in results with UCP affects the reliability of backcalculation;
- In the finite element simulation under a load of 6.0 tons, the highest horizontal tensile stress of approximately 0.14 MPa is observed in the granular foundation when the load is positioned outside the UCP. Additionally, the maximum deflection reaches 0.49 mm.
- The vertical deflection peaks at 350 μstrain when the load is directly above the road cut, while horizontal deformations induce tension at the base of the HMA, with maximum values occurring when the load is positioned at the side of the UCP.

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