Performance of foamed bitumen pavements in accelerated testing facility

Desempeño de pavimentos estabilizado con asfalto espumado en una prueba de pavimentos a escala real y carga acelerada

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PAG 05 - 17

Abstract

One of the key principal goals of pavement asset management is to develop and implement cost-effective pavement construction and maintenance strategies that achieve the required levels of service and performance. A sustainable, cost-effective technique for rehabilitating pavements is foamed bitumen stabilization. This paper presents a study on the performance of foamed bitumen pavements tested in the Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF), for full scale testing of pavements. Six pavement sections were tested; the variables were bitumen and cement content; one control section with the untreated unbound material was tested. Results showed that surface deflections decreased at sections with higher bitumen contents. After the application of 5,710,000 Equivalent Standard Axles (ESAs), the sections stabilised with cement only, bitumen only, and the control section all showed large amounts of rutting. Conversely, little rutting was observed in the three sections stabilised with foamed bitumen and 1.0% cement, showing that cement and FB together significantly improve pavement performance. The rutting results were used to develop models to describe the stable and unstable performance of the tested pavements. The paper concludes by outlining some of the practical benefits of utilising this technology in pavement asset management.

Keywords: *pavement recycling, foamed bitumen, full-scale testing, rutting models*

Resumen

Uno de los objetivos claves de la gestión de pavimentos es desarrollar e implementar una estrategia de construcción y mantenimiento rentables, con el fin de alcanzar niveles requeridos de servicio y desempeño. Una técnica rentable y sustentable para la rehabilitación de pavimentos es la de estabilización o reciclado con asfalto espumado (AE). Este artículo presenta un estudio sobre el desempeño de pavimentos estabilizados con asfalto espumado en el Canterbury Accelerated Pavement Testing Indoor Facility CAPTIF. CAPTIF es un laboratorio a escala real para pavimentos ubicado en Nueva Zelandia, que permite aplicar un gran número de cargas de tráfico en un breve período de tiempo. Seis secciones de pavimentos con distintos contenidos de asfalto y cemento fueron ensayadas en CAPTIF. Los resultados del experimento mostraron que las deflexiones disminuyen en las secciones con mayor contenido de asfalto espumado. Luego de aplicar más de un millón de ciclos de carga, las secciones estabilizadas sólo con cemento, sólo con asfalto y la sección sin estabilizar mostraron un deterioro significativo en forma de ahuellamiento. Por otro lado, las secciones que fueron estabilizadas con AE y cemento mostraron un buen desempeño, demostrando que el cemento y el AE juntos mejoran significativamente el desempeño del pavimento. Los resultados de ahuellamiento fueron empleados para desarrollar modelos y describir el deterioro estable y acelerado de los pavimentos en estudio, lo que puede ser utilizado para una mejor gestión de los pavimentos estabilizados con asfalto espumado

Palabras Clave: Reciclaje de pavimentos, asfalto espumado, pruebas de pavimento aceleradas, modelos de ahuellamiento

1. Introduction

In New Zealand more than 95% of the roads are constructed of flexible unbound granular pavements. A typical New Zealand pavement consist of a thin surface (usually not exceeding 50 mm thickness), the basecourse (which is constructed from unbound granular material that is usually crushed quarried rock or locally sourced aggregate) and the subbase (which is usually one or sometimes two layers of unbound granular aggregate). This pavement type has been adopted in New Zealand because in the past high quality aggregate has been readily available in most regions of the country and because in most New Zealand roads, low traffic volumes do not justify the incorporation of thick asphalt pavements, usually constructed in heavy trafficked roads.

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However in the last decade areas of New Zealand started to face a complex problem in the supply of high quality aggregates for road construction. A viable alternative to reduce the exploitation of these aggregates is the stabilization or recycling of pavements. Furthermore, New Zealand imports crude oil and therefore its production costs for bitumen are highly dependant on international oil prices. Research has demonstrated that pavement recycling using foam bitumen reduces energy and oil consumption (Thenoux et al., 2006; Jenkins, 1994), as well as aggregate use, and therefore foam bitumen becomes an attractive alternative for road rehabilitation.

Cold in place recycling of pavements using foamed bitumen is a construction technique that reclaims the existing distressed flexible pavement, simultaneously adding stabilising agents to improve the properties of the reclaimed material. The technique recycles 100% of the existing aggregates, reducing aggregate consumption and transportation of materials in the rehabilitation of roads, and although other types of recycling techniques exist (i.e. cold-in-plant), it is considered an attractive solution to reduce the aggregate supply problem in New Zealand.

Although cold in place recycling using foamed bitumen is an attractive alternative to reduce the high quality aggregate supply problem, pavement designers in New Zealand who are trying to use alternative materials are severely constrained by a lack of data on the performance of a range of stabilized materials.

A large research project was conducted in New Zealand to study the effects of foamed bitumen (FB) stabilisation in the performance, strength and deformational characteristics of pavements. The investigation consisted of a laboratory study, in which different types of tests were conducted, and a full-scale test, in which accelerated load was applied to FB pavements.

The full-scale experiment was carried out at the Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF), further described in this paper. Six pavements were constructed using different contents of bitumen and cement. Accelerated loading was applied to the pavement structures and the pavement responses, such as surface deformation (rutting), surface deflections and strains, were periodically recorded during the execution of the test. A total number of approximately 5.710.000 equivalent standard axles (ESAs) were applied to the pavement sections. The results showed that foamed bitumen stabilization has an important effect on the performance of the pavements studied, as further detailed in this paper.

2. Materials and mix design

2.1 Aggregates

The aggregates used in the full scale testing of pavements were a blend of coarse granular soils 'H40' and sand material ('AP5'). The H40 is a crushed aggregate of 40 mm maximum size, with specific gravity of 2.69 t/m^3, maximum dry density of 2.22 t/m^3 and optimum moisture content (OMC) of 4.0%. The H40 aggregate satisfied the following requirements:

- *To be a representative aggregate used in New Zealand for road construction and to have a grading in compliance with the current TNZ M/4 specification for basecourse aggregate (TNZ 2006)*
- *The aggregate source should be located in a region of New Zealand where high-quality aggregates are not readily available for road construction.*
- *The quality of the aggregate should be moderate to poor according to the experience of road engineering practitioners. In such case, the effects of stabilisation should be more relevant than in a good quality aggregate.*

The H40 aggregate particle size distribution was not directly suitable for FB stabilisation (Figure 1) because it was too coarse according to the recommended grading for FB mixes (Asphalt Academy 2002). Therefore, the H40 particle size distribution was adjusted using an AP5 crusher dust to bring the aggregate into the recommended grading zone. A final blend of 85/15 (H40/AP5) by mass was found suitable to satisfy the grading requirements for FB stabilisation. The maximum particle size of the AP5 is 5 mm, the maximum dry density is 1.82 t/m^3, and the OMC is 9.0%. No plastic fines were found in the H40/AP5 aggregate blend using the ASTM D4318-05 standard (ASTM, 2005). The OMC of the H40/AP5 was 6.0%, determined following the New Zealand Vibrating Hammer Compaction test NZS 4402.4.1.3:1986 (NZS, 1986).

2.2 Bitumen

An 80/100 grade bitumen commonly used for FB stabilisation in New Zealand was used for the full scale testing of pavements. The characteristics of the foam were investigated using the foamed bitumen laboratory model WLB10, which has been used by many researchers and practitioners for the production of bitumen foam. The results showed that 2.5% foaming water in combination with a bitumen temperature of 170°C yields a Foam Index (NZS, 1986) of 128, which is considered a good foam quality (Asphalt Academy, 2002), and is consistent with the properties of bitumen foams produced in New Zealand (Saleh, 2004a).

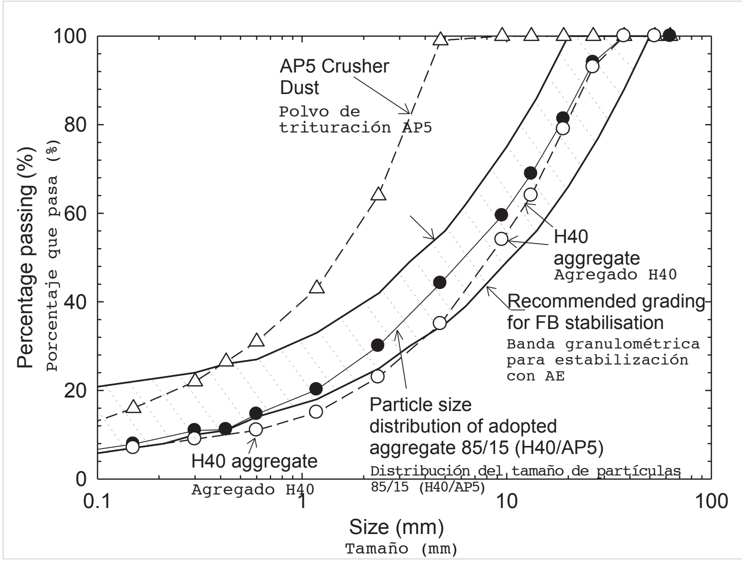

Figure 1. *Particle size distribution of H40, AP5 and H40/AP5 mix adopted for foamed bitumen stabilisation*

Figura 1. Distribución del tamaño de partículas de H40, AP5 y mezcla H40/AP5 adoptadas para estabilización con asfalto espumado

2.3 Mix design

Results from the Indirect Tensile Strength (ITS) test were used to determine the optimum foamed bitumen content. The ITS was determined in accordance with NZS 3112: Part 2:1986. The loading speed applied during the test corresponds to 50.8 mm/min. The specimens were prepared with 0%, 1%, 2%, 3% and 4% bitumen contents and a common 1% cement.

The results indicated that ITS increases when the bitumen content increases up to about 3.0%, and then from 4.0%, the ITS value decreases, showing that a large percentage of bitumen may negatively influence the tensile strength of the mix for the materials studied.

3. Full-scale study

3.1 Design and construction

Structural Design of Pavements

The structural design of pavements was carried out using the South African interim guidelines (Asphalt Academy, 2002) and the New Zealand supplement to the Austroads pavement design guidelines (Austroads, 2005). Details of the structural design are not presented in this paper, but a 200-mm basecourse combined with a relatively weak (60-80 MPa) subgrade provided a pavement structural capacity close to $1x10^6$ *ESAs of 80 kN using both the design methods.*

CAPTIF Description and Layout Design

CAPTIF is located in Christchurch, New Zealand. It consists of a 58-m long circular track contained within a 1.5-m deep and 4.0-m wide concrete tank in which the moisture content of the pavement materials can be controlled and the boundary conditions are known (Figure 2a).

A center platform carries the machinery and electronics needed to drive the system. Mounted on this platform is a sliding frame that can move horizontally by 1 m. This radial movement enables the wheel paths to be varied laterally and can be used to have the two 'vehicles' operating in independent wheel paths. At the ends of this frame, two radial arms connect to the Simulated Loading and Vehicle Emulator (SLAVE) units (Pidwerbesky, 1995).

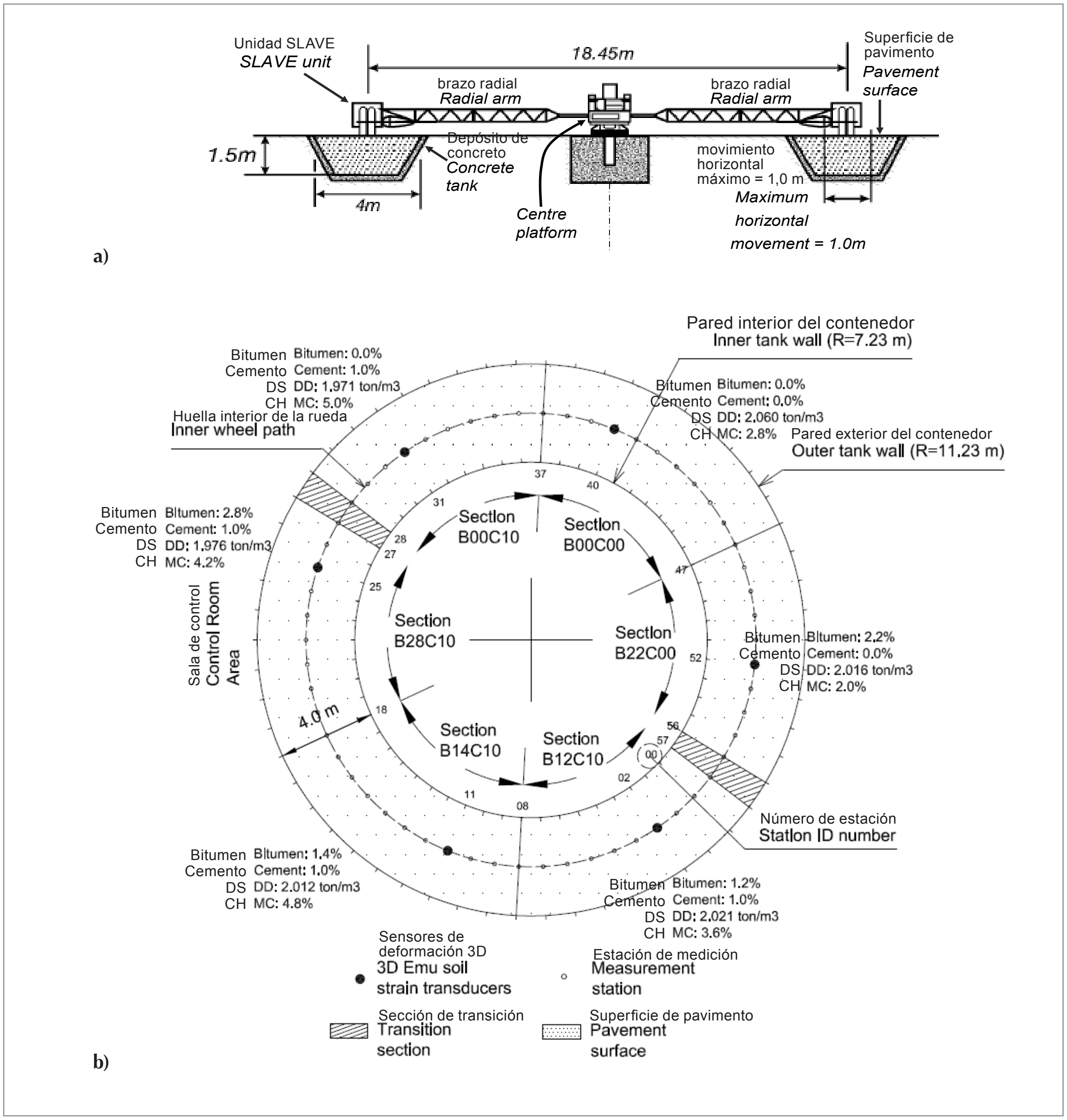

Figure 2. *CAPTIF (a) cross section; (b) Top view of the foamed bitumen test (DD = Dry Density, MC = Moisture Content), after (González et al., 2004)*

Figura 2. CAPTIF (a) Perfil; (b) Vista superior del experimento con asfalto espumado (DD = Densidad Seca, MC = Contenido de Humedad), luego de (González et al., 2004)

CAPTIF enables up to six pavement sections of about 10 m length each to be tested. Four sections were stabilised using 1% cement at different bitumen contents. One section was retained as a control with the H40 material only, and another section had FB only, to separate the effects of the FB with the cement. A top view of the pavement test track is presented in Figure 2b, in which the six pavement sections are depicted. The sections were named B12C10, B14C10, B28C10, B00C10, B00C00 and B22C00, where the first two digits (after B) indicate the bitumen content, and the last two (after C) indicate the cement content. For instance, section B14C10 was built adding 1.4% of FB and 1.0% cement. Section B28C10 had approximately the 'optimum' FB content determined from ITS test.

Materials and Construction

Subgrade

The top 525 mm of the subgrade was clay, extended in lifts of 225, 150 and 150 mm, and compacted using a roller available at CAPTIF. Back-calculation analysis using FWD data yields a subgrade stiffness of 60 MPa approximately, which is in agreement with the target stiffness from the structural design of pavements.

Stabilisation process

Details of the stabilisation process can be found in (González et al., 2004). Two hundred tonnes of H40 crushed aggregates were transported to CAPTIF. For the stabilisation process, trenches were excavated outside the CAPTIF building. Layers of H40 crushed aggregate material and AP5 were laid and compacted to 95% of maximum dry density at their optimum moisture contents so that the target mass ratio of 85/15 obtained in the laboratory mix design was achieved in the field. Once the untreated material was ready the trenches were stabilised with the recycling machine. The stabilised material was transported into the CAPTIF building by loaders. A paver was used to place the basecourse material and a steel roller was used for compaction. Before laying the final surface layer, the sections were cured at ambient temperature for 30 days.

Surface layers

All sections were sealed with a single coat chipseal. After a week to allow the chipseal to set up, all sections were surfaced with a skim coat of AC10 hot mix covering the top of the chipseal. The approximate thickness of this surface was 20 mm. Before the sealing, density and moisture measurements were taken using a nuclear gauge directly over the basecourse. Dry densities and moisture contents are included in Figure 2b.

During the execution of the experiment and after the application of 200.000 load cycles, the original thin surface started to show wear. A thin hot mix asphalt (HMA) layer of 30 mm was laid over the original surface, leading to a total surface thickness of approximately 50 mm for the rest of the project.

Instrumentation

The pavement instrumentation at CAPTIF includes 3D Emu (Dawson, 1994) soil strain transducers to measure the vertical, transverse and longitudinal strains in the pavement. Details of the strain measurements collected during this project can be found in González. The final cross section adopted in all pavement sections is shown in Figure 3.

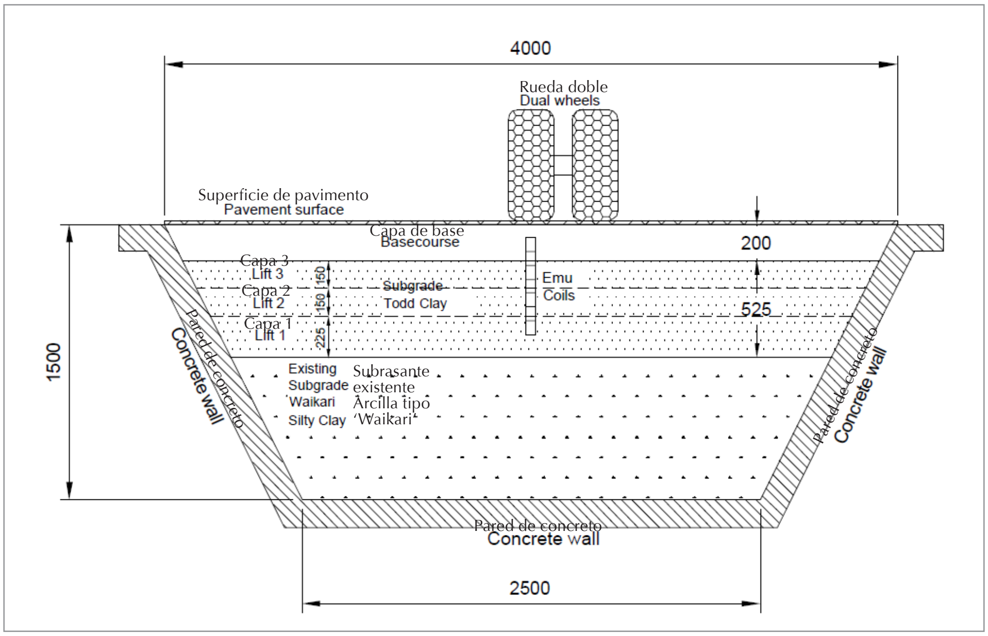

Figure 3. *Cross section of the pavements tested at CAPTIF*

Figura 3. Perfil de los pavimentos ensayados en CAPTIF

3.2 Experimental procedure

Loading sequence and speed

The load was a dual truck tire with a separation of 350 mm between the centers of the tires inflated to 700 kPa. The original project intended that a constant loading of 40 kN would be applied for each SLAVE unit. However, since little rutting was measured during the early stages of the project, the load was increased to 50 kN after 100,000 load cycles and again to 60 kN after 300.000 load cycles.

The speed of the vehicles was kept constant at 40 km/h during most of the project. The load was applied on one wheel path with a lateral wandering of 100 mm.

3.3 Analysis of pavement performance

Deflection tests

FWD deflections with a 40 kN load are presented in Figure 4. The results correspond to deflections measured before the trafficking of the sections (0 load cycles) and after $1x10^6$ load cycles. At $2x10^5$ load cycles the thin surface layer was overlaid with 30 mm of HMA. The unbound section (B00C00) shows considerably higher deflections in comparison with the other sections. Both cement and bitumen have an important effect in reducing the deflections of the pavements studied, as shown by the lowest deflection recorded in the section at the highest bitumen content and 1% cement (B28C10).

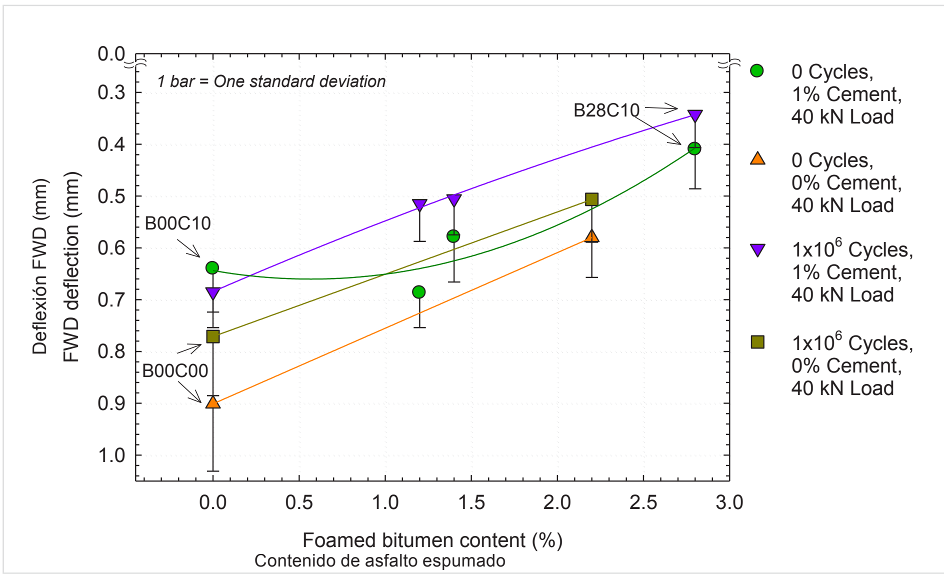

***Figure 4.** FWD deflections at 40 kN before trafficking (0 load cycles) and after $1x10^6$ load cycles*

Figura 4. Deflexiones FWD a 40 kN antes del trafico (0 ciclos de carga) y después de $1x10^6$ ciclos de carga

Average Rutting

The averaged rutting measurements for each pavement section are presented in Figure 5. The curves presented show the typical performance of pavements with a bedding-in phase during the initial vehicle loading, followed by a plateau phase. When the load was increased to 50 kN another increase in the rutting rate was observed. From 300,000 load cycles (after constructing the HMA overlay) the rutting increased approximately linearly up to 1.000.000 load cycles for all sections.

After 1.000.000 load cycles, sections B00C10, B00C00 and B22C00 started to show large amounts of heaving and rutting, while sections B12C10, B14C10 and B28C10 performed well, and little difference among them was observed. The pavement test results presented indicate that stabilisation using FB and cement improved the performance of the pavements. The rutting of sections B12C10, B14C10 and B28C10 was consistently lower than in the other three sections.

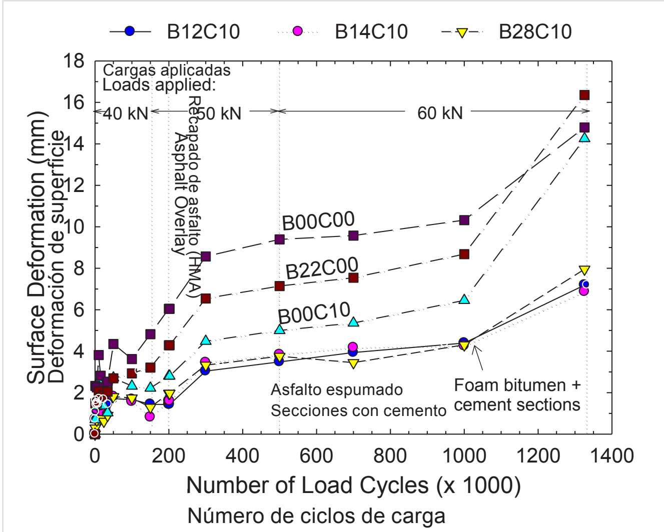

Figure 5. *Average rutting*

Figura 5. Ahuellamiento Promedio

By the end of the test little difference was found in the rutting measurements of sections stabilized with foam bitumen and cement (sections B12C10, B14C10 and B28C10). To accelerate the surface deformation in these sections it was decided to cut part of the pavement sections down from the HMA surface to the top of the basecourse (50 mm-deep cuts). The cuts were 200 mm apart, and the surface was sawed from stations 3 to 6 in section B12C10, from 14 to 17 in section B14C10, and from 20 to 23 in section B28C10. Once the cutting job was finished, water was uniformly applied over the surface. With a constant water flow, an additional 60 kN load cycles were applied. The load induced further deformation and surface cracking in the pavement sections. Nevertheless, the water penetrated into the subgrade causing swelling of this layer and modifying the final levels of the pavement structure. After the application of an additional 42,000 load cycles under wet conditions, Section B12C10 started to show extensive cracking and further surface deformation in comparison with the other two sections, with evidence of some loss of fines (Figure 6). Conversely, no cracking was observed in sections B14C10 and B28C10.

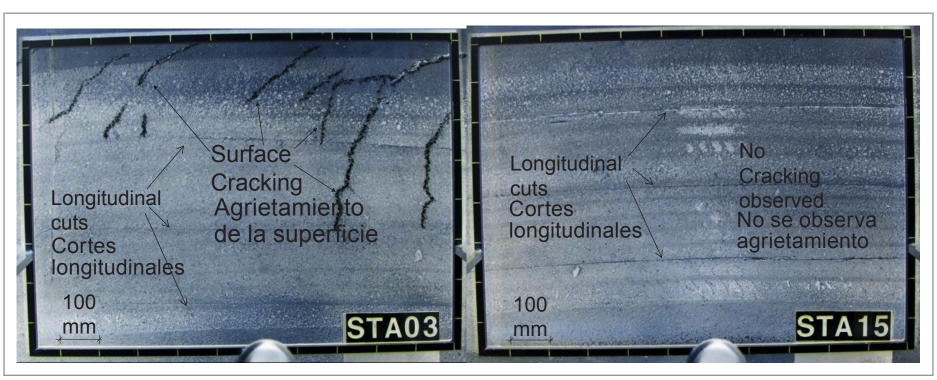

Figure 6. *Photo of pavement section B12C10 (left) and B14C10 (right)*

Figura 6. Foto de la sección de pavimento B12C10 (izquierda) y B14C10 (derecha)

Vertical surface deformation contour plots

Transverse surface profiles at each of the 58 pavement stations were taken at several stages of the project. The profiles were used to calculate the vertical surface deformation (VSD) by subtracting the original elevation of each transverse profile (before loading) minus the current transverse profile. The VSD was then used to build contour plots of each pavement section. The VSD data used for the contour plots was taken from transverse location from 1500 mm to 2300 mm, being 1900 mm the location of the centre of the wheel paths. The stations next to the transition zones (area between two pavement sections) were not used to build the contour plot. Figure 7 shows the contour plot for sections B28C10 and B00C10 after 500,000 load cycles. The figure shows that, as expected, higher VSDs are measured under the wheel paths. In addition, the figure shows the better performance of section B28C10 compared to B00C10.

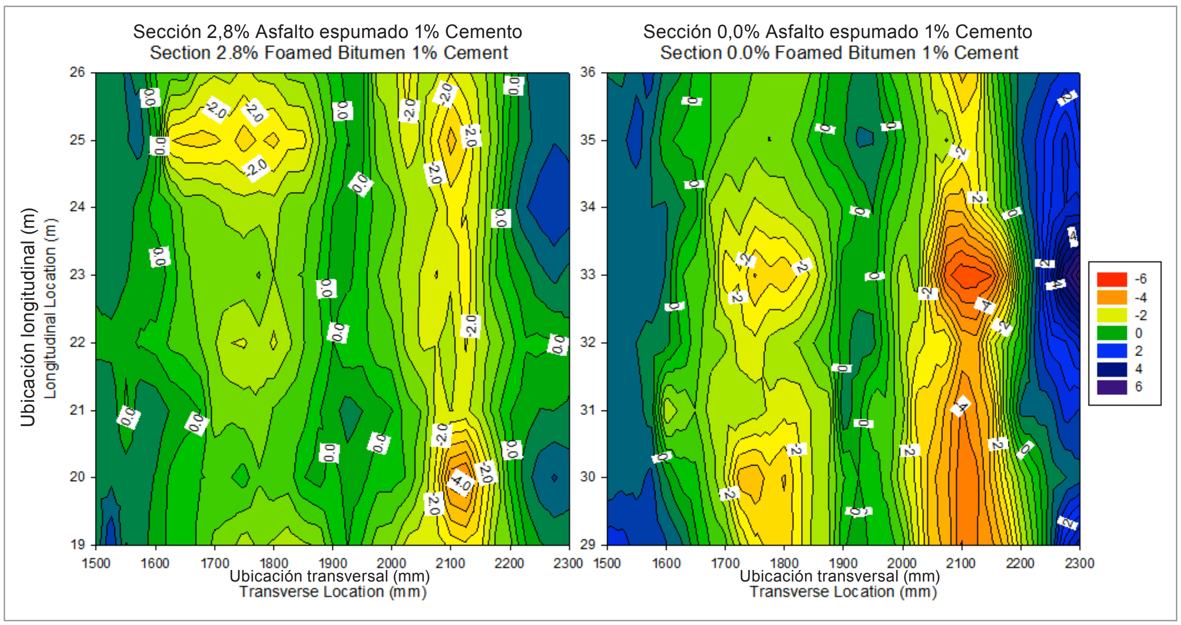

Figure 7. *Vertical surface deformation contour plots of sections B28C10 (left) and B00C10 (right) after 500,000 load cycles*

Figura 7. Deformación vertical de la superficie; trazados de curvas de secciones B28C10 (izquierda) y B00C10 (derecha) después de 500.000 ciclos de carga

Rutting modeling of stable and unstable behavior

Huurman (1997), proposed a four parameters model (Equation 1) to describe the permanent strain development in unbound granular pavements under traffic. The model was adapted to describe the rutting development instead of the permanent strain. The four parameters model has the following form:

$$\text{Ahuellamiento}/\textit{Rutting} = A*\left(\frac{N}{1000}\right)^{B} + C\left(e^{D\times\frac{N}{1000}} - 1\right) \qquad \textbf{(1)}$$

Where Rutting is expressed in mm, N is the number of equivalent standard axles of 80 kN and A, B, C and D are the model parameters. The first term of the model describes the linear increase of rutting with N on a log(Rutting)–log (N) scale. The second term of the model describes the unstable behavior observed after 1,000,000 load cycles that cannot be described by the first term alone, because an exponential instead of a linear increase of rutting with N on the same log (Rutting) – log (N) scales is observed. The vehicle loads of 40 kN, 50 kN and 60 kN applied during the experiment were converted to Equivalent Standard Axles (ESAs) of 80 kN assuming a fourth power law. The model was fitted to the rutting measured at $3x10^5$ load cycles ($5.16x10^5$ ESAs), $5x10^5$ load cycles ($1.528x10^6$ ESAs), $7x10^5$ load cycles ($2.541x10^6$ ESAs), $1x10^6$ load cycles ($4.059x10^6$ ESAs) and $1.326x10^6$ load cycles ($5.710x10^6$ ESAs). For the model fitting the root mean square (RMS) was used:

$$RMS = \left(\sqrt{\frac{1}{n} \times \sum_{i=1}^{n} \left(\frac{d_c - d_{mi}}{d_{mi}} \right)^2} \right) \times 100 \quad \textbf{(2)}$$

Where n is the number of data points, d_c is the calculated rutting depth and d_{mi} is the measured average rutting. The parameters A, B, C and D were modified using an optimization tool so that the RMS was minimized. Results of the model fitting are shown in Table 1 (top).

Table 1. *Results of model fitting*
Tabla 1. Resultados del ajuste del modelo

	4 parameters rutting model/ **4 parámetros del modelo de ahuellamiento**					
	B12C10	**B14C10**	**B28C10**	**B00C10**	**B00C00**	**B22C00**
A	3.4	3.7	3.7	4.8	9.0	6.8
B	0.17	0.11	0.08	0.17	0.09	0.14
C	$5.0x10^{-5}$	$5.0x10^{-5}$	$5.0x10^{-5}$	$5.0x10^{-5}$	$5.0x10^{-5}$	$5.0x10^{-5}$
D	1.90	1.88	1.95	2.10	1.99	2.10
RMS	3.1%	1.9%	6.2%	3.8%	1.7%	2.9%
	2 parameters rutting model/ **2 parámetros del modelo de ahuellamiento**					
	B12C10	**B14C10**	**B28C10**	**B00C10**	**B00C00**	**B22C00**
A	3.4	3.7	3.7	4.8	9.0	6.8
B	0.17	0.11	0.08	0.17	0.09	0.14
RMS	2.7%	1.3%	8.5%	4.6%	1.4%	3.8%

Rutting Modeling of Stable Behavior

In the last phase of the experiment a relatively high load of 60 kN was applied. This load level was applied to accelerate the damage of the pavements and to see a clearer difference in the performance of the pavement sections.

Since the 60 kN exceeds the legal limit and could have caused the observed accelerated deterioration of the pavement sections at the end of the test, the same Huurman (1997), model with the first term only was used to describe the stable phase of the rutting (i.e. up to 1x10⁶ load cycles). The model fitting of the two-parameter model is shown in Table 1 (bottom).

The two-parameter equations were used to extrapolate the rutting measurements up to 25x10⁶ ESAs assuming that pavements will perform in a stable condition within this number of load cycles. Results of the two- parameter modeling were used to extrapolate the observed measurements assuming stable behaviour of the pavement sections. The extrapolation (Figure 8) shows that sections B28C10 and B14C10 would have the lowest rutting while section B12C10 would show the highest rutting among the sections stabilised with foamed bitumen plus 1% cement, which is consistent with the performance observed when water was introduced in these pavement sections.

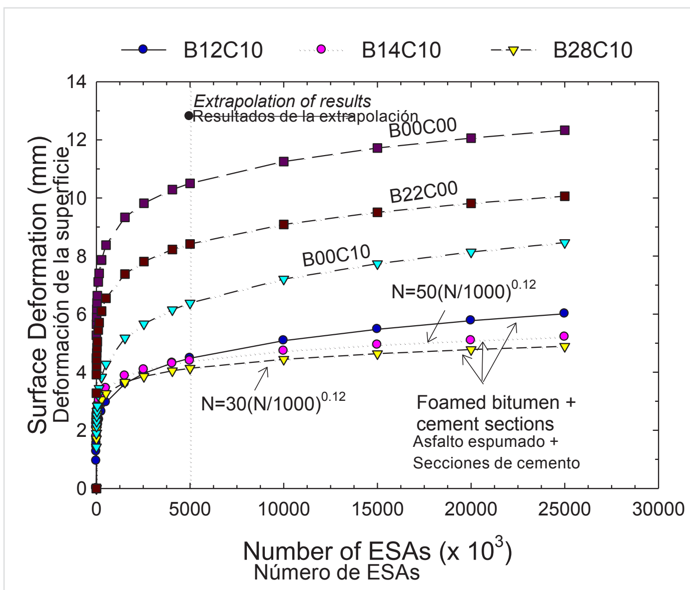

Figure 8. *Extrapolation of rutting measurements using the two-parameter model up to 25x10⁶ ESAs*
Figura 8. Extrapolación de las mediciones de ahuellamiento usando el modelo con dos parámetros hasta 25x10⁶ ESAs.

4. Conclusions

A full-scale accelerated testing on foamed bitumen pavements was presented in this paper. Results from the full-scale study lead to the following findings:

- *The rutting measured in the sections with foamed bitumen plus 1% cement was the lowest, showing that the addition of foamed bitumen significantly improved the performance of the pavements.*

- *The sections B00C10 and B22C00 and the control untreated section (B00C00) showed large amounts of rutting and heaving.*

- *The deflections of section B28C10 were lower than those of the other sections, while the untreated section (B00C00) showed the largest values.*
- *To differentiate the rutting performance of the sections stabilized with foam bitumen and cement, water was introduced through surface cuts. After the application of additional accelerated traffic load, section B12C10 started to show surface cracking, while sections B14C10 and B28C10 performed well.*
- *Two types of models were fitted to the rutting measurements. The first model described the stable and unstable rutting of the pavement sections while second model only considered the stable phase in where a steady increase in rutting with the number of cycles is observed.*
- *The developed models and the better understanding of the performance of foamed bitumen pavements leads to more accurate programming of treatments or maintenance of pavements.*

5. Acknowledgments

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