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Real-scale study of a heavy traffic road built with in situ recycled demolition waste

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Abstract

This real-scale study carries out a research of the behaviour of building demolition wastes in a road with high intensity traffic. A mobile recycling plant treated in situ the demolition wastes from 105 single-family homes. Recycled aggregates were made from two different sources: one aggregate came from concrete taken out of slabs and foundations (recycled concrete aggregate) and the second aggregate came from the remaining reinforced concrete structures, walls and roofs (recycled mixed aggregate). Both recycled materials and a crushed stone formed the granular base and subbase of the experimental paved section. A leaching test analysed the potential pollutant emissions of the recycled aggregates. Different tests were performed during construction of the experimental section, such as densities, loading plates and falling weight deflectometry. This research evaluated deflections and surface roughness for a period of seven years to study the behaviour of these recycled materials long term. The recycled aggregates used did not satisfy all the stipulations of the Spanish standards for granular material as road subbases/bases, such as size distribution, Los Angeles test limit, soluble salt and organic matter content in subbases. Despite this lack of compliance, the results of on-site tests over time compared the mixed recycled aggregate as subbase and the recycled concrete aggregate as the base with natural aggregates; the recycled aggregates presented a better structural behaviour and less surface deterioration than natural aggregates under a mean daily heavy vehicle flow of 371 vehicles per lane and an average daily traffic of 4469 vehicles per lane on average. The article includes the calculation of moduli through forward and back calculations for the recycled aggregates, which is a key aspect in pavement design The bearing capacity of recycled materials increased with time in the structural layer, which is unlike the trend in bearing capacity of the natural aggregates.

Keywords:

Experimental section; back calculation modulus; recycled aggregates; mobile recycling plant; surface roughness; deflections.

Acronyms:

EU – European Union; CDW - Construction Demolition Waste; RA - Recycled Aggregates; NA – Natural Aggregates; RMA – Recycled Mixed Aggregates; RCA – Recycled Concrete Aggregates; PG3 – Spanish general technical specification for road construction; Mixed Recycled Soil (MRS); Recycled Mixed Screening Wastes (RMSW); ES – Experimental Section; IRI (International Roughness Index); CS-1 – Crushed Limestone; AASHTO - American Association of State Highway and Transportation Officials; - ICP-MS - Inductively Coupled Plasma Mass Spectrometry; FWD – Falling Weight Deflectometer; LP – Laser Profiler; RL – Right Lane; LL – Left Lane; SPT – Standard Proctor Test; CBR – California Bearing Ratio; SG-1 – Subgrade; MPT – Modified Proctor Test; M –Mean; SD – Standard Deviation

1 Introduction

World aggregate production came from 21 billion tons in 2007 to 40 billion tons in 2014 (Tam et al., 2018). Natural aggregate extraction harms the environment, and the mineral resource depletion and waste generated per cubic metre of natural aggregate obtained were over 2400 kg and 2500 kg, respectively (Marinković et al., 2010). Total aggregate production on the European Union (EU) was 2660 million tons, and the total waste generation from construction was 868 million tons in 2014 (European Union, 2017). According to the Waste Framework Directive (2008/98/EC) of the European Union and the EU Parliament, by 2020, a minimum of 70% of construction and demolition wastes (CDW) should be recovered (European Parliament and Council of the European Union, 2008). There are countries where the percentage of recovery, including backfilling operations, reached 70% in 2014; these countries included

Belgium 91.8%, Germany 80.8% and Denmark 78.3% (European Union, 2017). However, there were several countries that did not meet this objective in 2014 (European Union, 2017). In these countries with low recovery rates, the main destination of CDW is the landfills. In 2014, in Spain, 5 million of tons were backfilled, and 6 million tons were recycled into various outlets from 20 million tons of CDW, while 9 million tons were landfilled (Waste statistics Statistics Explained, 2019).

Recycled aggregates (RA) production can play an important role in this objective because it can help to reduce the production of natural aggregates (NA) and avoid CDW from filling lands. According to the European National Aggregates Association, Spain produced 96 million tons of NA in 2015, while only one million tons of RA were produced and sold in commercial plants (European Aggregates Association, 2016) from the 20 million tons of CDW. Recycled mixed aggregates (RMA) and recycled concrete aggregates (RCA) production were 80% and 12%, respectively, of the total amount of CDW generated in Spain (CEDEX, 2010). The substitution of NA by RMA and RCA in road construction as unbound material layers is a plausible solution to meet the 70% recovery rate for CDW (European Parliament and Council of the European Union, 2008).

RA must cover longer distances to the recycling plant, whereas there is little to no transport from the quarry to the processing plant for NA; therefore, according to Bostanci et al. (2018), the processing of RA generates 51% higher CO_2 emissions than NA. This fact can be compensated for if NA need to cover a longer distance to the site or if mobile recycling plants are used. According to Rossi and Sales (2014) consumption of diesel was 3.4 km/L for a truck carrying 14-15 tons; when NA have an additional distance of 20 km, CO_2 emissions exceed the emissions that are generated by RA, according to Marinković et al. (2010).

Another way to reduce CO_2 emissions during RA production is with the use of mobile recycling plants, since transportation distances are shorter than stationary plants (Silva et al., 2016). The cost of mobile plants is less than that of stationary plants when the distance of transport is higher than 2.6 km (Zhao et al., 2010).

The viability of RMA and RCA in road construction was previously researched in laboratories, such as Poon et al. (2006), Poon and Chan (2006) and Vegas et al. (2011). Bassani et al. (2019) proved in a laboratory study that an alkali-activating solution mixed with CDW obtained a more suitable option than the RA that were stabilized with cement in other previous studies, such as those by del Rey et al. (2016), Bassani et al.

(2017) and Kien (2013), or through the construction of experimental road sections of low traffic intensity by researchers, such as Jiménez et al. (2012a), Jiménez et al. (2012b), Pérez et al. (2013), del Rey et al. (2016) and Tavira et al. (2018a, 2018b). Most of these studies, with the exception of Tavira et al. (2018a) and Lancieri et al. (2006), show short-term results and conclusions. All RA tested in these works came from stationary plants.

For eight years, Lancieri et al. (2006) studied two paved road sections that were 200 metres long and used RMA used as unbound base layers. An elastic modulus of RMA showed increments due to the low voids percentage in the asphalt layers that prevented incoming moisture and the cement hydration of the RMA fine fraction. Laboratory tests conducted with a gyratory compactor showed that small variations in the dry density induced significant increments in the California bearing ratio (CBR).

Jiménez et al. (2012a) investigate a rural road with no asphalt layers, it had two different sections with a hundred metres each; the materials that were used were obtained from selected CDW, as the surface course RCA and NA were used and, as a base course, RMA extended in both sections were used as the granular base. These authors concluded that during a period of two years open to traffic the bearing capacity of both sections kept steady and was slightly higher in sections built with RCA. The surface roughness was similar in both sections after construction, although in sections constructed with NA smoothness dropped more quickly. According to this research content limit of soluble salt in RA might be raised to 1.3% having no affection on the performance of the road layers. Jiménez et al. (2012b) studied two unpaved sections of 100 metres each; RMA or NA were used as surface courses on the different sections, natural soils formed the underneath layers. The RMA used had sulphur compounds and soluble salts contents higher than those values specified by the road construction Spanish standards (PG3). Both sections showed that the bearing capacity was slightly lower in the section built using RMA, although both sections presented acceptable structural performance. The Young modulus values increased by 27% after 3 years of traffic flow in the section built with RMA and decreased by 23% in the NA section. The surface roughness had more irregularities in the section built using RMA. This study concluded that the technical specification limits for the total sulphur compound and soluble salts can move up to a 6% and 3.3%, respectively, for this type of unpaved agrarian road. Tavira et al. (2018b) studied an experimental three section paved road, of which each section was 150 metres long. NA were used in bases and subbases in the first section; section three was built with mixed recycled soil (MRS) in the subbases and an RMA mixed with excavation soil; the second section had NA in the granular base and MRS in the subbase. The Los Angeles abrasion test and sand equivalent percentage of the RMA did not meet the limits of the Spanish standards, and RMAS and MRS showed average moduli of 349 MPa and 158 MPa, respectively, which proved that for low volume traffic roads, these limits should be modified.

Tavira et al. (2018a) studied three experimental sections of a paved bike lane made with recycled mixed screening wastes (RMSW). Moduli evolution of RMA and NA were obtained and compared, and the RA had high organic matter content (2%), a high Los Angeles abrasion test (40%) and low sand equivalent content (27%) compared with the limits allowed by PG3. RA showed their suitability as unbound layers instead of NA in these previous cases.

This study is a long-time performance study of an experimental road that was built with RA from remove of the 105 dwellings. The demolition of the houses was caused by the work on the extension of the runway of the airport of Córdoba (Spain). This paper includes three novel aspects: i) the in situ recycling of RMA and RCA obtained with a mobile plant used as the unbound layers; ii) the construction of an experimental heavy traffic road classified as T2 according with the Spanish standard (799-200 heavy vehicles/day per lane); and iii) a long-term study – 7 years – of structural and functional parameters, such as deflections and the International Roughness Index (IRI), which made it possible to evaluate recycled materials under traffic and weather conditions. The favourable results obtained in this experimental section are a key aspect to increase the recycling rate of CDWs in Mediterranean countries, such as Spain, and to meet the objectives set by the European Directive for 2020.

No previous studies were found related with the use of RMA and RCA made with a mobile plant as unbound layers in an experimental road with heavy traffic for such a long period of time.

2 Materials and methods

2.1 Airport enlargement works and demolition waste treatment

As a consequence of the enlargement of the runway of the airport of Córdoba (Spain), a total of 105 single-family houses had to be expropriated and demolished in 2009. Fig. 1 shows two aerial photographs of Cordoba´s airport runaway in the year 2009, before the enlargement construction (Fig. 1-a) and after the enlargement works in the year 2017 (Fig. 1-b).

Fig. 2 shows the type of single family homes and the machinery that was used in its demolition. Construction of these homes dates from the decade of the nineties. The building process is quite similar in all dwellings; reinforced concrete was the material used in structures and foundations, and the homes had shallow foundations composed of a slab over footings. Beams and columns formed the structure, and one-way spanning slabs made with concrete or ceramic composed the floors and roofs. External enclosures were made of bricks or concrete blocks plastered with coloured cement mortar. Brick tiles topped the roofs. Bricks with plastered gypsum formed the interior walls. These constructions also used ceramic tiles and plasterboards on the walls and floors.

To avoid landfilling the demolition waste from those houses, the debris was recycled in situ with a mobile plant. Because of the shorter travel distances, the economic and environmental costs and the CO_2 emissions were reduced.

The process began with a selective demolition. Workers manually removed doors, window frames, glass and gypsum plasterboard. As shown in Fig. 2, the demolition efforts were conducted with an excavator equipped with a crushing jaw; when the concrete was reinforced, the steel was removed.

A mobile jaw crusher plant Parker model 1165 (Fig. 3) was used to crush the demolition waste, and all the material passed through the 40 mm sieve.

The CDW of foundations and rigid pavements were processed separately to obtain a recycled concrete aggregate (RCA-1). CDW from walls, structures and roofs were processed by obtaining recycled mixed aggregates (RMA-1). CH-2 Road was constructed as an experimental section (Fig. 1).

2.2 Description of test sections

The ES has two sections of 180 m and 170 m. The total width of the road is 8 m; it has two 3.50 m lanes and a 1.00 m shoulder. Fig. 4 shows thickness and composition of the layers of the road. Two hot mix asphalt layers were set in the road; the wearing course was made of 4 cm asphalt concrete with an upper sieve size of 16 mm surface course type S according to article 542 of the PG3 (Ministry of Development, 2004), and the binder course was 6 cm asphalt concrete with an upper sieve size of 22 mm. The base course was type S according to article 542 of PG3 (Ministry of Development, 2004). The base course of section I was built with a crushed Siliceous rock (CS-1), an RCA-1 was used in section II, both granular layers were identified as A1a according to the

American Association of State Highway and Transportation Officials (AASHTO) (AASHTO, 2008). The subbase course was built with RMA-1 with a thickness of one metre for both sections, and it was catalogued as A1a according to AASHTO (AASHTO, 2008). The subgrade that was present in the ES is a clayey soil that would be classified as A6 (AASHTO, 2008). The construction of the ES started in February of 2010 and ended in May of 2010.

2.3 Materials identification.

UNE-EN 932-1 (AENOR, 2018) were followed to collect the samples of the granular materials employed in the ES.

2.4 Compliance test for leaching of granular waste materials

Both materials, RCA-1 and RMA-1, were tested according to UNE-EN 12457-3:2004 (Spanish Association for Standardisation-UNE, 2003) to be classified according to the Landfill Directive (Council of the European Union and 2003/33/EC, 2003) as inert, non-hazardous or hazardous materials. A total of five samples were studied for RCA-1 (C-1 and C-2) and RMA-1 (M-1, M-2 and M-3). There are two steps in this test. To start, the solution with a liquid-to-solid ratio of 2 was agitated during a total time of 6 $\pm$ 0.5 h. In the second step, a liquid-to-solid ratio of 10 was needed, therefore extra water was poured and then stirring continued for an additional 18 $\pm$ 0.5 h. The mixed was passed through a filter (0.45 µm) and an operating a spectrometer PerkinElmer (PerkinElmer Inc., MA, USA) evaluated the solutions by inductively coupled plasma mass spectrometry (ICP-MS).

2.5 On-site tests of the ES

2.5.1 Control of densities and moisture of granular layers

At the end of compaction of each unbound layer, a nuclear density equipment following ASTM D6938 (ASTM, 2015) determined field densities and moisture content. The distance between each test was 25 m. These tests determined the percentage of compaction of the granular layers.

2.5.2 Static plate bearing tests

On each of the two sections and on the two unbound layers two plate stations were conducted therefore eight tests were accomplished during the construction of the ES (May 2010). Spanish standard UNE 103808:2006 (AENOR, 2006) was followed.

2.5.3 Dynamic plate bearing tests

A Dynatest Falling weight deflectometer (FWD) 8012 (Dynatest Denmark A/S, Glostrup, Denmark) equipped with seven geophones measured the deflections and basins (Fig. 5-a). The geophones were displayed as in previous experimental study (Tavira et al., 2018a).

Every ten metres along the ES deflections were measured following the ASTM D4694 (ASTM, 2009). The Spanish standard (Ministry of Development, 2003a) does not correct deflections as in this case because the asphalt concrete is not thicker than 10 cm. The FWD tested every layer set on the ES during construction and at the end of the works (June 2010). On September 2011, June 2014 and April 2017, the deflections were controlled. FWD represents the effect of moving loads in a very precise way. FWD allows several times of testing along the road in a short time. FWD can detect deep failures in the pavement structure.

To obtain the dynamic moduli, the following equation proposed by Brown (Brown, 1996), it can be found in the preceding research (Tavira et al., 2018a). In the complete section a 0.35 Poisson ratio was adopted (Huang, 1993; Public Works Agency of Andalusia, 2007).

2.5.4 Road regularity measurement

The life of the roads is intimated ligated to its conservation and is determined by the smoothness of its profile. The International Roughness Index (IRI) (Sayers et al., 1986) is the most accepted parameter to determine the profile condition of the road. Road profiler followed standard ASTM E867-06:2012 (ASTM, 2012). Laser profiler (LP) RSP MARK-IV device (Dynatest Denmark A/S, Glostrup, Denmark) (Fig. 5b) measured IRI during a period of seven years from 2010 until 2017; the right lane (RL) and left lane (LL) of the two sections were measured. This device was used in a preceding investigation of Jiménez et al. (2012[a]) and Jiménez et al. (2012b). Five IRI evaluations of the ER were completed (years 2010, 2011, 2014, 2016 and 2017).

2.6 Moduli Backcalculation

Evercalc (WASDOT, WA, USA) (Washington State Department of Transportation, 2005) was the software used for calculating moduli. Using a recursive process, this software reproduce mechanical performance under falling weight deflectometer loading, obtaining moduli of the layers that form the pavement structure. This process was previously described by Tavira et al. (2018b). The process compares the deformations obtained on field with the theoretical deflections calculated, in the first step, it uses a root moduli for each layer. Convergence is met when the difference of surface deflection is close to a 2% difference (Washington State Department of Transportation, 2005). Tarefder and Ahmed (2013) showed that Backfaa and Modulus software produced less precise modulus values than those of Evercalc.

2.7 Climatic records

Roads are deeply affected by moisture and temperature. A weather station close to the ES measured rain and temperature data; it was located in the Cordoba´s Airport with UTM coordinates (337196, 4189963).

Fig. 6 displays the mean extreme temperatures and rainfall from 2010 to 2017. The months of June, July and August had an average precipitation under 30 mm. Pavement tests were used to study the evolution that took place during dry periods.

2.8 Automatic traffic counting

A station type TraficompIII (Streeter Richardson, Mangood Corporation, IL, USA) equipped with two pneumatic tubes was set on the kilometre point 0+225 of the Road CH-2. The electronic counters can classify vehicles attending to their standard axle-pattern. The station measured traffic for a week during the month of October for the years 2011, 2013 and 2016. As shown in Table 1, the mean value of daily heavy vehicles was 381 (RL) - 361 (LL) vehicles per day with an average daily traffic flow of 8937 vehicles, according to the Spanish standard (Ministry of Development, 2003b). Both lanes would be classified as a T2 (200 – 799 heavy vehicles/day).

2.9 Statistical analysis

Analyses of variance (ANOVA) were carried out with the statistical software Statgraphics Centurion XVI (Version 16.1.18, StatPoint Technologies, Inc., Warrenton, VA, USA). The F-test in the ANOVA determine the influence of each factor on the results. The non-overlapping bars indicates that there was no influence on the factor levels studied.

3 Results and discussion

3.1 Composition of the recycled aggregates

Basis elements of the RA were studied following UNE-EN 933-11 (AENOR, 2009), Table 2 displays its composition. RMA-1 and RCA-1 had high contents of concrete and unbound aggregates at 88 and 97%, respectively. According to Jiménez (2013), RMA-1 can be categorized as recycled mixed aggregates because its ceramic content is over

10%, and RCA-1 would be classified as recycled concrete aggregates. Ceramic particles were detected in both RA, 3.1% in RCA-1 and 11.3% in RMA-1, whereas gypsum contents were negligible (0.1%).

3.2 Material characterizations

The subgrade, subbase and base material were tested according to Spanish Standards UNE (AENOR, 2018), and Table 3 displays physical and chemical properties of the different materials employed as unbound layers and the PG-3 limits for their classification. Additionally, to know the material behaviour, the following tests were carried out: the standard proctor test (SPT), CBR, free swelling in odometer device and collapse.

Fig. 7 shows the particle size distribution curves. SG-1 had a passing fraction of 66.50% over the 0.063 mm sieve. RCA-1 is a coarse material, as shown in Fig. 7, and less than 10% passes the 4 mm sieve. RCA-1 did not meet the particle size distribution limits prescribed for NA as base layers in article 510 of the PG3 (Ministry of Development, 2004), RA were over the fine limit and maximum size, and both materials were classified as selected soils according to article 330 of the PG3 (Ministry of Development, 2004) and could only be used as granular subbases. On the other hand, CS-1 meets these limits, and it was classified as a base layer according to article 510 of PG3 (Ministry of Development, 2004). RA were less uniform in their gradation than NA.

SG-1 would be classified as a tolerable soil according to PG-3 (Ministry of Development, 2004) and as A6 according to AASHTO (2008). Subgrades of previous experimental sections had similar particle size distributions and CBR, according to Tavira et al. (2018a) and Tavira et al. (2018b), and were classified as tolerable soil and marginal soil, respectively.

The materials used in the ES were non-plastic and had no swelling, with the exception of SG-1, which had a very low shrinkage potential. CS-1 fulfilled the requirements of article 510 of PG3 (Ministry of Development, 2004). The densities of recycled materials were lower and the optimum moisture was higher than those obtained in CS-1, which can be explained because of the higher porosity of RA caused by the presence of ceramics and cement mortar; this finding is concordant with the preceding studies of RA (del Rey et al., 2016; Jiménez et al., 2012a; Tavira et al., 2018a, 2018b). RA and RCA-1 did not meet the limit prescribed for abrasion by the PG3 of 30% for T2 traffic. CBR in RMA-1 and RCA-1 was higher than in CS-1. Table 3 showed that RMA-1 manifested stiffer CBR than those presented in other researches (del Rey et al., 2016; Jiménez et al., 2012a, 2012b; Tavira et al., 2018a, 2018b). Past researches abrasion is not expected to surpass a 44% in RMA (Jiménez, 2013; Lancieri et al., 2006). Regarding the chemical properties, PG3 limits for organic matter and soluble salts are surpass. Past researches (Jiménez et al., 2012a; Jiménez et al., 2012b; Jiménez, 2013) proved that soluble salt content over 3.9% does not represent expansive behaviour. Jiménez (2013) stated that organic content in unbound layers can rise to one percent.

3.3 Results of the compliance test

The Landfill Directive 2003/33/EC regulates the limit values for leachate concentrations, and it was used for the comparison of heavy metals, since the anion data were not available. The results of the five samples that were analysed are shown in Table 4. The C-1 and C-2 samples came from RCA, and M1, M2 and M3 came from RMA. The samples extracted from the RCA-1 material comply with the inert limits (IL), and the RMA-1 samples comply with the IL. The only element that was detected in a concentration such that it should not be considered as inert was chromium (Cr) in the samples M2 and M3. Thus, analysing the values that were obtained for the fraction L/S = 10, which was the most unfavourable of the two studied, a Cr concentration of 0.825 mg/kg was obtained for M2 and 0.549 mg/kg was obtained for M3, which classify these samples as non-hazardous. A previous study detected high levels of Cr in RA (del Rey et al., 2015). Therefore, all RCA-1 and RMA-1 samples meet the requirements of being classified as non-hazardous; their use as unbound layers in roads do not represent a risk to the environment.

3.4 Quality control of the on-site works

The aspect that influenced most on the layer stiffness of an unbound material is the compaction obtained (Molenaar and van Niekerk, 2002). Tests of moisture took place on each granular layer. SPT was used on the subgrade, the MPT was used on bases and subbases. As stayed on the PG-3 (Ministry of Development, 2004) degree of compaction has to be over 95% in subbases and 98% in base. Compaction met specifications, as shown in Table 6. On the subgrade this percentage went up to a 96.66% and 97.34% for sections II and I, respectively (Table 6). These results are above 95%. Regarding to subbases, RMA-1 had a 100.59% and 101.41% degree of compaction on sections I and II, respectively, so the limit of 98% for MPT required by PG3 (Ministry of Development, 2004) was met. All values were over 98% of the MPT in granular bases, obtaining a mean value of 98.67% on section II and a 101.2% on section I.

Optimum moisture values were higher in recycled materials (RCA-1 and RMA-1), because of the higher specific surface than conventional aggregates, this explains why densities of standard aggregates are higher than RA, as displayed in Table 3. These results are consistent with those of preceding researches (Jiménez et al., 2012a; Jiménez, 2013; Jimenez et al., 2011; Jiménez et al., 2012b). Del Rey et al. (2016) and Tavira et al. (2018a, 2018b).

3.4.1 Plate load tests

On the granular subbases, Ev2 was similar in both sections, as shown in Table 7, with values between 194-219 MPa. The plate load tests that were obtained on the granular bases were 25% higher in section II 307-269 MPa (RCA) than in section I (CS) 248-214 MPa, which was due to the cement fraction present in RCA. According to the Spanish Pavement instruction (Ministry of Development, 2003b), the subbase would be classified as an E2 (Ev2>120 MPa). The results obtained in this experimental section are higher than those that were obtained by Tavira et al. (2018b), who obtained a value for Ev2 of 190-163 MPa for RA mixed with excavation soil. These authors also found lower CBR values (65.5%) than RCA-1 values (138%). The RMA from non-selected CDW were used by Jiménez et al. (2012b) in an unpaved rural track, its Ev2 showed lower values (145-168 MPa) than the RMA-1 used in this ES due to the lower quality of RA. In the same way, RMA was used by Del Rey et al. (2016), who showed lower values 159-144 MPa, due to the lower bearing capacity shown on the CBR of the selected RMA (67.3%) and the non-selected RMA (63.7%) used for the experimental unpaved rural road. Nevertheless, the RMA from selected CDW used by Jiménez et al. (2012a) for another unpaved rural road were higher 270-405 MPa, which can be explained because of the high bearing capacity of the subgrade 312-453 MPa. Regarding the RCA used for these rural roads Ev2 values are between 321-642 MPa.

3.4.2 Deflection tests with FWD.

Table 8 shows that section I and II had similar deflections and equivalent moduli for the subbases of both sections. On granular bases, section II (RCA-1) showed an 18-20% higher modulus than that of section I (CS), the CBR values shown in Table 3 for CS-1 (68%) and RCA-1 (138%) are compatible with these results. Ev2 values (Table 7) are in sequence with the FWD results that were obtained in Table 8. Deflections were lower than those that were obtained in a paved road section made with RA mixed with excavation soil by Tavira et al. (2018b) and were higher than those that were obtained for an experimental paved road of Malaga made with RCA stabilized with cement, according to Pérez et al. (2013).

3.4.3 Field control of deflection and equivalent moduli over time.

The F-test in the ANOVA that was conducted (Table 9) showed that the section factor influenced the deflections and equivalent moduli results.

One-way ANOVA detected that the date factor was critical for section II, but it did not have influence on the equivalent moduli of section I (Table 10).

No statistical differences between the date factor levels were found after calculating the least significant difference (LSD) test. This result can be seen in Fig. 8, where the 2010 and 2011 LSD intervals did not overlap the 2017 interval. The increment in the equivalent modulus between 2010 and 2017 was 10% in section I, whereas in section II, this gain was 20%. Conversely, comparing the deflection that occurs in the two sections, section I experienced a decrease of 7.86%, whereas in Section II, a reduction of 14.75% was obtained. The decrease could be attributed by the self-cementing effect that takes place in rehydrated cementitious particles in RCA. Del Rey et al. (2016) investigated the cause of this effect and concluded that particles below 0.6 mm in size have a key role, which means that deflection is limited by the proportion of the particles.

Comparing the data with those of other authors, the deflections of ES are lower to those obtained in previous studies with mixed recycled aggregates, such as RMA-MRS (52-73 0.01 mm) Tavira et al. (2018b) and RMA-RMSW (79-92 0.01 mm). The Ev2 values are above those published for RMA in an unpaved rural road (148.2 MPa) (Del Rey et al., 2016) and 235 MPa with RMA-RMSW in (Tavira et al., 2018a). This result is explained because of the higher CBR of the RA that were used in this research and the cement mortar content of the RA of this ES.

Table 11 shows that the section factor in the F-Test of ANOVA did not have a significant effect on the structural stiffness of RMA-1 calculated by EVERCALC. Both sections presented very similar values, which means that the RMA layer had a similar performance, which were executed well on-site, independently of the section.

In this long-term study, the date factor had significant effect (p-value <0.05) on the modulus of the granular sub-base RMA-1 calculated by EVERCALC with a 95% of confidence (Table 12).

It was evaluated if the date factor was a critical issue for the modulus value of the granular sub-base (RMA-1). The non-overlapping bar corresponding to the year 2017 (Fig. 9) indicates that an important gain in the load bearing capacity takes place in the sub-base. There was an increase of 11.4% between 2010 and 2017 in the modulus of the subbase. This trend is congruent with the research produced by (Garach et al., 2015), through the CBR test in mixed recycled aggregates.

One-way ANOVA was performed with the variable granular base modulus calculated by EVERCALC and the section factor Table 13. There was statistical significance in the two section sections.

As it has been previously researched, the effect of the date factor on the modulus in the granular base calculated by EVERCALC was studied for each section. According to the statistically analysis modulus obtained in the granular base by EVERCALC were similar in both sections. The moduli of section I with RCA-1 increased 14%, while the CS-1 moduli decreased 5% between 2010 and 2017. RCA moduli were similar to those obtained with RCA treated with cement (558-955 MPa) processed in static plants (Pérez et al., 2013). This result shows that mobile plants can obtain similar results in terms of load bearing capacity without cement stabilization. RCA obtained lower moduli than RMA due to the lower finer fraction proportion in RCA, in accordance with the aforementioned conclusion of (Poon and Chan, 2006). (López-Uceda et al., 2018) obtained a significant load bearing capacity increase over time in the RCA samples, measured by an increase of 80% in the CBR test between 7 days and one year.

3.5 International roughness index

To detect the effect of each section on the IRI test results, the F-test in ANOVA was conducted. The P-value was higher than 0.05, so there was no statistically difference in the IRI performance of Section I built with a standard aggregate layer and RMA and Section II built entirely with RA from CDW.

Two one-way ANOVAs were performed to inquire if the date factor was critical for IRI results on sections I and II. The date factor was decisive on the test results obtained, with a 95% confidence level, for both sections.

Then, the non-overlapping bars among the level factors 2010-2011, 2014 and 2016-2017 indicated that the date factor is predominant in the IRI test results (Figs. 10 a and 10 b). The increase in the IRI over time is reasonable because, as traffic drives across the road, the surface of the road deteriorates (Federal Highway Administration and U.S. Department of Transportation, 2013).

The mean values for each date met the criteria that were established by the American Department of Transportation (Federal Highway Administration and U.S. Department of Transportation, 1990) to classify general standards as acceptable in terms of the road quality for the experimental section. According to the World Bank (Sayers et al., 1986), the values obtained after 82 months correspond to an acceptable level. A previous study on a paved road made with RMA and MRS showed also acceptable values (Tavira et al., 2018b), by 2017 IRI mean values where between 2.38 and 2.64 exposed to a low volume traffic of under 50 heavy vehicles per day and lane. The threshold established by the PG-3 (Ministry of Development, 2004) for the IRI in new road constructions were below the IRI corresponding to the three percentiles imposed, which were 50%, 80% and 100% for both sections (Fig. 11). (Múčka, 2017) analysed the different specifications of the IRI around the world. In the EU, Sweden stablished the most detailed specification corresponding to this case study. The IRI limit is 2.9 m/km for in-service roads. In Fig. 11, the mean IRI linear regression is plotted for both sections. For section I, the number of years that the service-roads reached the Sweden limit was 16.2 years, whereas for section II, it was 16.7 years. This result means that the RCA application as a base layer in comparison to the section constructed with NA did not diminish the service life of the road. The IRI mean regression over time was greater in terms of slope and initial IRI in accordance with (Susanna et al., 2017), who collected different data, including the IRI, from different high-speed and high-quality roads to perform pavement deterioration models.

4 Conclusions

This research focuses on the evolution of the structural and functional parameters of an experimental section with a high amount of daily traffic (200-799 heavy vehicles per day on each lane). Two unbound RA from the demolition of single family homes with a mobile plant were used as the base and subbase layers. Long-term evaluations of the experimental section were conducted, and the deflections and roughness were measured during a period of seven years from its implementation into service.

Partial conclusions extracted from this research were as follows:

- Recycled aggregates used in this study met the non-hazardous requirements of the European Landfill directive; their use as unbound layers in roads did not represent a risk to the environment.
- The construction and demolition waste after treatment in a mobile plant was proven to be a viable option as new raw material for unbound base/subbase layers in traffic roads with a T2 traffic intensity (200-799 heavy vehicles/day and lane). The recycled aggregate produced did not meet the requirements of the Spanish national standard (PG3) for use as granular base or subbase layers because of their size distribution, Los Angeles abrasion test percentage, soluble salt and organic matter content.
- The experimental section had an adequate structural performance for a T2 traffic intensity road. The recycled aggregates used in this research had a higher bearing capacity than conventional aggregates. The mixed recycled aggregates mean moduli (674 MPa) were greater than those of recycled concrete aggregates (476 MPa) due to the higher percentage of finer fraction. The evolution along the seven years of the study showed an increment in the values of the equivalent and mechanical moduli of the recycled aggregates.
- Recycled concrete aggregates obtained a mean modulus of 476 MPa, which was higher than the mean value of the natural aggregates of 424 MPa. Recycled mixed aggregates had the higher mean modulus of all granular layers obtaining 674 MPa.
- Deflections and moduli test results had different contrasted results depending on the section tested, as well as on the moduli of the granular base calculated by EVERCALC, but not on the moduli of the granular sub-base RMA-1 calculated by EVERCALC or on the IRI results. This finding suggests that: (i) the base layer affected the deflections and moduli test results; (ii) the back-calculate software EVERCALC estimation was in accordance with the results obtained previously; (iii) the granular subbase RMA-1 was properly executed and did not interfere with the other results obtained; and (iv) the roughness surface performance was not affected by the road base layers underneath. The date had a significant effect on section II in deflections and moduli test results. This effect, along with the greater reduction in deflections and an increase in moduli with

respect to section I, implies better performance of the granular base made by RCA than the granular base built with NA.

- The asphalt concrete surface met the PG-3 requirements at its implementation and presented an acceptable International Roughness Index throughout the study period of seven years. The service-life estimation in the section with an RCA granular base was not less than the one built with NA.

As shown in this research, the in situ recycling of building debris from mobile plant was proven to be a suitable second raw material as base/subbase layer in road construction with a daily heavy vehicle flow of approximately 400 per lane. The test results that were carried out from putting this material into service up to seven years earlier showed that the recycled aggregates that were used provided good structural behaviour and stability over time, without increased surface deterioration, in terms of surface roughness, than the base made by natural aggregates. This observation contributes to the sustainability of the construction sector given that transport distances from stationary plants to sites are reduced with the use of mobile plants, thus providing economic and environmental advantages. The reuse of building debris instead of Natural aggregates prevents from landfilling with rests of demolitions and quarry and riverbanks overexploitation and mitigates the effect of the building sector on the planet, this helps to build a new circular model where materials have more than one use enlarging its life cycle.

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Table captions

Table 1 Average Traffic 2011-2013-2016

Table 2 Composition of recycled aggregates

Table 3 Properties of the different materials in the unbound layers

Table 4. Leachate concentrations (mg/kg) for RCA and RMA according to UNE EN 12457-3 (Spanish Association for Standardisation-UNE, 2003)

Table 5 Limit levels regulated by the Landfill Directive (Council of the European Union and 2003/33/EC, 2003)

Table 6. Moisture content and density

Table 7 Strain moduli and ratios

Table 8 Deflections and equivalent moduli during construction on granular layers

Table 9 ANOVA of defections and moduli test results for factor section

Table 10 ANOVA of defections and moduli test results for factor date

Table 11 ANOVA of moduli in granular sub-base (RMA-1) for factor section

Table 12 Results of the ANOVA of moduli (EVERCALC) for year factor on RMA subbase.

Table 13 ANOVA of moduli in granular base for factor section

Figure captions

Fig. 1 Orthophoto of the ES (left image year 2009, right image year 2017)

Fig. 2. Selective demolition of single family homes

Fig. 3. Mobile Plant: Aggregate Screen and Jaw crusher.

Fig. 4 Cross-sections of the Experimental Section

Fig. 5. Falling Weight Deflectometer and laser profiler

Fig. 6 Average monthly maximum, minimum temperatures and rainfall

Fig. 7 Particle size distribution curves of materials used in ES

Fig. 8 Mean values of: deflection for section I (a) and section II (b), and equivalent moduli for section I (c) and section II (d), and 95% LSD intervals vs. date

Fig. 9 Mean values of moduli in RMA-1 subbase and 95% LSD intervals vs. date

Fig. 10. Mean values of IRI section I (a) and section II (b), and 95% LSD intervals vs. date.

Fig. 11. Mean values of IRI over time and IRI of the 80% percentile and the mean, and three percentiles (50%, 80% and 100%) and PG-3 IRI limits for new roads for section I (a) and II (b)

Real-scale study of a heavy traffic road built with in situ recycled demolition waste

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Highlights

- An experimental road section was built with in-situ recycled aggregates from demolition wastes.
- Structural parameters and surface roughness were evaluated for a period of seven years.
- Moduli backcalculation and its evolution over time was performed using deflections, which is a key aspect for pavement design.
- Recycled aggregates showed better structural behavior than natural aggregates and both materials had similar surface deterioration.
- The bearing capacity of recycled aggregates structural layers increased over time.

Figure

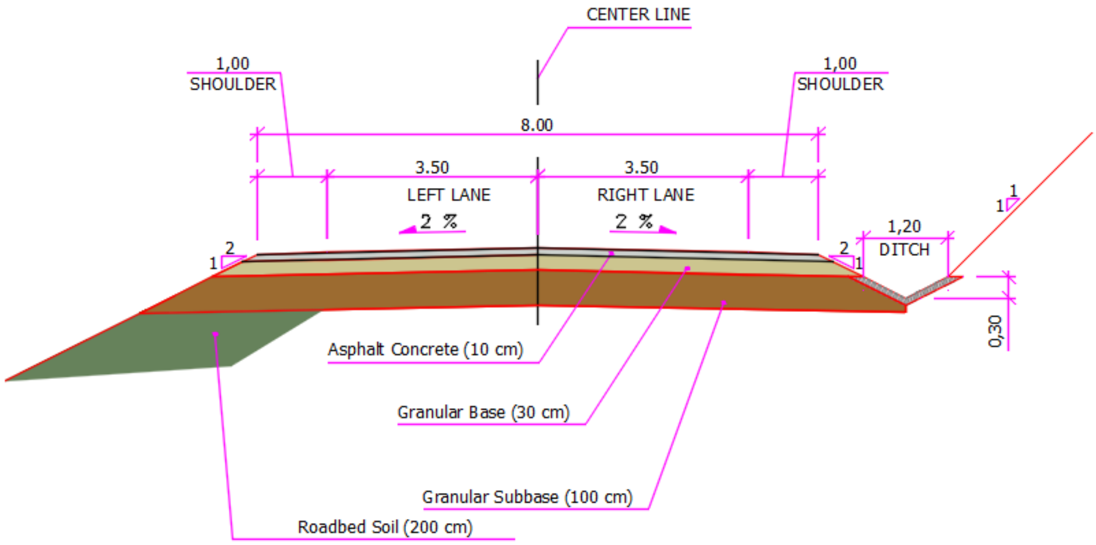
a) 2009

b) 2017

Fig. 1 Orthophoto of the ES (left image year 2009, right image year 2017)

Fig. 2. Selective Demolition of single family homes

Fig. 3. Mobile Plant: Aggregate Screen and Jaw crusher.



	SECTION I	SECTION II	Thickness
Surface Course	Asphalt Concrete	Asphalt Concrete	10 cm
Granular Base	Crushstone (CS-1)	Recycled Concrete Aggregates (RCA-1)	30 cm
Granular Subbase	Recyced Mixed Aggregates (RMA-1)	Recyced Mixed Aggregates (RMA-1)	100 cm
Roadbed Soil	Subgrade (SG-1)	Subgrade (SG-1)	
mileage (km)	0+000 0+180	0+280 0+450	

Cordoba Airport* ⟶ *Almodovar del Río

Fig. 4 Cross sections of the Experimental Section

a). Dynatest FWD 8012 – Testing Deflections on ER on 2017

b). RSP MARK-IV equipment – Testing Roughness on ER on 2017

Fig. 5. Falling Weight Deflectometer and laser profiler

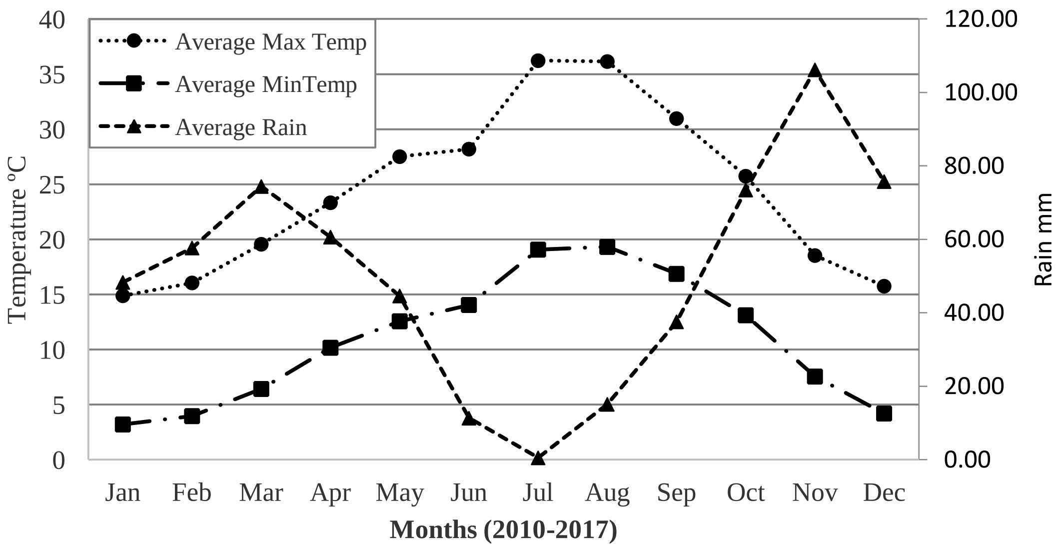


Fig. 6 Average monthly maximum, minimum temperatures and rainfall

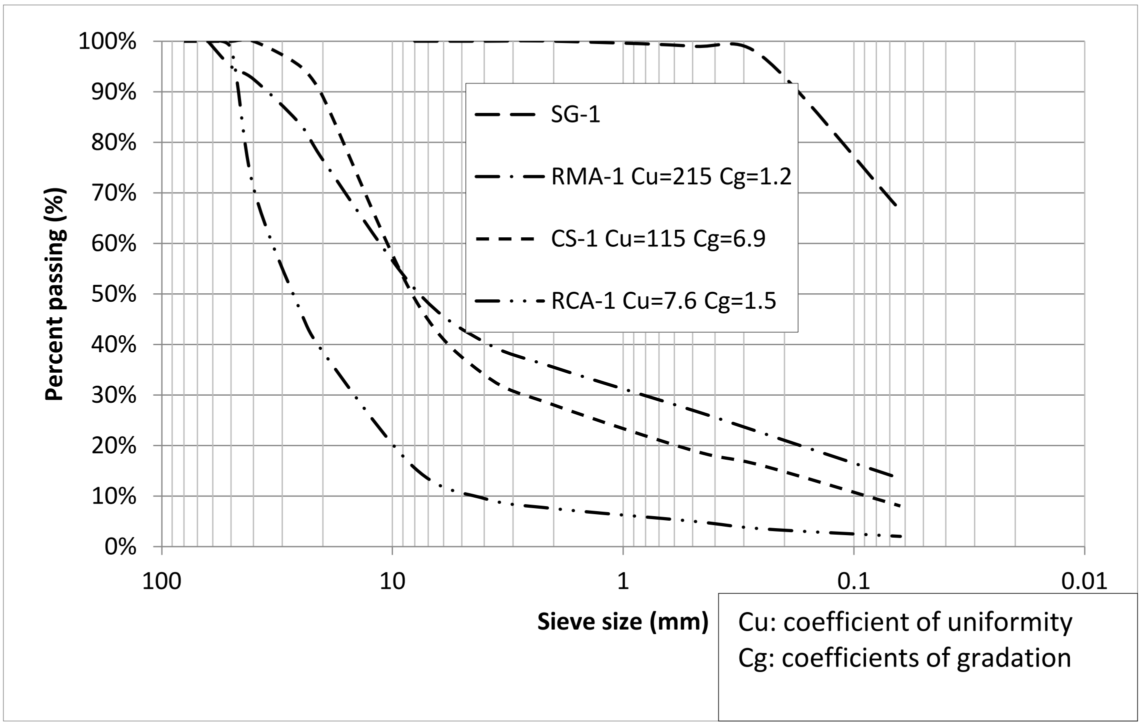


Fig. 7 Particle size distribution curves of materials used in ES

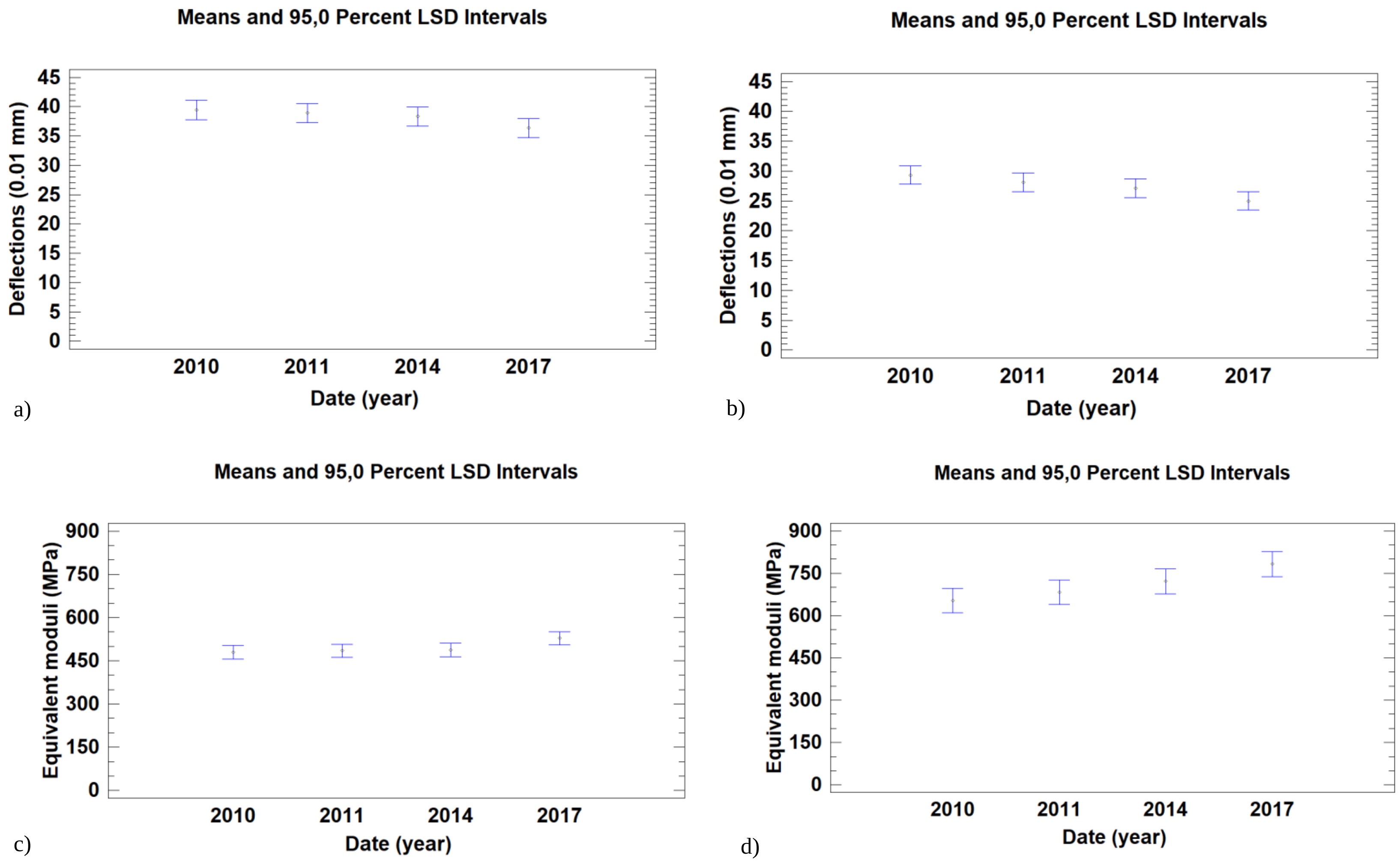


Fig. 8 Mean values of: deflection for section I (a) and section II (b), and equivalent moduli for section I (c) and section II (d), and 95% LSD intervals vs. date

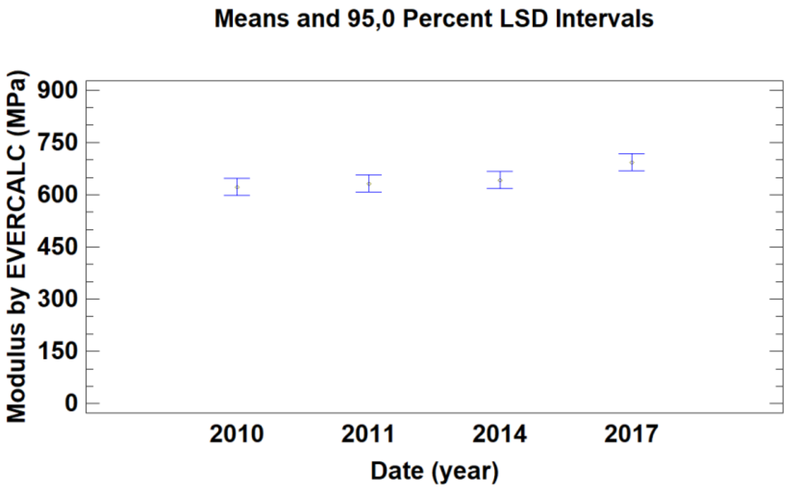


Fig. 9 Mean values of moduli in RMA-1 subbase and 95% LSD intervals vs. date

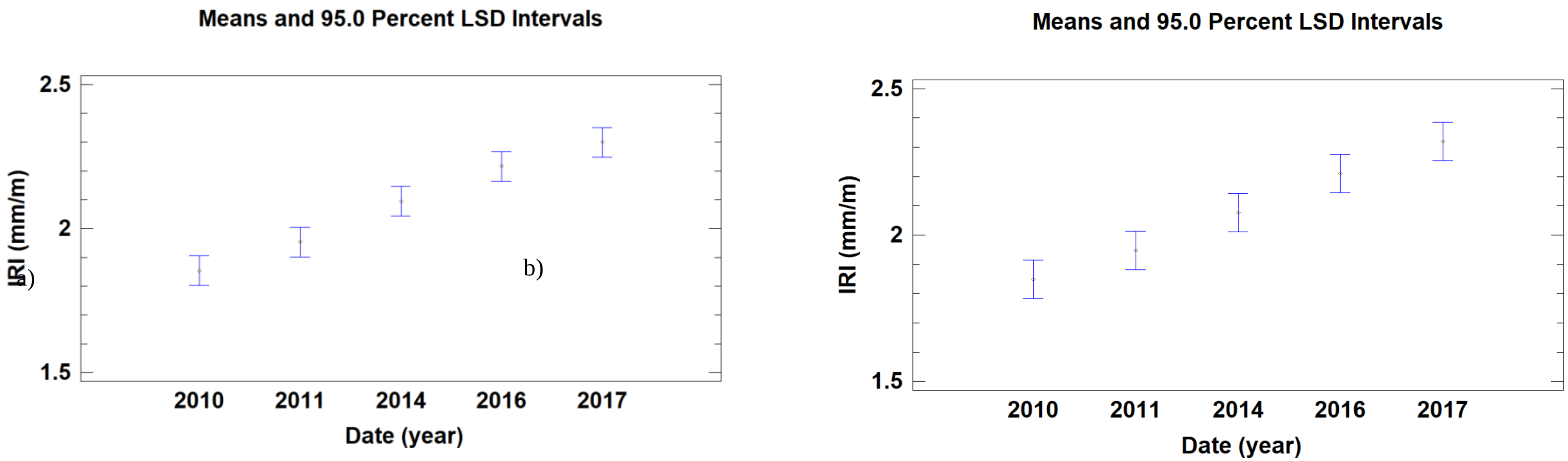
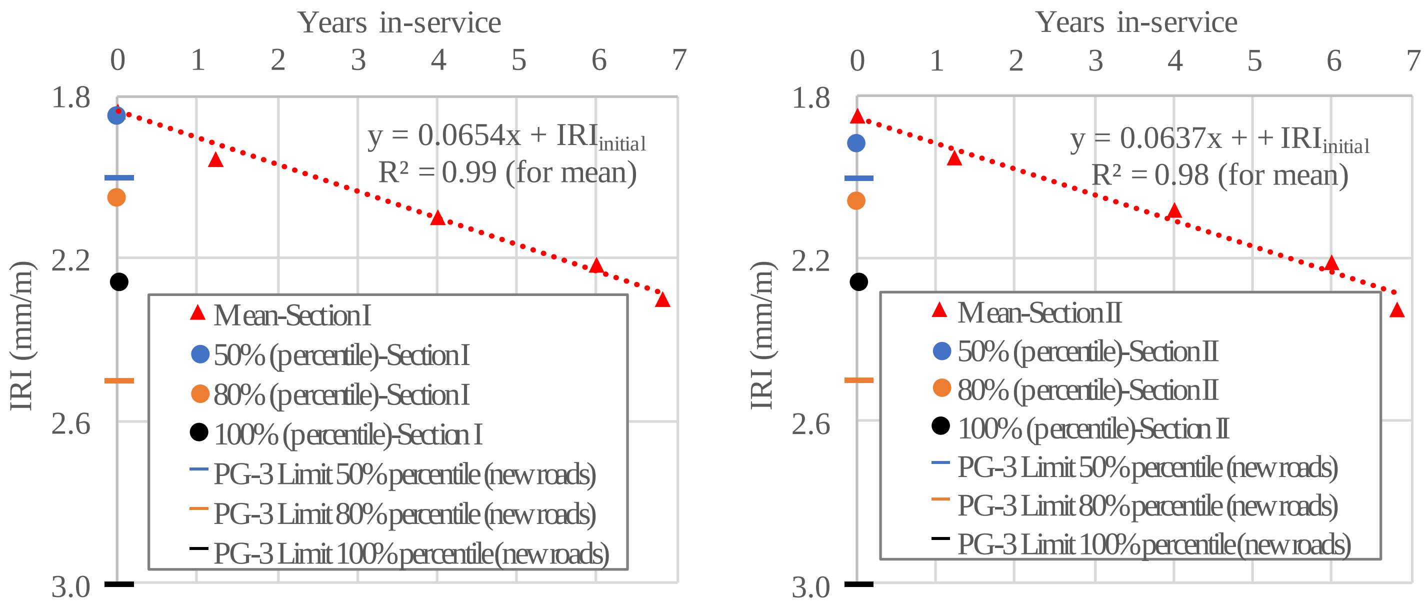


Fig. 10. Mean values of IRI section I (a) and section II (b), and 95% LSD intervals vs. date.



a)

Fig. 11. Mean values of IRI over time and IRI of the 80% percentile and the mean, and three percentiles (50%, 80% and 100%) and PG-3 IRI limits for new roads for section I (a) and II (b)

Table

Table 1 Average Traffic 2011-2013-2016

Date	ADT	RL HTD	LL HTD
10/2011	9595	407	392
10/2013	7600	271	261
10/2016	9616	465	429
Mean	8937	369	373

Average Daily Traffic (ADT)

Traffic Heavy Daily (HTD)

Right Lane (RL)

Left Lane (LL)

Table 2 Composition of recycled aggregates

Compositions (UNE-EN 933-11)	RCA-1	RMA-1
% RA (Asphalt)	0	0.2
% RB (Ceramics)	3.1	11.3
% RC (Concrete and Mortar) (a)	76	60.2
FL (Floating particles) (cm3/kg)	0	0.0
% RU (Unbound aggregates) (b)	20.8	28.0
% X1 (Natural ground)	0	0.1
% X2 (Other) (c)	0	0.1
% X3 (Gypsum)	0.1	0.1
Total	100	100.0

[a] Natural aggregates with cement mortar attached.

[b] Natural aggregates without cement mortar attached.

[c] Wood, glass, plastic, metals

Table 3 Properties of the different materials in the unbound layers

Properties	Fraction	SG-1	RMA-1	RCA-1	CS-1	PG3 limits	Standards used (AENOR, 2018)
Particle density ρr (g/cm3)	0.063/4	--	2.154	2.138	2.399		UNE-EN 1097-6: 2000
	4/31.5	--	2.116	2.243	2.590		UNE-EN 1097-6: 2000
Water absorption (%)	0.063/4	--	8.5	8.8	4.7		UNE-EN 1097-6: 2000
	4/31.5	--	8.3	6.7	1.6		UNE-EN 1097-6: 2000
Plasticity (IP)		NP	NP	NP	NP	S.S. <10, A.S.<4, TS>0.73(LL-20) IF LL>40	UNE 103103 :1994 & UNE 103104 :1993
Clean coefficient (%)		--	0.84	0.34	0.86	NA<1	UNE 146130 :2000
Sand equivalent (%)		--	39	51	41	NA>40 (T00-T1) >35 (T2-T4)	UNE EN 933-8 :2000
Los Angeles Abrasion (%)		--	36	34	20	NA<30 (T00-T2) <35 (T3-T4)	UNE EN 1097-2:1999
Flakiness index		--	19	8	8	NA<35	UNE EN 933-3 :1997
Crushed particles (%)		--	70	70	95		UNE EN 933-5:1999
Maximum dry density PM (g/cm3)		1.88	1.92	1.99	2.26		UNE 103501:1994
Optimum moisture content PM (%)		13.7	12.7	11.6	6.3		UNE 103501:1994
CBR (%)		6.61	119	96	87	S.S. >20, A.S.>5, T.S.>3,	UNE 103502:1995
Swelling after 4 day's soaking (%)		0.004	0.05	0.01	0.03		UNE 103502:1995
Free swelling in odometer (%)		0					UNE 103601:1996
Collapse (%)		0.04					NLT 254
Organic matter (%)		0.3	0.5	0.3	0.2	S.S. <0.2, A.S. <1, T.S.<1.0, M.S. <5.0	UNE 103204:1993
Soluble salts (%)		0.05	1.3	0.8	0.1	NA<0.07, S.S. <0.2, A.S. <0.2	NLT 114:1999
Water soluble sulfates (% SO4)		< 0.01	0.7	0.3	< 0.01	T.S.<1.0	UNE 103201:1996
Gypsum content (%)		< 0.01	1.2	0.5	< 0.01	T.S.<5.0	NLT 115:1999
Total sulfur content (% S)		< 0.01	1	0.6	< 0.01	NA<1	UNE EN 1744-1:1998

NP: non plastic; PM: Modified Proctor; HVDL (Heavy Vehicles per Day and Lane)
S.S. Selected Soils, A.S. Appropriate Soils, T.S. Tolerable Soils, Marginal Soils, R.S.S. Recycled Selected Soils, R.T.S. Recycled Tolerable Soils.
T00 (>4000 HVDL), T0 (3999-2000 HVDL) T1 (1999-800 HVDL) T2 (799-200 HVDL) T3 (199-50 HVD) T4 (<50 HVDL)
Samples for the CBR tests were compacted at their corresponding maximum dry density of Modified Proctor and 4-day soaked conditions

Table 4. Leachate concentrations (mg/kg) for RCA and RMA according to UNE EN 12457-3 (Spanish Association for Standardisation-UNE, 2003)

Element (mg/kg)	RCA-1				RMA-1					
	C-1		C-2		M-1		M-2		M-3	
	L/S 2	L/S 10	L/S 2	L/S 10	L/S 2	L/S 10	L/S 2	L/S 10	L/S 2	L/S 10
Ba	0.114	0.242	0.01	0.495	0.083	0.312	0.104	0.368	0.098	0.328
Ni	0.021	0.023	0.003	0.023	0.013	0.001	0.018	0.014	0.013	0.005
Cd	0	0	0	0	0	0	0	0	0	0
Cu	0.147	0.247	0.043	0.227	0.037	0.078	0.136	0.216	0.046	0.089
As	0.005	0.007	0.001	0.009	0.004	0.009	0.002	0.006	0.005	0.011
Zn	0	0	0	0	0	0	0	0	0	0
Pb	0.003	0.002	0	0.005	0.001	0	0	0	0	0
Se	0.001	0	0.001	0	0.01	0	0.016	0.011	0.01	0.027
Hg	0	0	0	0	0	0	0	0	0	0
Mo	0.077	0.088	0.031	0.136	0.04	0.067	0.067	0.099	0.072	0.102
Sb	0.003	0.021	0.001	0.019	0.003	0.016	0	0.005	0.002	0.016
Cr Total	0.131	0.223	0.03	0.164	***0.32***	0.45	***0.623***	***0.825***	***0.355***	***0.549***
classification	I	I	I	I	NH	I	NH	NH	NH	NH

Notes: I: inert; NH: non-hazardous; Value limit exceeded are given in bold and italics

Table 5 Limit levels regulated by the Landfill Directive (Council of the European Union and 2003/33/EC, 2003)

	Compliance test UNE EN 12457-3 (Spanish Association for Standardisation-UNE, 2003)]					
	I≤	**NH**	**H**	**I≤**	**NH**	**H**
	L/S = 2 (mg/kg)			**L/S = 10 (mg/kg)**		
As	≤0.1	0.1-0.4	0.4-6	0.5≤	0.5-2	2-25
Ba	≤7	7-30	30-100	≤20	20-100	100-300
Cd	≤0.03	0.03-0.6	0.6-3	≤0.04	0.04-1	1-5
Cr	≤0.2	0.2-4	4-25	≤0.5	0.5-10	10-70
Cu	≤0.9	0.9-25	25-50	≤2	2-50	50-100
Hg	≤0.003	0.003-0.05	0.05-0.5	≤0.01	0.01-0.2	0.2-2
Mo	≤0.3	0.3-5	5-20	≤0.5	0.5-10	10-30
Ni	≤0.2	0.2-5	5-20	≤0.4	0.4-10	10-70
Pb	≤0.2	0.2-5	5-25	≤0.5	0.5-10	10-50
Sb	≤0.02	0.02-0.2	0.2-2	≤0.06	0.06-0.7	0.7-5
Se	≤0.06	0.06-0.3	0.3-4	≤0.1	0.1-0.5	0.5-7
Zn	≤2	2-25	25-90	≤4	4-50	50-200

Inert (I); Non-Hazardous (NH); Hazardous (H)

Table 6. Moisture content and density

	Subgrade			**Subbase**			**Base**		
Average	**Dry Density (g/cm^3)**	**Moisture (%)**	**Compaction (%SPT)**	**Dry Density (g/cm^3)**	**Moisture (%)**	**Compaction (%MPT)**	**Dry Density (g/cm^3)**	**Moisture (%)**	**Compaction (%MPT)**
Section I	1.82 ± 0.06	13.56 ± 0.6	96.66 ± 3.11	1.93 ± 0.02	10.26 ± 0.85	100.59 ± 1.18	2.23 ± 0.02	4.14 ± 0.64	98.67 ± 1.08
Section II	1.83 ± 0.03	13.29 ± 0.92	97.34 ± 1.74	1.95 ± 0.01	10,13 ± 0.53	101.41 ± 0.58	2.02 ± 0.04	8.48 ± 0.93	101.26 ± 1.82

Table 7 Strain moduli and ratios

KP	Subbase			Base		
	E_{V1} (MPa)	E_{V2} (MPa)	E_{V2}/E_{V1}	E_{V1} (MPa)	E_{V2} (MPa)	E_{V2}/E_{V1}
0+070 (Section I)	86	194	2.26	107	248	2.32
0+170 (Section I)	131	218	1.66	98	214	2.18
0+300 (Section II)	123	201	1.63	127	269	2.12
0+390 (Section II)	87	219	2.52	149	307	2.06

Table 8 Deflections and equivalent moduli during construction on granular layers

	Date	Section I				Section II			
		Deflections (0.01 mm)		Equivalent moduli (MPa)		Deflections (0.01 mm)		Equivalent moduli (MPa)	
		Mean (M)	Standard deviation (SD)	Mean (M)	Standard deviation (SD)	Mean (M)	Standard deviation (SD)	Mean (M)	Standard deviation (SD)
Base	12/05/2010	117.52	15.28	147.27	18.85	95.30	14.42	182.31	25.24
Subbase	04/05/2010	69.06	8.68	142.94	17.18	68.50	9.65	144.90	21.63

Table 9 ANOVA of defections and moduli test results for factor section

		Factor Section	
	Factor levels	I	II
	D. of f.[a]	(1;286)	
Deflections (0.01 mm)	F-test	179.68	
	p-value	<0.001	
	Mean	38.2	27.7
	s.d.[b]	7.5	6.9
Equivalent Moduli (MPa)	F-test	140.83	
	p-value	<0.001	
	Mean	495	710
	s.d.[b]	100	193

D. of f.[a]*= Degrees of freedom (n1;n2); s.d.*[b] *= standard deviation.*

Table 10 ANOVA of defections and moduli test results for factor date

		Factor date							
		Section I				Section II			
	Factor levels	Jun-2010	Sep-2011	Jun-2014	Apr-2017	Jun-2010	Sep-2011	Jun-2014	Apr-2017
Deflections (0.01 mm)	*D. of f.*[a]	(3;140)				(3;140)			
	F-test	1.33				2.79			
	p-value	0.268				0.042			
	Mean	39.5	38.9	38.3	36.4	29.3	28.1	27.1	25.0
	s.d.[b]	6.9	6.7	5.9	8.4	6.7	6.4	7.0	6.2
Equivalent moduli (MPa)	F-test	1.81				3.14			
	p-value	0.148				0.028			
	Mean	479	485	487	528	653	683	722	782
	s.d.[b]	102	97	76	118	147	158	207	230

D. of f.[a]*= Degrees of freedom (n1;n2); s.d.*[b] *= standard deviation.*

Table 11 ANOVA of moduli in granular sub-base (RMA-1) for factor section

		Factor Section	
	Factor levels	I	II
Moduli of granular sub-base (MPa)	*D. of f.*[a]	(1;142)	
	F-test	1.34	
	p-value	0.234	
	Mean	646	648
	s.d.[b]	107	110

D. of f.[a]*= Degrees of freedom (n1; n2); s.d.*[b] *= standard deviation.*

Table 12 . Results of the Anova of modulus (EVERCALC) for year factor on RMA subbase.

	Factor: Year				
	Factor levels	Jun-2010	Sep-2011	Jun-2014	Apr-2017
Modulus by EVERCALC (MPa)	*D. of f.*[a]	(3,140)			
	F-test	3.2			
	p-value	0.025			
	Mean	622	631	642	693
	s.d.[b]	111	103	111	98

D. of f.[a]*= Degrees of freedom; s.d.b = standard deviation*

Table 13 ANOVA of moduli in granular base for factor section

	Factor Section		
	Factor levels	I	II
Moduli of granular base (MPa)	*D. of f.*[a]	(1;142)	
	F-test	12.55	
	p-value	< 0.001	
	Mean	424	476
	s.d.[b]	70	103

D. of f.[a]*= Degrees of freedom (n1; n2); s.d.*[b] *= standard deviation.*