Recycling RAP in concrete roads

Thierry SEDRAN

University G. Eiffel

PIARC International Seminar of TC 4.1 on Use of Recycled Materials in Pavements

20-22 September 2021, Argentina

Introduction

- A phd study was realized at LCPC on recycling RAP into concrete pavements between 2001 and 2004:
  - Very few cases of recycling with hydraulic binder: always in well-graded materials
  - RAP was not as well recycled in asphalt materials as now
  - ➔ interest to diversify the outlets of RAP
  - This interest remains todays for local needs to avoid movements of granular materials
  - Study sponsored by French Cement Association (ATILH)

- Attractive properties :
  - Drop of elastic modulus
  - Small decrease of tensile splitting strength

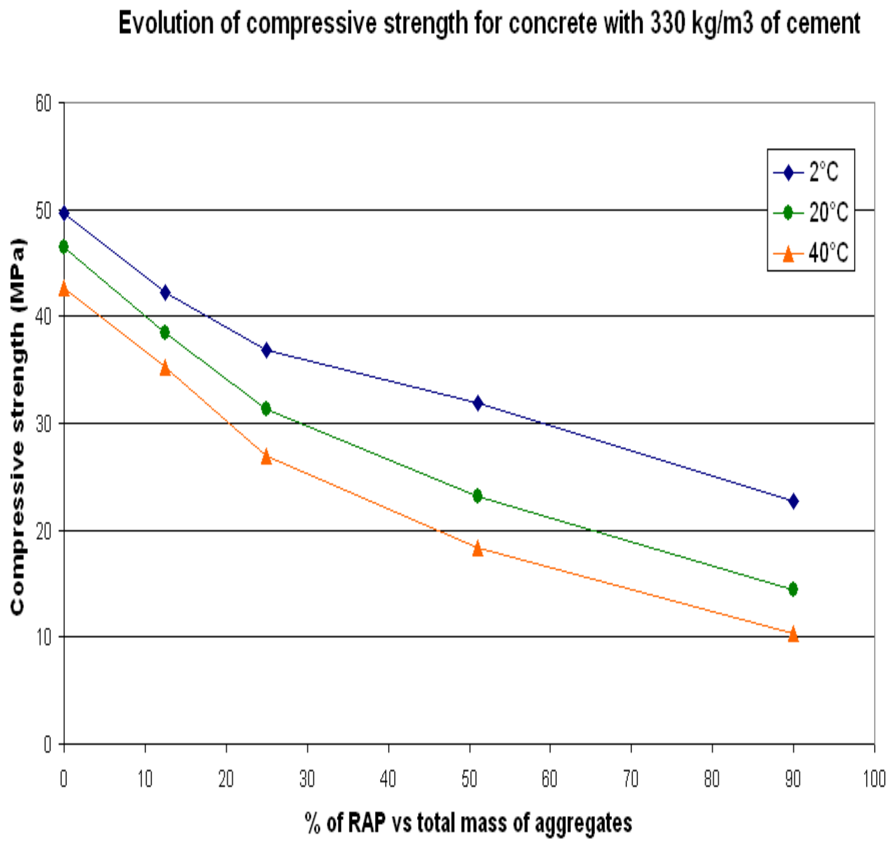
Introduction

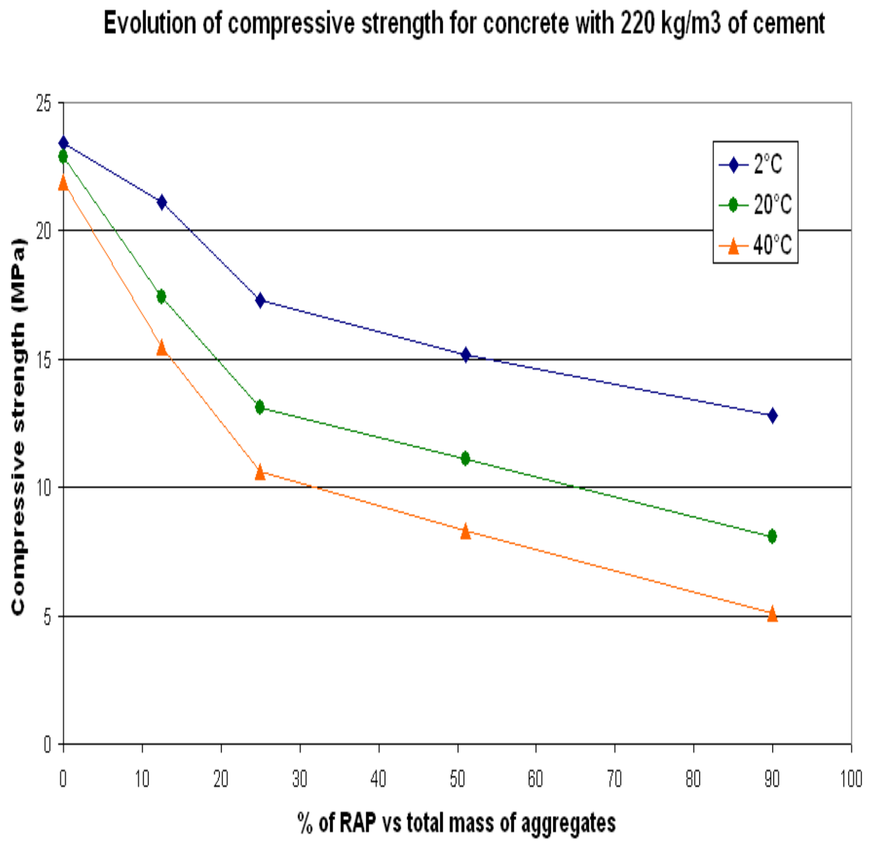
- The objectives of the study were:
  - To characterize the influence of RAP on mechanical properties of concrete dealing with pavements :
    - compressive strength
    - tensile splitting strength
    - elastic modulus
    - fatigue
    - cracking performances
  - To find mathematical models to describe the influence of RAP on these properties
  - To design pavements including concrete with RAP.

Characterization tests

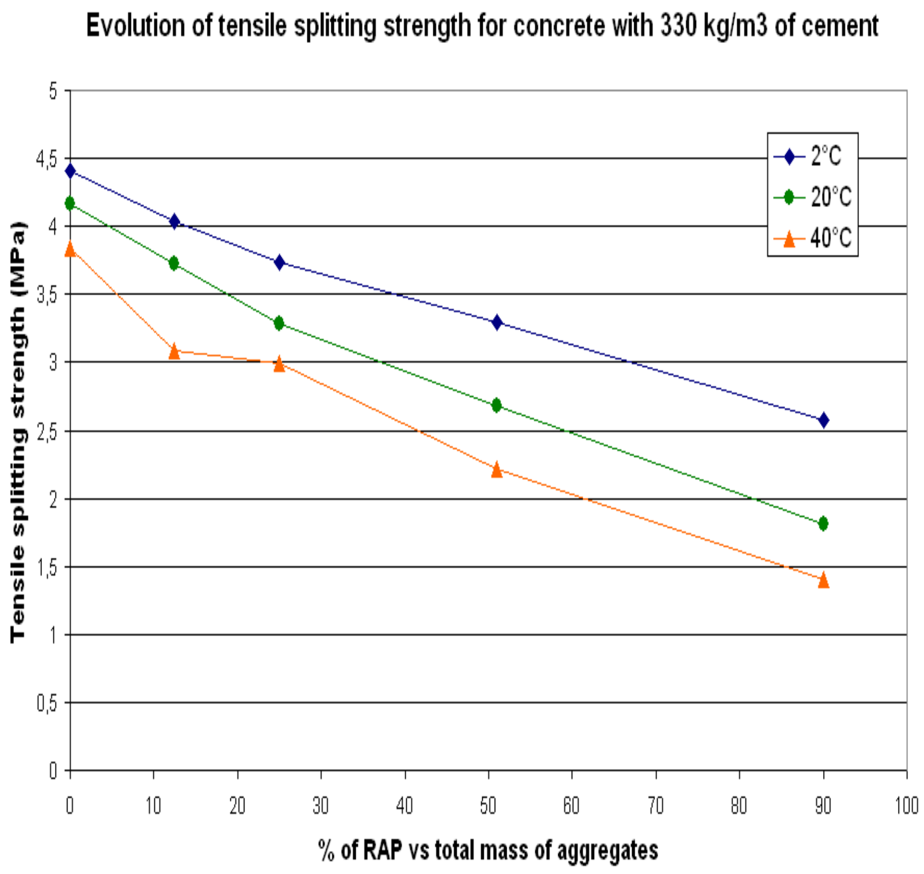
- 2 types of concrete :
  - Surface layer concrete (with 330 kg/m^3 of cement)
  - Foundation layer concrete (with 220 kg/m3 of cement)
- For each type of concrete, 5 different ratios of RAP, from 0 to 90 % of total aggregates mass.
- For each mix, compressive strength, tensile splitting strength and elastic modulus tests, at 28 days and at 3 different temperatures (2°C, 20°C and 40°C).

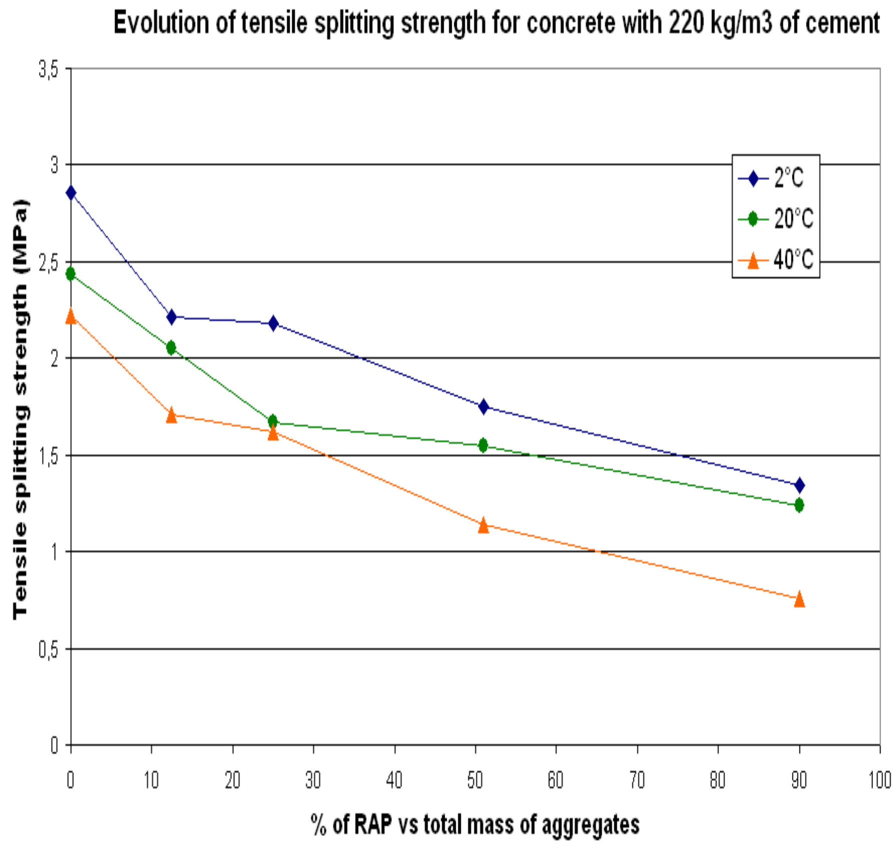
Compressive strength



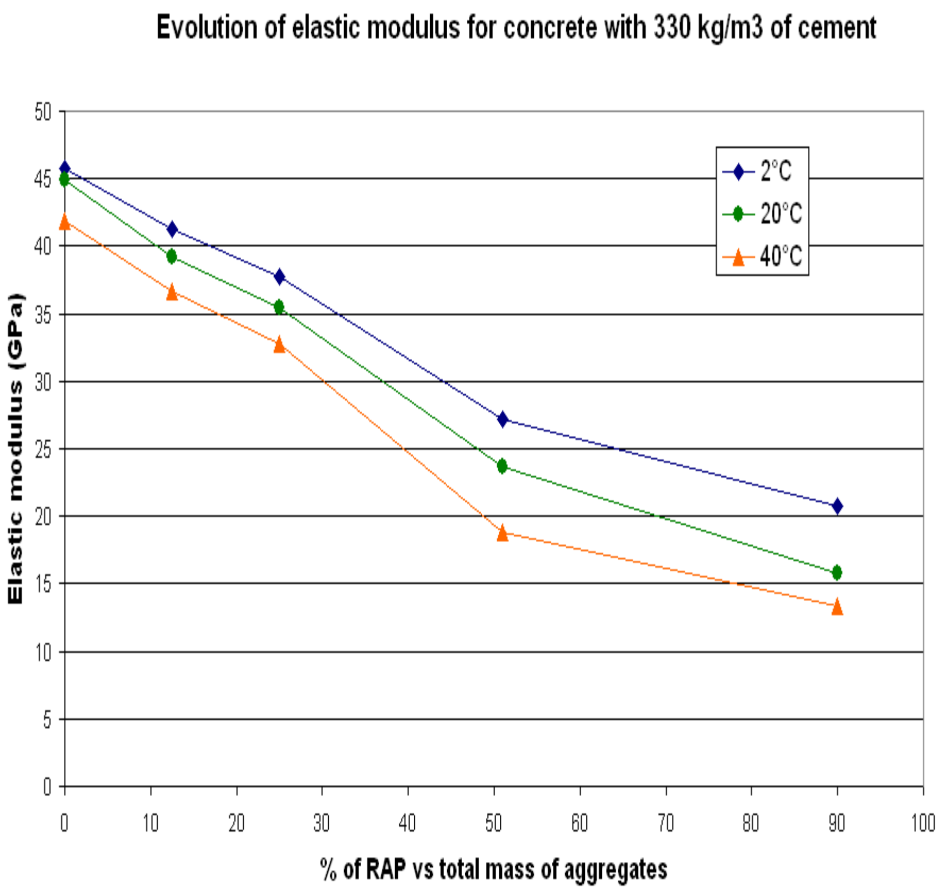


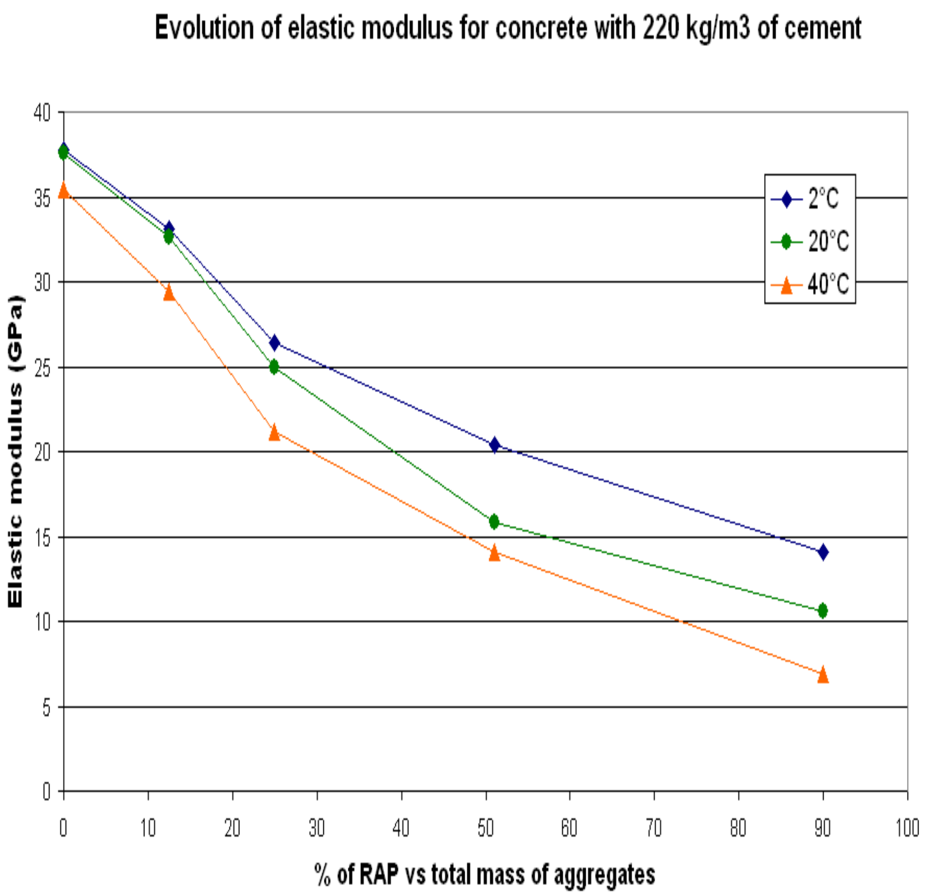
Tensile splitting strength





Elastic Modulus





Adaptation of existing model for concrete

- Effect of the RAP accounted for with bitumen content in cement paste
- Example of compressive strength:

$$F_c \propto \left(\frac{v_c}{v_c + v_c + \beta\ v_a}\right)^{2,85}$$

$$\Rightarrow \quad F_c \propto \left(\frac{v_c}{v_c + v_c + \beta\ v_a + \beta' v_b}\right)^{2,85}$$

- V_b residual volume of bitumen in concrete
- β' a coefficient increasing with temperature

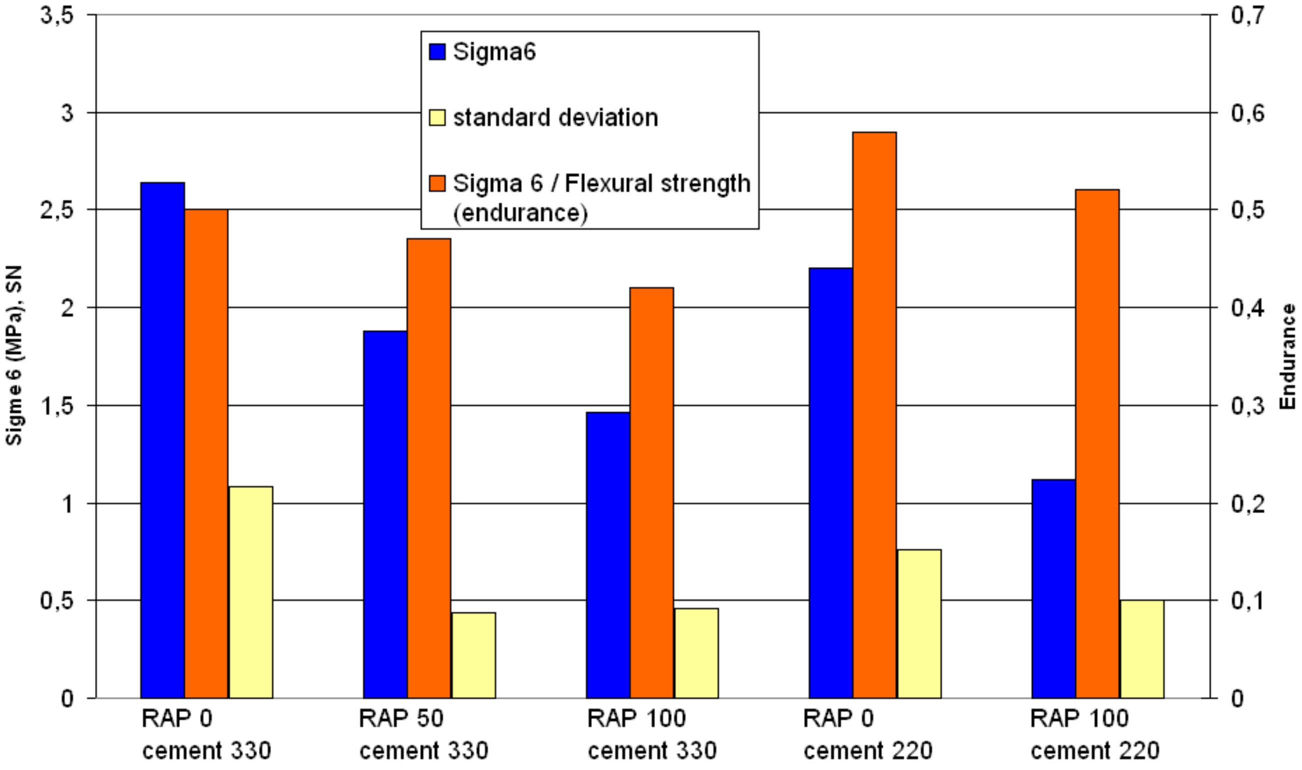
Fatigue tests

- Three fatigue tests on concrete with 330 kg/m^3 cement and with 0, 50 and 90 % of RAP.
- Two fatigue tests on concrete with 220 kg/m^3 cement with 0 and 50 % of RAP.
- ➔ σ_6: stress leading to failure at 10^6 cycles.
- $\sigma_{adm} = \sigma_6 . (N/ 10^6)^b . k_r . k_d . k_s . k_c$

Fatigue tests

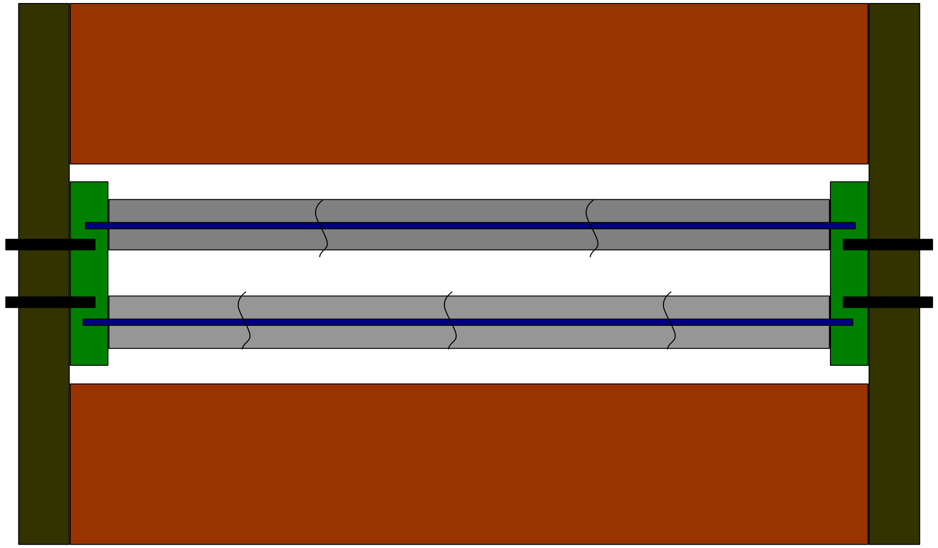
- Slight decrease of endurance (σ_6/σ_0)

- But also decrease of standard deviation



Restrained shrinkage test

- Crack tendency depends on:
  - Thermal and hydric shrinkage level
  - Long term elastic modulus or concrete relaxation
  - Tensile strength of concrete
- Effect of RAP difficult to predict
  - + : elastic modulus, visco-elastic behavior of bitumen,
  - - : higher shrinkage, lower tensile strength
- ➔Use of a bench to compare CRCP sections



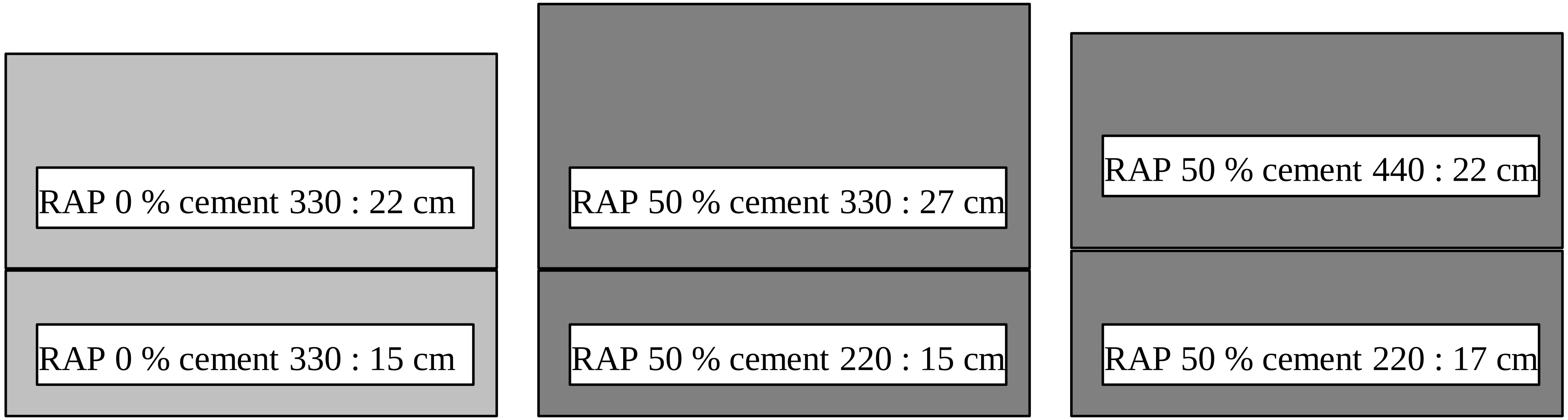
Restrained shrinkage test

- Concrete with 50 % of RAP is compared with control concrete (without RAP). 2 cases:
  - Same content of cement (330 kg/m^3) and increase of thickness for concrete with RAP
  - Same thickness and increase of cement content for concrete with RAP to have same bearing capacity

- ➔No significant difference between plain concrete and RAP concrete concerning cracking. Opening of cracks limited to 0,3 mm after a 30 degrees warming of the bench.

Theoretical pavement design

- Properties included in French design method to calculate different structures with the same service life duration
- Structure : BC5 / BC2 on a PF3 (150 Mpa) platorm,
- Traffic TC5
- Assumptions: cement : 80 € / ton, aggregates : 8 € / ton, RAP : 0 € / ton



14,2 € / m2 13,0 € / m2 13,6 € / m2

Real site experiments : Aire des Chataigners in 2003

- Rest area on French A6 highway between Courtenay and Joigny
- 7x150 m lane used for trucks parking was first milled
- RAP was recycled in a 10 cm white topping (40% of total aggregate)
- Practical production and laying of this RAP concrete was readily performed
- Continuous pouring without joints nor reinforcements ➔ after 6 years, good behavior but no positive effect of RAP on crack tendency

Real site experiments : The “Ecoparc des Cettons” in 2009

- Main road in a business area named in Chanteloup-les-Vignes (Yvelines, France), near Paris
- Independent concrete slabs (width 3,75 m, length 4,5 m) placed on a 45 cm layer of treated soil, covered with 15 cm of cement treated aggregates
- Dimensions: 800 x 7,5 m^2 separated in 3 sections
  - 1rst section: slabs with a 18 cm thickness made of a conventional concrete dosed at 350 kg of cement /m^3
  - 2nd section: idem but with concrete including 40% of RAP. Lowest tensile strength (2,5 MPa) but still higher than the minimum required (2 MPa)
  - 3rd section: idem but with 40% of RAP and slabs with 22 cm thickness to have the same theoretical bearing capacity

Real site experiments : The "Ecoparc des Cettons" in 2009

- The three sections behave well up to now under traffic
- Photometric measurements confirm that although RAP are dark, they do not affect negatively the reflection of light by the concrete surface

Conclusions

- Models for properties of concrete including RAP are available and allow to better assess the effects of RAP and to study different recycling scenarios combined with the Pavement French design method
- These effects are taken into account through the volume of bitumen brought into the concrete paste by the RAP
- From a pavement design point, replacement of natural aggregates by RAP:
  - have a negative effect by lowering the tensile strength and fatigue endurance of concrete
  - a positive effect by lowering the elastic modulus and the dispersion on the fatigue test
  - no effect on the risk of cracking

Conclusion

- Finally the recycling of RAP into pavement concrete does not raise technical problems

- The decrease in service life of concrete pavement including RAP can be compensated by an extra-thickness of concrete layer or an increase in the cement content

- Calculations show that these two solutions are economically viable and may be of environmental interest when unused RAP stocks are available near a construction site.

Thank you for your attention!

For more information contact

Thierry.sedran@univ-eiffel.fr