Scientific paper

On-Site Concrete Segregation Estimation Using Image Analysis

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Abstract

Segregation remains one of the major problems for traditional and self-compacting concrete. The consequences of this pathology are numerous and may affect the long-term properties of the structures. In order to ensure the expected characteristics of the concrete, it is essential to be able to check its homogeneity.
Some tests allow the checking of the fresh concrete properties at the concrete mixing plant, but there is at the present time no method to assess concrete segregation on site.
The development of a quick and low disturbance method allowing quantification of the segregation phenomenon automatically within structures constitutes an advance in the pathology detection area. The method presented here relies on the use of geoendoscopy and automatic image processing techniques. After a short presentation of the tools and the auscultation methodology, the image processing techniques developed in order to measure the concrete homogeneity and to control the concrete particle size distribution are exposed. Results obtained with this methodology in laboratory experiments are then compared with those obtained with the traditional video counting technology. Finally, the last part is devoted to the application of this method to a real self-compacting concrete structure.

1. Introduction and purposes

Segregation which corresponds to the loss of homogeneity between both the granular and the suspending phases (Bethmont 2005), remains one of the major problems of both traditional and self-compacting concretes. Consequences of this pathology are numerous and may affect the long-term properties of the structures (resistance, durability).

To ensure the concrete's quality and characteristics, it is essential to be able to control its homogeneity both during manufacture and also once the concrete has been poured into formworks.

Some techniques and tests, concrete index of segregation, column of static segregation, sieve segregation resistance test, stability test, (Jin 2002; Buy *et al*. 2002; AFGC 2002; EFNARC 2005; Bartos *et al*. 2002; Sedran 1999) allow the control of fresh concrete at the concrete mixing plant and prevent some problems of delivery and implementation of the concrete. There are however presently very few methods allowing the measurement of on-site segregation in order to check or to diagnose the structure pathology. These methods include video-counting (Mournet 2003) or the method proposed by Schwendenmann *et al*. (2005) based on gammadensimetry.

Therefore, in order to develop diagnosis and assessment tools for structures in service, we have studied a rapid and low disturbance method measuring automatically the segregation within built structures. This method which relies on the use of geoendoscopy and of automatic image processing was initially developed by Breul (1999) for the granular media study as well as for diagnosis of pathology of structures in service (Breul *et al*. 2003).

After a presentation of the auscultation methodology, the image processing methods developed in order to measure the concrete homogeneity and the concrete particle size distribution are exposed. The results obtained in laboratory experiments are then compared to those obtained from the traditional technology by video-counting. Finally, the last part is devoted to the application of this method on a real self-compacting concrete structure.

2. Devices and methodology

For the sake of convenience, the auscultation methodology had to be simple, useful and adapted to any type of structure. It had to cause minimum trauma in order to affect the structure as little as possible.

The trial protocol is based (**Fig. 1**) on the realization of a drilling of small diameter (16 mm) in which a frame grabbing is performed thanks to a geoendoscope (**Fig. 3**). Before the frame grabbing, an improvement of the boring surface is carried out so as to simplify the subsequent image processing.

The improvement of the boring surface is obtained first by a cleaning with air and water to eliminate dust and then by the use of a chemical agent which colors the cement paste and increases the contrast between paste and grains in the concrete. A study of different products was carried out to define the most effective agent according to the type of concrete analysed.

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In the face of dark aggregates (basaltic origin, dioritic), baseline gives the best contrast (**Fig. 2**). Concerning the bright aggregates (granitic, silico-calcareous origin), Idanez (2004) tested seven chemical agents and Haddani (2004) demonstrated that thymolphtaléïne gave the best results as presented in **Fig. 4**.

After surface improvement, frame grabbing is performed with a rigid endoscope of 8 mm of diameter throughout the boring hole (**Fig. 3**).

Each drilling is sounded along four orthogonal axes. The magnification of this endoscope is 14 µm/pixel and each image represents a surface of 8 x 10 millimeters. An example of an image acquired is presented in **Fig. 4**.

3. Image processing

Once the images were recorded, the relevant information has to be extracted in order to characterize the concrete homogeneity. Previously, image processing was carried out in order to eliminate or reduce the image's defects (illumination heterogeneity, reflection, etc.). Then an automatic analysis (Idanez 2004) based on mathematical morphology tools and on signal treatment allowed us to isolate the particles from the rest of the image. **Figure 5** shows an example of the different image processing stages.

Image processing, allows particle extraction of diameter ranging from 0.1 mm to 10 mm. It is adapted for particles of over 10mm. But these particles are always cut off at the image edges because of its size and of the magnification. Concerning the surface analysis, it does not have any influence on the results. The particles size reconstruction for particles over 10 mm needs a specific method adapted to this problem, which is still not developed.

The study of the concrete homogeneity is realized according to two different ways. On one hand by a quick analysis allowing us to obtain the particle surface in the

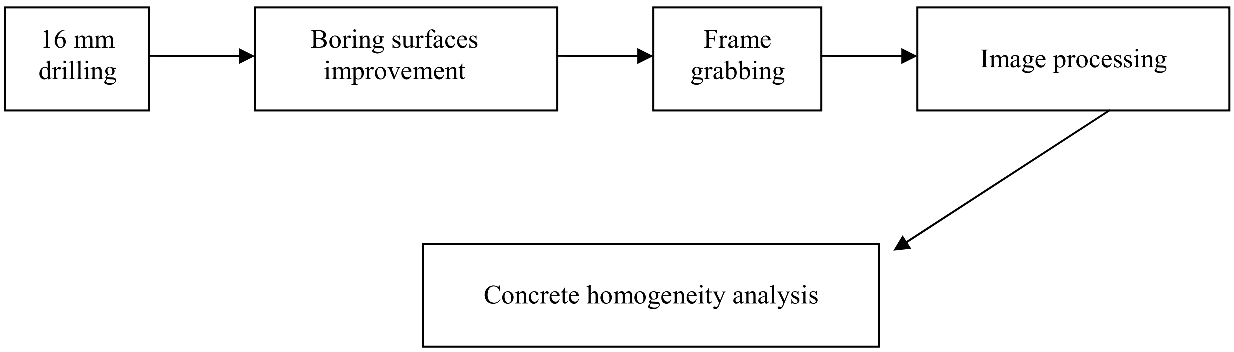
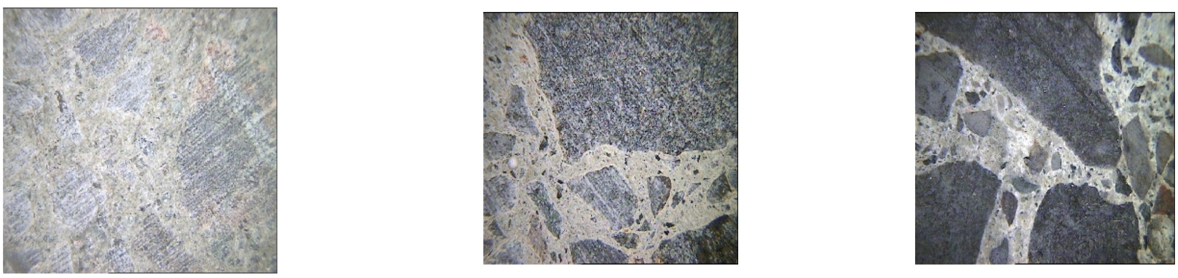


Fig. 1 General methodology.



A B C

Fig. 2 Images of boring surface: A) raw, B) moisturized C) with vaseline.

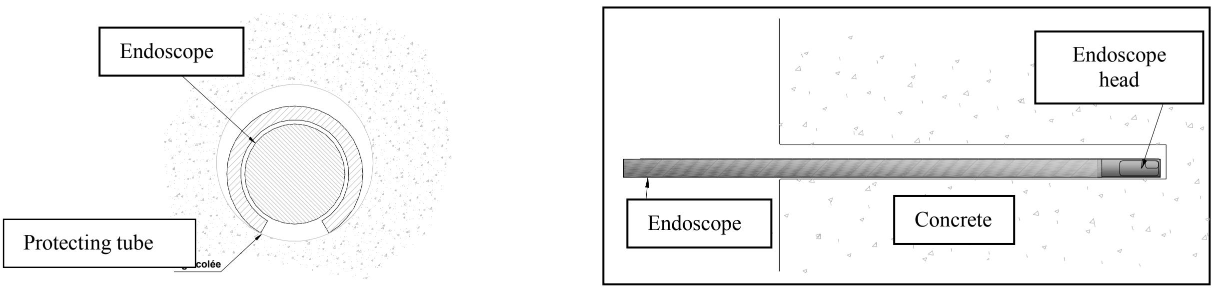


Fig. 3 Scheme of the endoscope positioning in the boring.

image and then by computing an Aggregates Surface Content (ASC) correlated to the degree of concrete segregation. On the other hand, procedures providing the aggregates size distribution within the concrete were developed.

4. Experimental study of segregation

To adapt and validate this technology, experimentations were carried out on columns of 16/64 cm or 16/32 cm of self-compacting concrete or crushed particle concrete. Each sample includes deliberate homogeneity defects (segregation and bleeding) obtained by increasing the water-cement ratio or the amount of adjuvant. Columns were sounded by 3 or 5 borings distributed on the column height. Measurements were compared with results acquired on the same columns by the video-counting method (**Fig. 6**).

The video-counting technology remains strictly a laboratory method. This method (**Fig. 6**) consists in making several cross sections at regular intervals on the sample and counting all the particles appearing on the concrete cross sections. The particle surface is then computed. From hypotheses on the particle shape, the surface analysis is interpolated in a volume analysis.

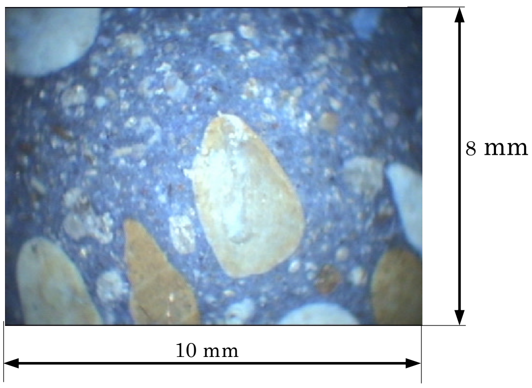


Fig. 4 Example of recorded image obtained by the geoendoscope after treatment by thymolphtaléïne.

4.1 Aggregates surface content (ASC) analysis

From the endoscopic images obtained, we computed the aggregates surface content (ASC) in each boring hole spaced every 12 cm along the height. The particle surface content (ASC) is defined as:

$$\mathrm{ASC} = Sg\,/\,S\mathrm{img} \qquad (1)$$

where Sg: particle surface in the image (in pixel) and Simg: image surface.(in pixel).

Results were compared by taking into account only particles whose minimal Féret diameter was superior to 4 mm. Indeed, segregation is measured in practice on the granular class 4/20 mm. Studies were led on 5 different concretes (**Table 1**) and the results acquired are given in **Fig. 7**.

In this figure, the longitudinal axis corresponds to the aggregates surface content. We compared the results obtained by video-counting, geoendoscopy and the theoretical content calculated for a homogeneous con-

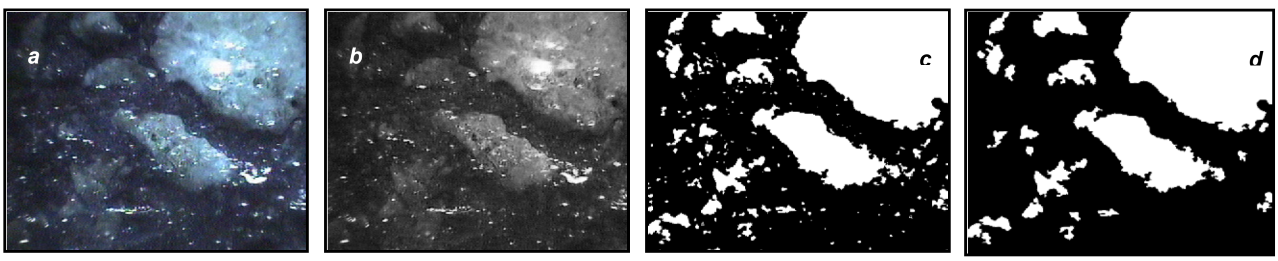


Fig. 5 a) Recorded image, b) Iintensity image, c) Treated image and d) Cleaned image ready for analysis.

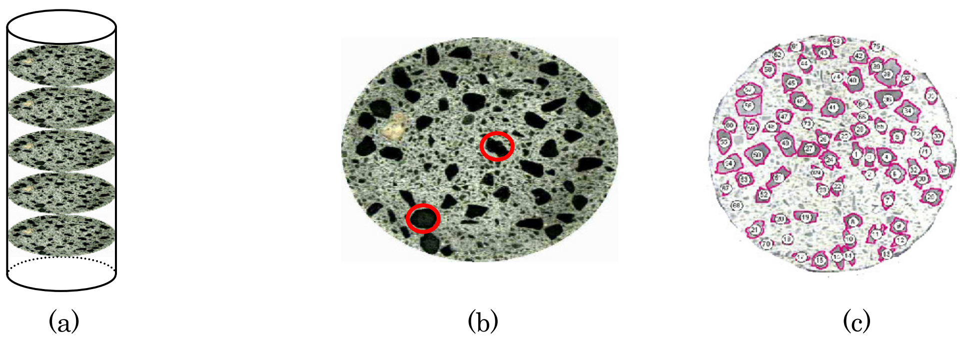


Fig. 6 Video-counting: (a) Column sampling, (b) Particle counting based on the efficient circle and (c) Particle counting based edge extraction.

Table 1 Concretes composition.

	Concrete I	Concrete II	Concrete III	Concrete IV	Concrete V
Aggregates origin	dioritic	granitic	granitic	dioritic and granitic	alluvial
Water (l)	164	268	238	203	208
Cement (kg)	400	400	400	365	350
Water-cement ratio	0.41	0.67	0.60	0.56	0.59
Sand (kg/m^3)	1180	1180	1180	965	751
Gravel (kg/m^3)	750	750	855	865	860
Adjuvant (kg/m^3)	6.0	6.0	4.0	3.6	-

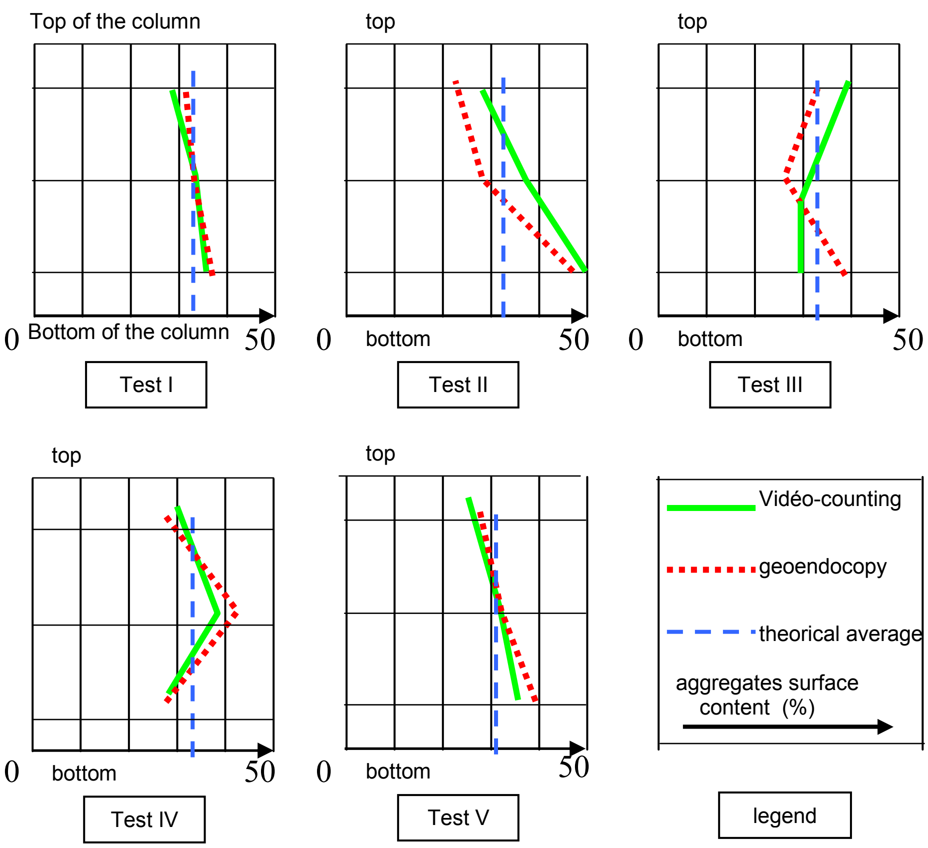


Fig. 7 Comparison between results obtained by video-counting and geoendoscopy for the measurement of concrete homogeneity on laboratory columns.

crete. The concrete used in test I does not present segregation despite a little increase of the aggregates surface content near the bottom of the specimen. On the other columns, both experimental techniques showed segregation. As a whole, considering the measurements uncertainties, video-counting and geoendoscopy results are identical. On test III, a slight difference between the two methods can be noticed. Geoendoscopy analysis at the bottom of the column shows an increase of the particle contents while video-counting shows a relative stability.

Compared to video-counting, Geoendoscopy provides relevant results and moreover it can be realized on-site after a drilling.

Aggregates surface content analysis is interesting because it is a quick and automatic method which allows segregation detection. But, at the present time, this method does not quantify the segregation. Indeed, it does not provide any information concerning the type, the size and the repartition of the particles segregated.

4.2 Particle size distribution characterization

Starting from a material whose particles have a space isotropic distribution, Gourvès (1983) and Auvinet (1986) demonstrated that it was possible to determine the distribution function of diameters of circles intercepted by a plane section and to find the corresponding particle size distribution of the material. The reconstruction of the particle size distribution led to the hypothesis that:

• particles are convex,
• the number of particles in every class of size is sufficient,
• particle orientation and site are assumed to be random.

Image processing allows particle individualization within concrete. Therefore it seems interesting to see if it is possible to find the real particle size distribution from the analysis of endoscopic images.

In practice, as shown on **Fig. 8**, the visible diameter ¨*y*¨ of a particle - that is to say the one measured on the image which corresponds to the diameter of the particle projected surface– does not necessarily correspond to the real diameter ¨*x*¨ of this particle. In this case, a relation between these two diameters has to be found.

This relation can be obtained from a probabilistic method of the cross section (Gourvès, 1983). This relation is the function $F(x)$ which represents the cumulated volume of particles having a lower diameter in x. Simplified but justifiable hypotheses are applied:

• particle size distribution is assimilated to a probabilistic distribution function,
• particles are assumed to be spherical,
• D is the diameter of the biggest material particles and d is the diameter (> 0) of the smallest particles measured in an image,
• particle position in the space is defined by the position of their centre,
• material is assumed to be isotropic and homogeneous.

If ¨*t*¨ is the distance between the center of a particle of diameter ¨*x*¨and the plan of cross section (**Fig. 9**), on the plane section a circle of intersection of diameter ¨*y*¨ will appear such as:

$$y^2 = x^2 - 4t^2 \tag{2}$$

If $g(y)$ is the density function of circles of diameters y present on the cross section, if $H(x)$ is the particle size distribution function in volume, then:

$$H(x) = \iint_\Delta g(y)dydt \tag{3}$$

The domain of integration Δ is defined by:

$$\begin{aligned} &\frac{y^2}{x^2} + \frac{t^2}{x^2/4} \geq 1 \\ &y \in (0, x) \\ &t \in (0; x/2) \\ &x \in (d.D) \end{aligned} \tag{4}$$

and so

$$H(x) = \int_0^x \frac{1}{2}(x - \sqrt{(x^2 - y^2})g(y).dy \tag{5}$$

The density function in number $h(x)$ is obtained by deriving $H(x)$.

$$\begin{aligned} h(x) &= \frac{dH(x)}{dx} \\ &= xg(x) + \int_0^x (1 - \frac{x}{\sqrt{(x^2 - y^2)}})g(y).dy \end{aligned} \tag{6}$$

with $x < D$

Therefore, function $x^3h(x)$ represents the density in volume. Finally the expression of the particle size distribution will be:

$$F(x) = \frac{\int_0^x x^3h(x)dx}{\int_0^D x^3h(x)dx} \tag{7}$$

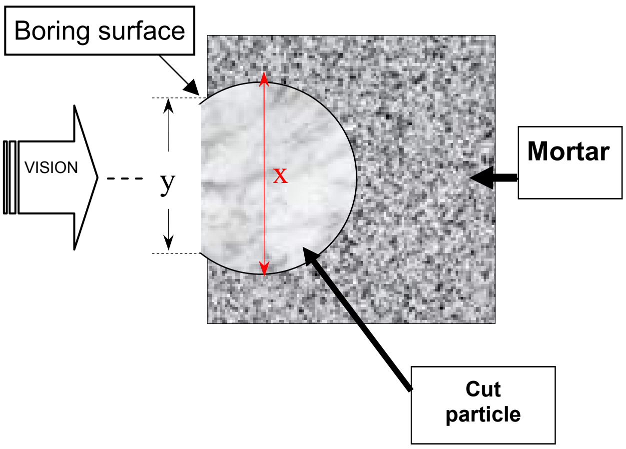


Fig. 8 Scheme of the lateral view of the boring surface.(y measured particle diameter, x: real particle diameter).

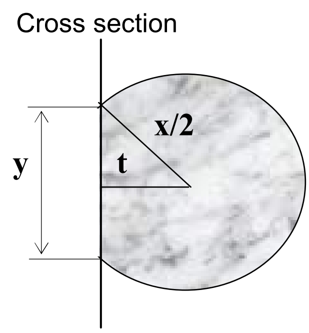


Fig. 9 Deduction of the diameter "y" on a section from the knowledge of real particle diameter "x".

$g(y)$ is obtained by interpolation from the experimental analysis realized on the images. According to the observation of the sharing out of the experimental analysis, $g(y)$ is defined as:

$$g(y) = k / y \quad \text{for } d < y < D \tag{8}$$

$$g(y) = 0 \quad \text{elsewhere}$$

and k a constant depending on the experimental particle size distribution.

This procedure provides accurate estimations in measuring the large diameter particles, but for particles of small diameters the precision decreases because of the difficulty in measuring them accurately. A statistical method allowing the resolution of this kind of problem was developed by Auvinet (1986) but was not tested here.

To test this method, a comparative study was carried out on the specimens tested previously. **Figure 10** shows the results obtained on the concrete of type II.

As we can notice, the probabilistic method provides results very close to the real manual sieving curve. These results have been obtained in all the cases of treated concrete. The plane section probabilistic method allows a reconstruction of the particle size distribution starting from the measurement of the particle diameter present on the boring surface. This method is convenient for particle size greater than 2 mm in diameter. For smaller particles, this method is not very accurate at the present time. The method proposed by G. Auvinet (1986) could perhaps solve this problem.

5. Application on a real structure

To test and validate this method, a study was carried out on a real structure composed of self-compacting concrete. This structure is composed of several shells and pavements built with different concrete formulations and different implementations (**Fig. 11**).

Our study focused on the shell II (**Fig. 11**) which was

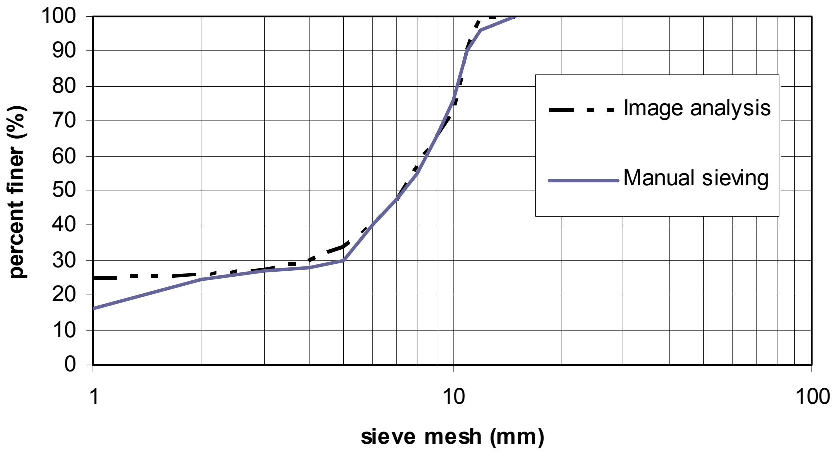


Fig. 10 Particle size distribution comparison between manual sieving and image analysis method. (concrete II).

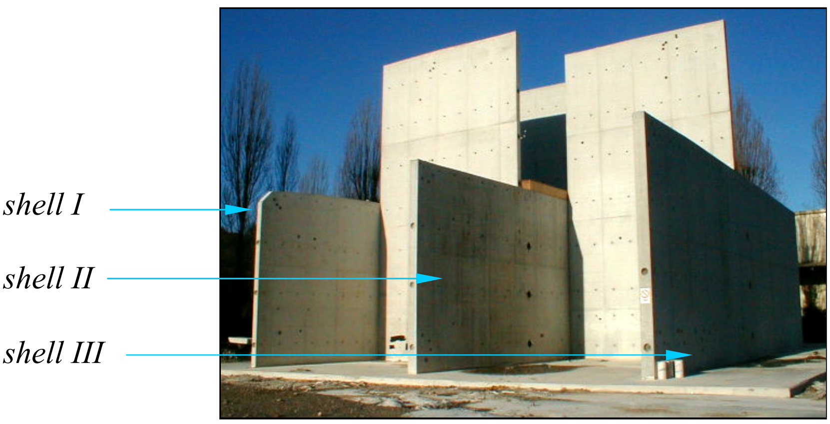


Fig. 11 Structure on which method has been tested.

made of self-compacting concrete composed of 3/8mm silico-limestones particles. Concrete was injected from the upper West end (**Fig. 12**). This wall is 25 cm thick, 14.8 m long and 5 m high. 16 borings of 16 mm of diameter were carried out within the wall. The boring holes disposition and their coordinates are provided in **Fig. 12**.

A first study based on the image surface analysis was carried out to distinguish the shell areas including a large aggregate proportion from those where this proportion is weaker. The main goal of this study is to realize a mapping of the shell according to the aggregates surface content in order to highlight the segregation areas.

Figure 13 shows a total mapping of the shell II allowing to highlight the areas of segregation (areas where the aggregates surface content is important). The isovalues lines of aggregates surface content were obtained by interpolation between borings. The mapping shows a large segregation phenomenon in the lower part of the wall. This segregation is due to the concrete introduction place and depends on the height and on the

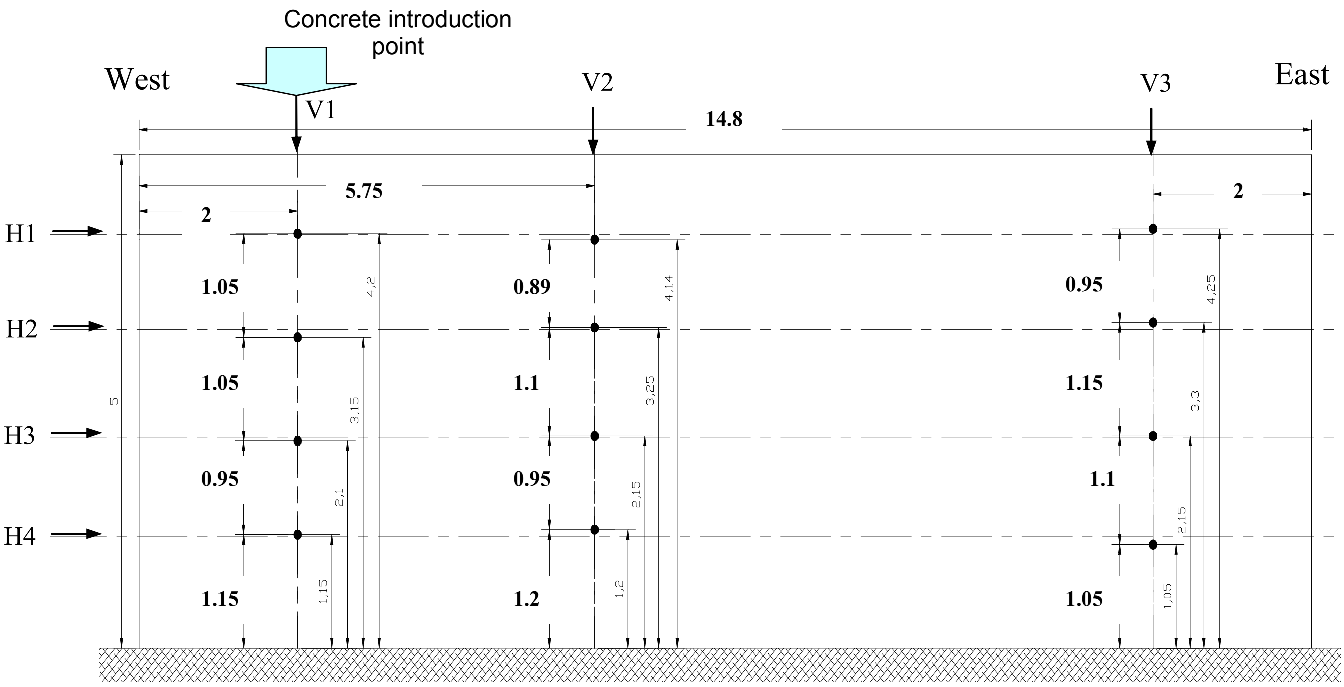


Fig. 12 Shell II: borings localization.

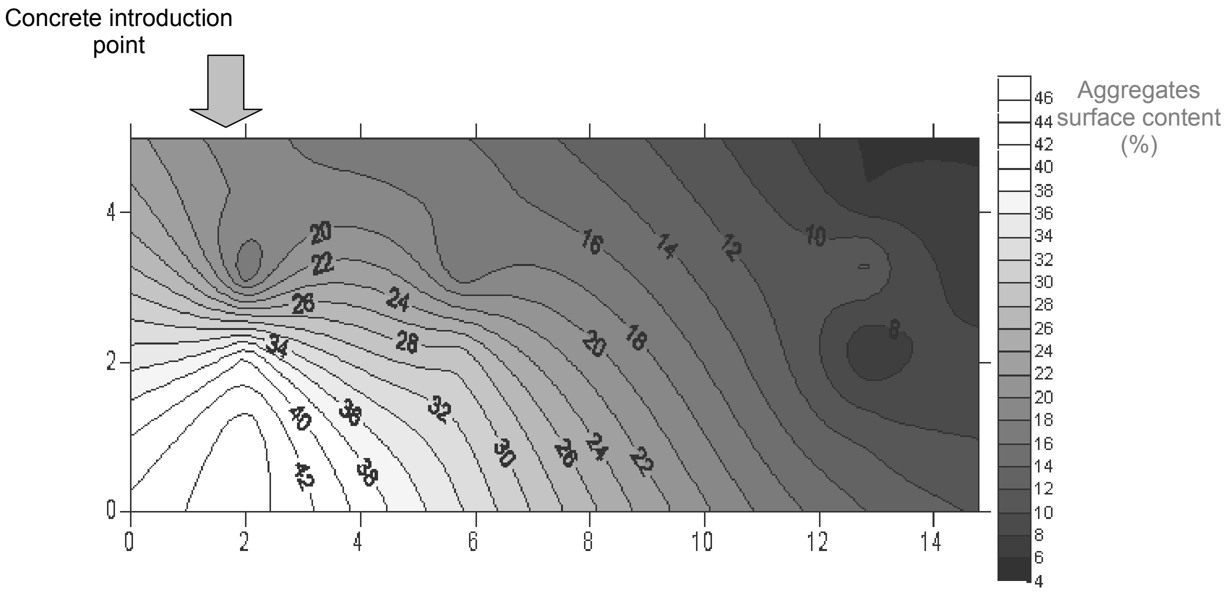


Fig. 13 Mapping of aggregates surface content (ASC) repartition within the shell II.

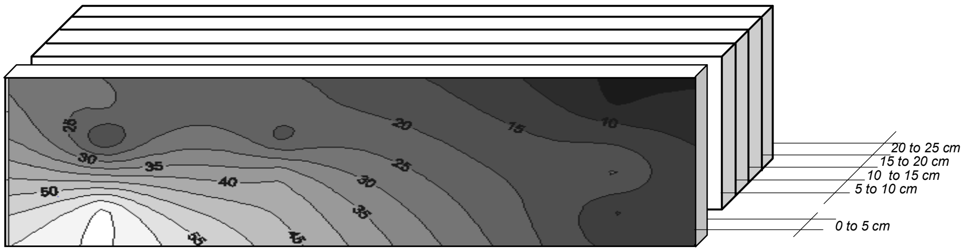
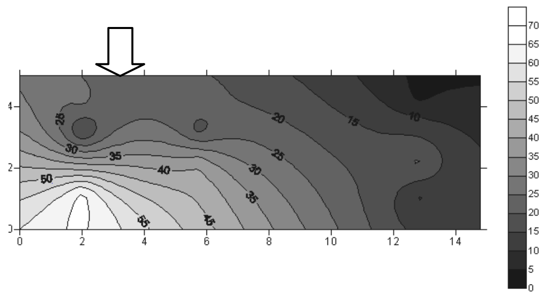
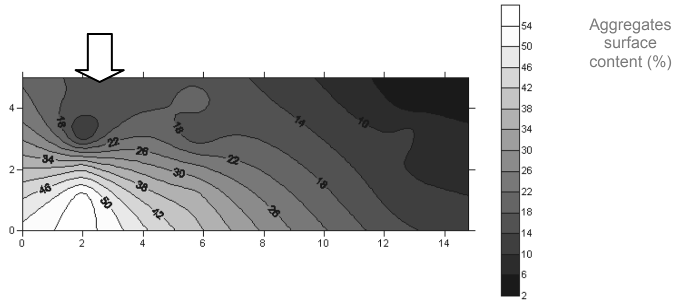


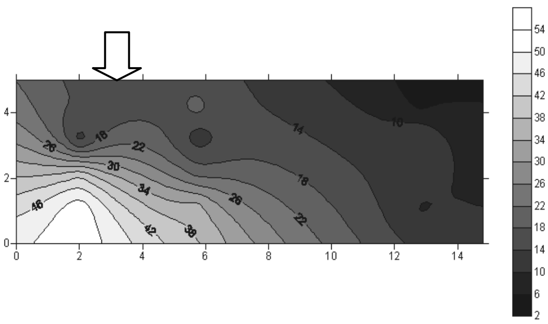
Fig. 14 Sheme of aggregates surface content repartition in the shell thickness.



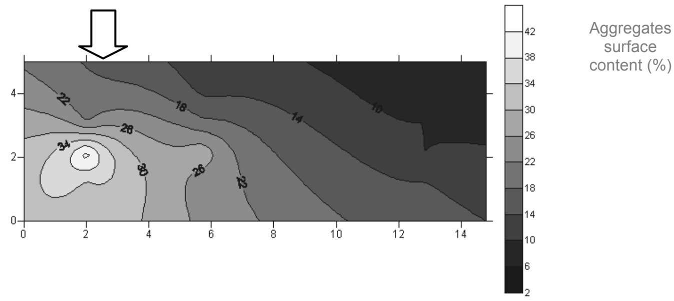
Section from 0 to 5cm.



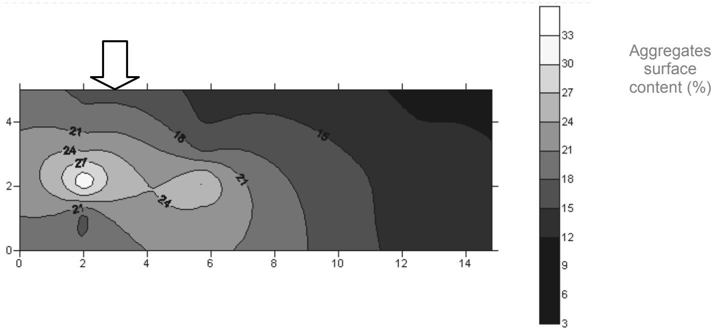
Section from 5 to 10cm.



Section from 10 to 15cm.



Section from 15 to 20cm.



Section from 20 to 25cm.

Fig. 15 Mapping of aggregates surface content (ASC) distribution in function of 5cm thickness sections within the shell II.

distance from this point.

To assess the segregation phenomenon in the thickness of the wall, an analysis of the aggregate distribution was led by layers of 5 cm in the thickness of the wall (**Fig. 14** and **15**).

The vertical and longitudinal segregation phenomenon, detected on the global mapping of the shell, can be observed on each section. A wall effect, an effect on particle size distribution near a wall, can be shown with this analysis. Segregation is more important in the central part and on one side (section 0 to 5 cm) of the shell than on the other side. This remark is an observation that has to be confirmed on several studies. It highlights the influence of the implementation on the final con-

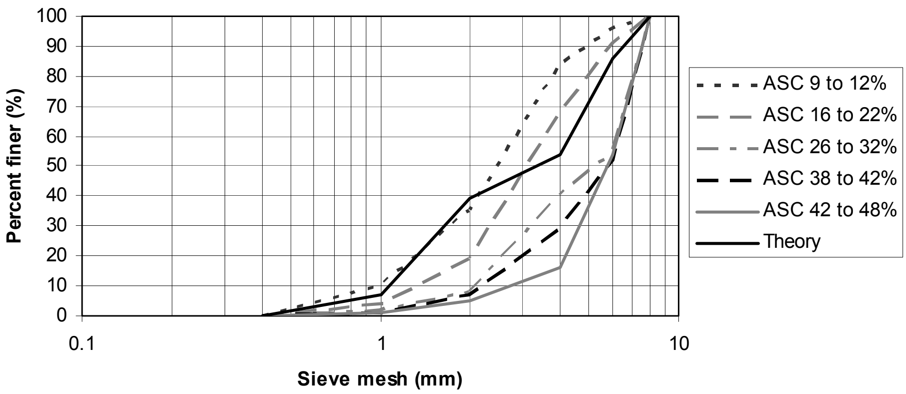


Fig.16 Particle size distributions comparison for different Aggregates Surface Content (ASC) obtained in the different shell areas with the theoretical ones.

crete characteristics.

Further to this preliminary study, the real particle size distribution was studied in each part of the shell to collect quantitative information concerning the segregation. Five different aggregates surface content areas were studied and a comparison with the theoretical particle size distribution is presented in **Fig. 16**.

This figure shows the particle size distributions calculated for different Aggregates Surface Content (ASC) obtained in the different shell areas. The comparison between the different distributions confirms the results obtained before concerning segregation. Due to the limits of the method, the measurement of fine particles (0-2 mm) is always underestimated by image analysis. A considerable amount of fine particles is present in the eastern part of the shell. In the other areas, the percentage of fine particles seems much lower than the theoretical value. We can however observe a gradual increase of coarser particles in every area with a high concentration at the bottom of the shell just under the concrete introduction point.

6. Conclusions and prospects

This article has presented a new method of analysis and diagnosis of concrete structures in service. This method is based on frame grabbing using endoscopy and automatic image analysis. It is a low trauma and fast method. Concerning the characterization of segregation, the methodology seems well adapted and provides a fast mapping of the structure by interpolation.

The stereological analysis that has been set up to find the particle size distribution within the structure has provided very good results for particles of diameter ranging from 2 to 6 mm. For particles of lower size, an underestimation linked to a statistical effect is noted.

The methodology presented here was tested on different concrete compositions, on aggregates of various geological origins as well as on a real structure, and its robustness is satisfactory.

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