UNIVERSITAS INDONESIA

STUDY OF EXPANSIVE CONCRETE – PRELIMINARY STUDY FOR THE USE IN ROADWAY CONSTRUCTION

UNDERGRADUATE THESIS

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PREFACE

This research was carried out in Laboratoire des Ponts et Chausses (LCPC) Bougeanais, France in partnership with Ecole central de Nantes.

First of all, I would like to express my greatest gratitude to Mr. Thierry SEDRAN and Mr. Frédéric GRONDIN, to have supported me in the achievement of this work, for all the help which has allowed me to progress scientifically throughout my training course. Without them, this work would not have been carried out.

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Thank you very much!

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ABSTRACT

The use of the expansive cements to minimize the effects of the shrinkage is still little studied. Concrete, which is known for its durability, could not be implemented directly in concrete roadways construction. One of the biggest problems is shrinkage which occurs since it is in the paste concrete form. Shrinkage induced to cracking is not preferable in the roadways construction, which usually use the system of reinforced concrete and joint separating system.

We will consider the expansive cement as one of the solution to reduce the effect of the shrinkage. The expansion of the concrete during its hardening state is studied to compensate the shrinkage effect.

This study is based on preliminary study on existing method of expansive cement, designing a measure apparatus, which we will use later for future testing, and the possibility of using the expansive cement in the roadways construction.

Keyword: Expansive cement, Shrinkage, Additives, Roadway Construction

RESUME

L'utilisation des ciments expansifs pour minimiser les effets de la retrait est encore peu étudiée. Béton, qui est connu pour sa durabilité, n'a pas pu être mis en œuvre directement dans la construction de routière. Un des plus grands problèmes est le retrait qui se produit lorsqu'il est encore dans sa forme de la pâte forme. Retrait induite à la fissuration n'est pas préférable à la construction des routes, qui utilisent généralement le système de béton armé et conjointes du système de séparation.

Nous allons examiner le ciment expansif comme l'une des solutions pour réduire l'effet du retrait. L'expansion du béton au cours de son état de durcissement est étudié pour compenser l'effet de rétrécissement.

Cette étude est basée sur l'étude préliminaire sur la méthode actuelle de ciment expansif, la conception d'un appareil de mesure, que nous utiliserons plus tard pour les essais, et la possibilité d'utiliser le ciment expansif dans la construction routière.

Mot Clé: Ciment expansif, Retrait, Additif, Construction Routière

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CHAPTER 1
GENERAL PRESENTATION

The use of the expansive cements to minimize the effects of the shrinkage is still little studied. According to ASTM C845-90, the **Shrinkage Compensating Concrete (SCC)** is made with expansive cement for which the expansion, if it is prevented, induced a compressive force which compensates the tensile stresses roughly induced by the shrinkage. The ACI 223-93 defines SCC as an inflating concrete which, when it is retained by the reinforcement, will inflate of an equal volume or slightly larger than the shrinkage envisaged.

In the current case, after the volume of concrete increased, the shrinkage will reduce these expansive constraints, but ideally, a residual compression will remain during some time, leading to the elimination of cracking due to the prevented shrinkage.

Since the crack of the shrinkage generally does not affect the structural integrity directly, it is always undesirable especially in certain applications, such as floors in the industrial buildings, the roadways, etc. for which its repair can be expensive and long, particularly when the cracks work under machines, or on the surface of roadways that makes it possible to water to enter. Moreover, the shrinkage's crack also exposes the steel of reinforced concrete to the external environment where the corrosive of water, of salt, etc, will drive to the structural defects by time.

1.1 General information

Cement which we use is the "Portland cement" type, which was invented by the Aspdin Scot. This name was given to this type of cement because its color pointed out that the stone of the Portland cement area. The history of cement started with the Romans who mixed lime and volcanic ash which is came from the area called Pouzzoles. But the phenomenon of the hydraulicity had remained unexplained until Louis VICAT developed the theory of it. Since then, the developments of cement as a construction material continue.

The principal material of cement is the clinker which is a mixture of 80% limestone and 20% clay. The manufacturing process starts with the extraction and the crushing of the raw materials. In continuation there is the mixture between the limestone and clay grains which is made by crushing, and then we obtain a very fine mixture called "cru". This mix is then cooked until 1400°C which makes it possible to decarbonizes the limestone, then form it into a new mix which will react with water (mainly of calcium silicates). We obtain then the clinker, which is mixed with gypsum (about 5%) to regularize the grain. Hence, cement is obtained.

1.1.1 Characteristics of cement

The characteristics of cement can be divided according to its conditions, when it is still powders or paste of cement (mixed with water). France Standard *NF 197-1* gives a classification of cements, as follows:

- Powder characteristic

$S_{spé}$ = 2800 – 5000 cm²/g

ρ_{app} = 1000 kg/m ^{3}

ρ_{abs} = 2900 – 3150 kg/m^3

- Characteristic in paste

1. The beginning of hardening

   Based on the pression of the needle of Vicat which does not exceed until the bottom of a specific plate (±4 cm diameter) with the time of hardening must be higher than 45 minutes.

2. The expansion

   The expansion of cement must not higher than 10 millimeters.

3. Mechanical resistances

   Characterize the resistance of cement defined by its face value. With the lower limit of resistance in compression than 28 days according to the characteristic of cement (32; 42,5; 52,5 MPa in 28 days).

1.1.2 Types of cement

There are several types of cement, but current cements are subdivided in five types according to the standard NF 197-1

1. CEM I Portland cement (CPA - française)

   At least 95% of clinker contain and 5% of secondary components

2. CEM II made up Portland cement (CPJ)

   Contains clinker 65% and 35% of other components like slag of blast furnace, silica fume, natural pozzolana, etc

3. CEM III/A or B Cement of blast furnace (CHF)

   Contains from 20 to 64% of clinker and 36 to 80% of slag

4. CEM III C

   Contains from 5 to clinker 19% and at least 81% of slag

5. CEM V made up Cement (CLC)

   Contains from 20 to 64% of clinker, 18 to 50% of fly-ashes, and 18 to 50% of slag

1.1.3 The hardening of cement

"The hardening" of cement is the development and the multiplication of the hydrates in the presence of water. This phenomenon results in the increase of the mechanical resistance of the cement paste. There are three principal phases before the hardening reaches its final state,

1. The dormant phase

   It is the paste of cement which remains seemingly unchanged. It's the gypsum which makes it possible to control the hardening and to provide one period of sufficient use.

2. The beginning and end of hardening

   The beginning of hardening results in an increase in viscosity and a release of heat. When the paste is transformed into a rigid material, it is the end of hardening.

3. Hardening

   It is the period when the mechanical resistance of the cement mortar raises up to its maximum value.

1.1.4 Components of the concretes

Aggregates

It's the natural inert materials which are mixture with cement and water. According to his density, it can be classified into normal (ρ > 2t/m3) or light (ρ < 2 t/m3). The aggregates which we often use for the concrete are the fillers, sands, the fine gravels, and the small gravels. Each rock has specific characteristics in terms of mechanical resistance, hardening behavior, and physicochemical properties. Normally these aggregates are the origin of alluvial rocks origin or massive rocks. The characteristics of these aggregates depend on their nature, according to the layers, and also the process of production.

There are four types of aggregate compared to its size with "the ratio d/D", with d is the lower dimension of the aggregate, and D is the higher dimension of the aggregate.

Table 1. Aggregate family

Family	Dimension	Characteristic
Fillers	0/D	D < 2 mm with minimum of 85% passed at 1,25 mm and 70% passed at 0,063 mm
Sands	0/D	d = 0 et D ≤ 4 mm
Fine Gravels	0/D	D ≥ 6,3 mm
Small Gravels	d/D	d ≥ 2 mm et D ≤ 63 mm

There are three types of the aggregate according to its nature

1. Origin

   Mineral of origin, not having undergone any transformation other than mechanical (such as crushing, sifting, etc.)

2. Artificial

   The result from an industrial process including the thermal or different transformations

3. Recycled

   Origin of material used previously in the construction industry, such as concretes of the demolition of buildings.

Additives

An additive is a product which one mixes in low dose with the concrete, the mortar, or the cement paste during the mixing process or before the pouring to have the required modifications of some their properties, at the fresh or hardened state.

Classification of the additives

According to their principal function, we can classify them in three main categories.

1. The workability of the concrete

   For example: plasticizer and water reducers, super plasticizer.

2. The hardening

   For example: concrete accelerator or retarders.

3. Modification of the particular properties

   For example: air-entraining agents, etc.

1.2 Various shrinkages

The concrete volume changes during its life period. The various types of volume changes/ variations follow one another during the hydration of the cement paste, for example swelling and shrinkage. The shrinkage and swelling are slow modifications of the cement paste's volume during the hardening or in a hardened state and are related to the modification of its state. In this part we present the different types of shrinkage.

Deformation of the concrete, in the absence of the loads applied, which is the consequence of the reduction in volume is called the shrinkage and is related on the change of temperature or the loss of moisture. There are 5 various types of shrinkage differentiated by their origin.

1.2.1 Plastic shrinkage

The plastic shrinkage is caused by the change of volume which occurs in all fresh cementing materials in the first hours after the placement when the mixture is always plastic and does not have yet significant resistance(Toledo Filho, Ghavami et al. 2005). This change of volume is mainly caused by the pressure which develops in the capillary pores of the concrete when the rate of evaporation in the surface water of the concrete exceeds the rate to which the bleeding goes up on surface.

During evaporation, water left the surface of the concrete and form the curved between surfaces of the solid particles in the concrete, introducing surface meniscus. The negative capillary pressure forms in the concrete because of the surface tension in the meniscus, which, alternatively, reduces the distance between the solid particles of the concrete, according to the indications of this figure.

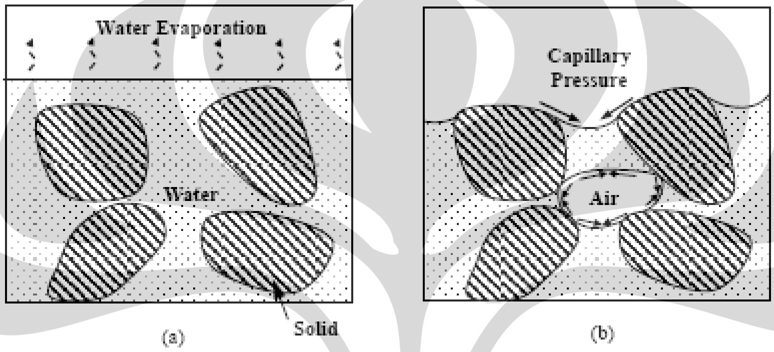

Figure 1. Plastic shrinkage mechanism

In a saturated mixture, the capillary pressure depends on the geometry of spaces between the solid particles close to surface, the quantity of evaporated water and the quantity of water transferred from the interior of the mixture towards surface. The plastic shrinkage can be defined as a volume contraction of the inside reaction where its water constitutes a continuous phase with water meniscuses located on the surface. These water meniscuses will not be the only reason of the plastic shrinkage, indeed possible actions due to the hydration will be taken into consideration.

Consequently, the concrete starts to narrow. If the shrinkage is retained in some way, the tensile stress develops, and the shrinkage crack in a plastic state can occur.

1.2.2 Endogenous shrinkage

The products of hydration obtained at the time of the setting with the water occupy a volume lower than the sum of volumes of the reactive components. It is the chemical shrinkage. Thus at the time a cement paste is made, the vacuums are created in the structure of the hardening paste leading to a fall of the relative humidity interns and thus to a shrinkage called endogenous shrinkage.

A graphic description of the concrete composition’s change due to the reactions of cement hydration is given on the following diagram (Japan Concrete Institute 1999).

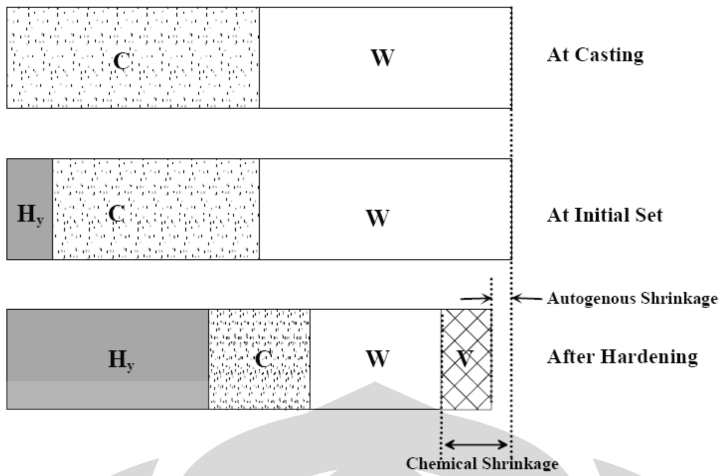

Figure 2. Endogenous shrinkage mechanism

This figure explains how the endogenous shrinkage is a part of the chemical shrinkage. While the chemical shrinkage is an internal reduction of volume, the endogenous shrinkage is an external change of volume. It is thus possible to measure the endogenous shrinkage.

The endogenous shrinkage, from its chemical origin, occurs primarily in the young age and increases when ratio W/C decreases. After a few days, a strong correlation exists between the internal hygroscopic and the free autogenously shrinkage, according to the indications of Baroghel-Bouny (Baroghel-Bouny 1996).

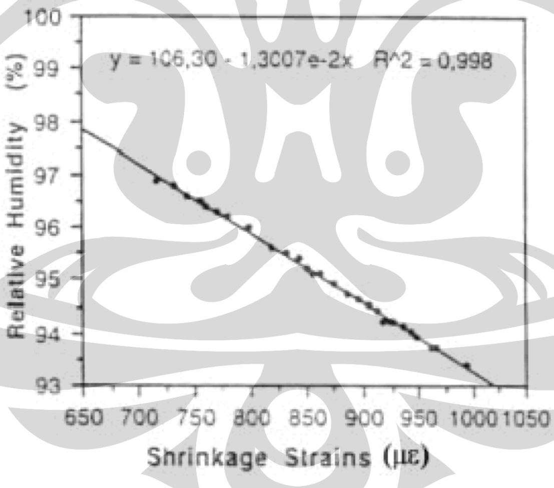

Figure 3. Baroghel-Bouny's Humidity-Strain Relation

The preliminary European standard prEN 1992-1 [Euro codes 2001] is the first which includes a method to envisage the constraint due to the endogenous shrinkage, based in the approximation on the following equation, where the constraint is based on the type of cement and the compressive strength of the concrete.

$$\varepsilon_{cs} = \beta_{cc}(t)\varepsilon_{cs,\infty}$$

With:

εcs	*= the constraint of the deformation of the endogenous shrinkage*
βcc (T)	*= the factor (indicated by the following equation)*
εcs, ∞	*= 2.5 (FC' - 10) X* 10^{-3}

FC' = *compressive strength of the concrete at 28 days*

$$\beta_{cc}(t) = \exp\left\{ s\left[1-\left(\frac{28}{t/t_1}\right)^{1/2}\right]\right\}$$

With:

S = *coefficient which depends on the type of cement (S = 0,20 for the quick-setting cement; 0,25 for normal cement; and 0,38 for a slow-setting cement)*

T = *the age of the concrete (days)*

T1 = *1 day*

1.2.3 Thermal shrinkage

Thermal dilation refers to the volume changes which occur when the concrete undergoes fluctuations of the temperature. Dilation can occur because of the heating or cooling, at all the ages. When the temperature increase, it increase the volume of concrete, then is followed by contraction of concrete. Thermal dilation poses problems when the rate of temperature changes is too large and when the gradients exist in the cross section of the concrete.

In young age, the temperature variation of the concrete can be due to the hydration of cement. In general, there is 5-8°C adiabatic heating by 45 kilograms of cement (Kosmatka and Panarese 1988). A mixture of mortar will thus have a quantity of the heat much larger compared with a mixture of concrete since it is richer in cement. The rise in the temperature occurs typically in the first 12 hours. This can have two consequences. For the massive structures of concrete, variations in temperature can appear revealing auto constraints and often of the cracking in the surface. The cooling led to a thermal shrinkage which if it is prevented will lead to cracking.

Each type of concrete has "a thermal coefficient of dilation" which depends on the various material properties (such as the aggregate, etc). The thermal coefficient by dilation changes very quickly in the young age. The research by Hedlund provided measurements of the thermal concrete coefficients to the young age with time, according to the indications of the diagram (Hedlund 1996).

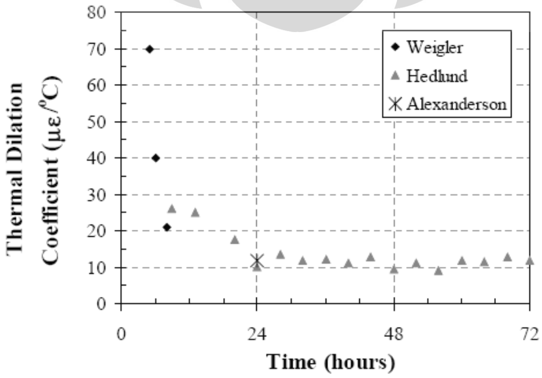

Figure 4. Hedlund Thermal Dilatation Relation

These tests are supplemented with results obtained by Weigler and Alexanderson (Byfors 1980), still providing higher values in the first hours. The thermal coefficient of dilation reaches a value of (roughly) 12 με/°C (12 X 10^{-6}/°C) after 12hours. For the comparison, the thermal dilation coefficient of water in the 23°C is 237 με/°C.

In the posterior ages, dilation or the thermal contraction is the result of the fluctuations of the temperature in the environment. Thus the concrete can fissure if the contraction or growth rates are too large and are prevented. Thermal dilations can indeed be a problem if the concrete is retained in any way and there is no space so that the change of volume occurs, like a large stone retained without joints. These changes depend on the quantity of interstitial water in the concrete.

The typical values of the thermal coefficient of dilation for the concrete are from 6 to 12 με/°C (Mehta and Monteiro 1993). Values according to are the typical values for the Finnish concrete (Jokela, Kukko et al. 1980) are:

Table 2. Aggregate Cement Ration for Thermal Expansion

Aggregate-Cement Ratio	Coefficient of Thermal Expansion (με/°C)
Cement Paste	18.5
1	13.5
3	11.2
6	10.1

1.2.4 Drying shrinkage

Drying shrinkage refers to the volume reduction of concrete resulting from a water loss of the concrete (Neville 1992). When the concrete dries, it narrows as example, a sponge.

During the evaporation of some water particles (bleeding), the concrete is subjected to drying. The most current situation resulting from the drying shrinkage in the young ages is external cracking (Mindess and Young 1981) .

The mechanisms of drying shrinkage depend on the internal pores. The description of the various sizes of pore is represented by a diagram in the figure with the solid particles of the hydrated cement paste.

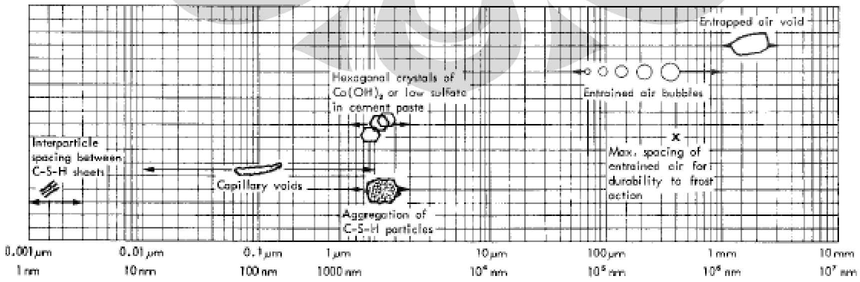

Figure 5. Drying Shrinkage Mechanism

The capillary vacuums are the spaces occupied by the excess water which was removed during reactions of cement hydration. On the diagram, the most present size of the capillary vacuums will shift towards the size of 0.01 μm when the paste has a denser microstructure.

The withdrawal is typically measured on a linear scale, with the conversion of directional measurements into change of total volume given the following equation.

$$VolumeChange = 1 - \left(1 - \frac{shrinkage}{length}\right)$$

The values of drying shrinkage are varies about the 500-1000 με (0.5 to 1 mm/m) in the long time, but it can exceed 5000 με (5 mm/m) in the particular case (Holt 2001), of a accelerated drying during the young age.

1.2.5 Other shrinkages

Carbonation Shrinkage

The carbonation shrinkage occurs when hardened concrete of cement paste reacts with moisture and carbon dioxide in the air (Mehta and Monteiro 1993).

$$H_2CO_2 + Ca(OH)_s \rightarrow CaCO_3 + 2H_sO$$

This has consequence in a light shrinkage and a reduction of the pH of the concrete. The lowering of the pH can be harmful and lead to other forms of deterioration, mainly corrosion of steel. Rust can cause the expansion and the cracking of the concrete (Kosmatka and Panarese 1988).

The quantity of carbonation depends on the density and the quality of the concrete and is usually limited to 2 cm of depth on exposed surface. The quantity depends on the age on the concrete and the environment. The carbonation is generally regarded as a problem at long term.

1.3 Mechanical properties of the concrete

This part presents a literature review on the factors influencing the elastic module and the creep of the concrete and the existing models of prediction.

1.3.1 Modulus of elasticity of the concrete

The modulus of elasticity or “the Young modulus” is defined like the slope of the stress-strain curve within the yield stress of a material (Neville 1992). For a concrete, the secant module is defined like a slope of the traced straight line of the origin of the axis to the curve of stress-strain to a certain percentage of the final force. It is the value which we often use for the design of structure. Since there is no part of the stress-strain curve is a straight line, the standard method to determine the modulus of elasticity is to measure the tangent module, which is defined like the slope of the tangent to the curve of stress-strain to a certain percentage of the compressive strength of the concrete.

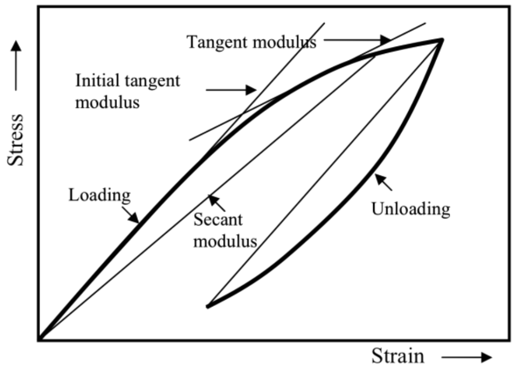

Figure 6. Modulus of Elasticity - Stress and Strain Diagram

The modulus of elasticity is important to evaluate the constraints during dimensional variations.

1.3.1.1 Prediction model of the modulus of elasticity of the concrete

The formulation of the concrete plays a big role in the variation of modulus elasticity. Factors like the type of aggregate and the type of cement are also considerable for the concrete's modulus of elasticity. Although the concrete's modulus of elasticity increases with the resistance of the concrete, a certain number of secondary parameters also intervene. Thus, there is no universal standard of conditions which is applied to associate the compressive strength with the modulus elasticity of the concrete. Some models to predict the modulus elasticity of the concrete are shown below,

Model recommended by LRFD of Florida

According to this conditions, in the absence of the more precise data, the modulus of elasticity for concretes with the unit weights between 0.090 and 0.155 kcf (thousand cubic feet), can be estimated from the following formula: (FDOT 2002)

$$E_c = 33000 \cdot w_c^{1.5} \cdot \sqrt{f_c^{'}}$$

With,

E_c = *the modulus of elasticity (ksi)*

w_c = *density of the concrete (kcf)*

$f_{c'}$ = *compressive strength of the concrete (ksi)*

The equations recommended by ACI to calculate the modulus of elasticity of the concrete are given as follows: (ACI committee 1993)

$$E_c = 57000\sqrt{f_c^{'}}$$

With,

E_c. = *the modulus of elasticity (psi)*

$f_c{}'$ = *compressive strength of the concrete (psi)*

The following equation is recommended by ACI 381-89 (revised in 1992) for a structural analysis which uses a normal concrete: (ACI 1983)

$$E_c = 3.32\sqrt{f_c^{'}} + 6.9$$

With,

E_c. = *the modulus of elasticity (GPa)*

$f_c{}'$ = *compressive strength of the concrete (MPa)*

The following equation is given by ACI 363R- 92 which are applicable to predict the modulus of elasticity to compression force more than 83 MPa:

$$E_c = 3.65\sqrt{f_c^{'}}$$

With,

E_c. = *the modulus of elasticity (GPa)*

$f_c{}'$ = *the compression force of the concrete (MPa)*

Model of CEB - FIP (European Committee)

The European committee proposed a model to predict the elastic module of the concrete which depends on time. (CEB-FIP 1990)

$$E_{ci}(t) = \left(\exp\left(s \cdot \left(1 - \left(\frac{28}{t/t_1}\right)^{0.5}\right)\right)\right)^{0.5} \cdot E_{ci}$$

With,

E_{ci} = *the modulus elasticity of the concrete at 28 days*

s = *the cement coefficient; S = 0,20 for cement in rapid hardening; S = 0,25 for normal cement in hardening; S = 0,38 for cement in slow hardening*

t = *the concrete age (days)*

t_1 = *1 day*

1.3.2 Differed modulus of elasticity of the concrete

When a concrete is subjected to a permanent constraint, it undergoes an elastic strain first then a differed deformation called creep (see the graph). In the absence of drying, we speak about endogenous creep, in the presence of drying we speak about total creep.

During unloading, the recovery process is not total and a permanent deformation persists.

The creep stress is composed of two principal components. The first component is the true creep or the basic creep, which occurs under the conditions without movement of moisture or the ambient support. The second component is the shrinkage creep, which is caused by drying. Normally, the creep stress which is considered in the structural design is the sum of basic constraint of creep and constraint of creep drying.

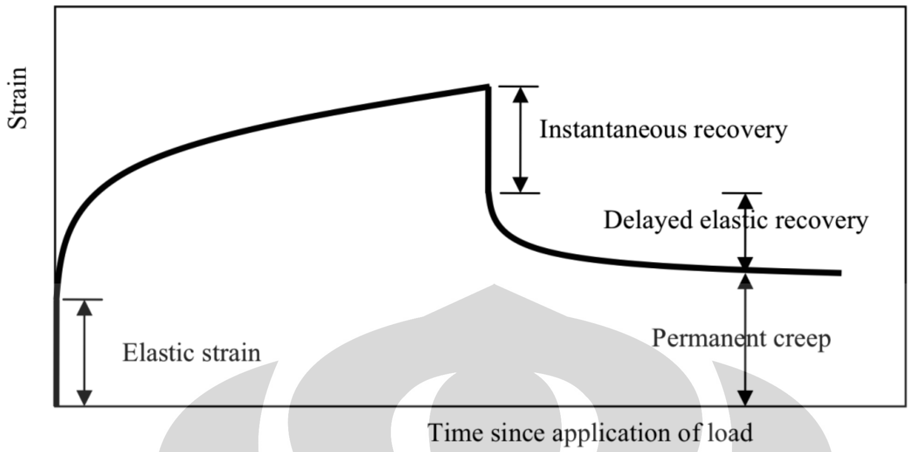

Figure 7. Various Strain

Creep on the concrete can have two effects: one positive, the other negative on the concrete structure. The positive side, creep can relieve the force concentrations induced by the shrinkage, the change of temperature, or the movement of the supports. For example, in a beam with two fixed ends, the deformation caused by creep will be very useful by reducing the tension load caused by variation of shrinkage and temperature.

In addition, creep can be dangerous for the safety of the structures. Creep can lead to an excessive deflection on the structure, or a loss of pre-stress in the case of pre-stress works. For the pre-stress structure, such as the composite bridges, of the pre stress carcasses, the continuous beams, the desirable creep of the concrete would be also low possible.

Models of creep

Independently of any models of creep, the rheological or the numerical one, used to envisage the relationship between the deformation of creep and time, none of them can give us a precise prediction. The components of the concrete as well as the environmental conditions on the behavior of creep make the value prediction difficult.

However, when the data of creep are not available for a specific concrete and that it is not possible to make a creep test, equations can be employed to obtain an estimate of the creep stress.

Equation of LRFD (FDOT, 2002)

This method is presented by Collins and Mitchell (1991), is based on the recommendation of the committee of ACI 209 with the addition of the recent data. According to this method, the coefficient of creep can be calculated with this formula, (FDOT 2002)

$$\varphi(t,t_1) = 3.5k_c k_f \left(1.58 - \frac{H}{120}\right) t_1^{-0.118} \cdot \frac{(t-t_1)^{0.6}}{10.0 + (t-t_1)^{0.6}}$$

With,

$$k_f = \frac{1}{0.67 + \left(\frac{f_c'}{9}\right)}$$

H = *relative humidity*
k_0 = *the factor which is affected by the ratio of volume on the surface*
k_f = *the factor of the force of the concrete*
t = *the age of the concrete (days)*
t1 = *the age of the concrete when the load is initially applied (days)*

Model of CEB-FIP (1990)

The creep stress can be calculated by using this formula, (CEB-FIP 1990)

$$\varepsilon_{cr}(t,t_0) = \frac{\sigma_c(t_0)}{E_{ci}} \cdot \phi_{28}(t,t_0)$$

With,
$\varepsilon_{cr}(t,t_0)$ = *the creep stress at the time*
$\sigma_c(t_0)$ = *the load applied*
$\phi_{28}(t,t_0)$ = *the coefficient of creep*

$$\phi_{28}(t,t_0) = \phi_0 \cdot \beta_c(t-t_0)$$

With,
ϕ_0 = *the coefficient of initial creep*
β_c = *the specific coefficient of creep*
T = *the age of the concrete (days)*
t0 = *the age of the concrete to the loading (days)*

$$\phi_0 = \phi_{RH} \cdot \beta(f_{cm}) \cdot \beta(t_0)$$

$$\phi_{RH} = 1 + \frac{1 - RH / RH_0}{0.46 \cdot (h / h_0)^{1/3}}$$

$$\beta(f_{cm}) = \frac{5.3}{\sqrt{f_{cm} / f_{cmo}}}$$

$$\beta(t_0) = \frac{1}{0.1 + (t_0 / t_1)^{0.2}}$$

$$\beta(t - t_0) = \left[\frac{(t - t_0)/t_1}{\beta_H + (t - t_0)/t_1} \right]^{0.3}$$

$$\beta_H = 150 \cdot \left[1 + \left(1.2 \cdot \frac{RH}{RH_0} \right)^{18} \right] \cdot \frac{h}{h_0} + 250 \le 1500$$

With,

f_{cm}	$= f_{ck} + \Delta f$
h	*= notational dimension (mm) = 2Ac/u*
A_c	*= surface (mm2)*
U	*= surfaces it contact of the atmosphere (mm)*
h_0	*= 100 mm*
RH	*= relative humidity (%)*
RH_0	*= 100%*
t_1	*= 1 day*

E_{ci} = the modulus of elasticity at 28 days
With the estimation of modulus of elasticity as follows,

$$E_{ci} = \alpha_E \cdot 10^4 \cdot \left(\frac{f_{ck} + \Delta f}{f_{cmo}}\right)^{\frac{1}{3}}$$

With,

F_{ck}	*= the characteristic of the concrete (MPa)*
Δ_f	*= 8 MPa*
f_{cmo}	*= 10 MPa*
α_ε	*= 2,15 X 10^4 MPa*

<u>Model of ACI 209</u>

ACI proposes following formulation to define the creep stress (ACI committee 1993).

$$\phi_{28}(t,t_0) = \phi_\infty(t_0) \cdot \frac{(t-t_0)^{0.6}}{10+(t-t_0)^{0.6}}$$

With,

$\phi_{28}(t,t_0)$ = *the coefficient of creep at the time*

$\phi_\infty(t_0)$ = *the final coefficient of creep*

t0 = *the time of load*

The final coefficient of creep can be expressed:

$$\phi_\infty(t_0) = \gamma_c \cdot \phi_\infty$$

With constant the ϕ_∞ = 2,35 recommended. The factor of correction γ_C can be calculated by using this formula,

$$\gamma_c = \gamma_{la} \cdot \gamma_{RH} \cdot \gamma_{at} \cdot \gamma_s \cdot \gamma_\rho \cdot \gamma_a$$

γ_{la} = *the factor of correction for the age of load.*

- *For the age of load more than 7 days* $\gamma_{la} = 1.25 \cdot (t_0)^{-0.118}$
- *For the age of load more than 1 - 3 days* $\gamma_{la} = 1.13 \cdot (t_0)^{-0.094}$

γ_{RH} = *the factor of correction for the relative humidity, For relative moisture larger than 40%,* $\gamma_{RH} = 1.27 - 0.0067 \cdot RH$ *(with RH is the relative humidity percent some)*

γ_s = *the factor of correction for the freshly-mixed concrete (test of cone)*

$\gamma_s = 0.82 + 0.00264 \cdot S_l$ *(with SSL is depression with the cone in mm)*

γ_ρ = *the factor of correction for the air-entraining agent* $\gamma_a = 0.46 + 0.09 \cdot a_a$ *(a_a = contents of air)*

γ_{at} = *the factor of correction for the thickness of the member of structure.*

$$\gamma_{at} = \frac{2}{3} \cdot \left[1 + 1.13 \cdot e^{-0.0213 \cdot (\frac{v}{s})} \right]$$

(With v/s the volumetric ratio on the surface in mm)

1.4 Effects on the roadways crack

All the shrinkages mentioned above are primarily restraint shrinkages. Along with the development of the elastic module, they lead, generally, into the cracking of the concrete surfaces when the generated constraint exceeds resistance in traction.

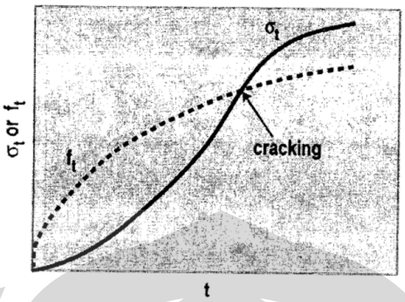

Figure 8. Mechanism of cracking - Stress over Time

1.4.1 Restrained shrinkage leads to cracking

The analysis and the interpretation of the restrained shrinkage obtained by using a concrete shaped like a ring around a metal ring are rounded together to quantify the characteristics of cracking due to the shrinking of concrete or mortar of Portland cement (See, Attiogbe et al. 2003). This method is well adjusted particularly to determine the relative probability of cracking in the young age of various formulations of concrete and mortar. The real cracking, which occurs during serviceability, depends on many variables, such as the type of structure, the degree of constraint, the methods of construction, and the environmental factors during the cure and the life of the structure.

Cracking is becoming more current and it's generally considered as the increasing use of high performance concretes and thus water/cement ratios (W/C) increasingly weak. Indeed, the desiccation increases in intensity with the reduction of W/C. Thus, this phenomenon would be one of the main causes of cracking in the young age concrete.

Shrinkage, particularly the endogenous shrinkage, can cause cracking when the concrete is not free deformed (Pigeon, Toma et al. 2003). A testing method was proposed by Pigeon to evaluate the shrinkage phenomena during the first 24 hours. These tests use 2 types of cement: the first with a normal Portland cement and the second one with cement containing silica smoke, with W/C ratios used differ from 0,25; 0,35; and 0,45.

The analysis of the restrained shrinkage during the first 24 hours makes it possible to experience the development of the important constraint when the concrete is hardening. Moreover, this method enables us to evaluate further the viscous deformation, which is equal to the difference between the cumulative sum of the deformations in the test-tube subjected to the restrained shrinkage and the value of the shrinkage measured in the test-tube simply subjected to the free shrinkage (Pigeon, Toma et al. 2003).

$$\varepsilon_{visqueuse} = -\left\| \sum \varepsilon_{cumulatives\ de\ retrait\ empêché} - \varepsilon_{retrait\ libré} \right\|$$

Thus, we notice important results on the method of Pigeon that:

1. Deformation of the concrete during the first 24H can't be neglected

Table 3. Deformation of Concrete during Curing

Measurement	**Normal Cement (Portland)**						**Cement with fly ash**					
	0,25	0,35	0,45	0,25	0,35	0,45	0,25	0,35	0,45	0,25	0,35	0,45
	24 H			**7 days**			**24 H**			**7 days**		
Free Shrinkage (µm/m)	255	104	3	456	252	128	293	160	62	517	282	138
Liquid Deformation (µm/m)	222	71	-5	354	171	66	197	89	30	336	169	89

2. The 100% increase in the shrinkage (due for example to a fall of W/C ratios) generally does not cause such a high increase in the constraint.
3. The importance of this phenomenon is clearly very large (with the effects of creep, of relaxation, etc.) and to analyze the risks of cracking in the young age only from the free shrinkage would be an error.

The combined effects of the rate of deformation and creep have a significant influence over the time net of cracking(See, Attiogbe et al. 2003). This two indicates that the rate of the development of the force in material due to drying is the dominant factor which controls time net of cracking.

The restrained shrinkage tests (with the ring around the concrete) were also carried out to find the relation between the shrinkage and the time of cracking. It is found that the constraint, which is developed in the ring, is the part of the free shrinkage which is allowed to occur under the conditions selected. Thus, the relation between the force of cracking and the time net are,

$$S(t) = \frac{G|\alpha|}{2\sqrt{t}}$$

With,

S(t) : *Cracking force (MPa/day)*

G : *Ring constant (GPa), by equation G=,,E-st.,r-ic.,h-st.-,r-is.,h-ic..*

α : *Deformation constant*

t : *Time Net*

For G = 72,2 GPa, and α = 1,27^{e}-5 ;

Table 4. Net-Time to Cracking

w/cm	Mixture I.D.	Curing Method	Net Time-to-Cracking, t_{cr}, Days	Stress Rate Cracking, MPa/Day[a]
0.45	NSC-1	1 day in mold	21.00	0.10
	NSC-2 (SRA)	1 day in mold	32.00	0.08
0.55	NSC-3	7 days moist	52.00	0.07
	NSC-4	7 days moist	49.00	0.08
	NSC-5	7 days moist	40.50	0.09
0.35	HPC-1	1 day in mold	5.50	0.30
	HPC-2 (SRA)	1 day in mold	18.25	0.15
	HPC-3	5 h in mold	3.75	0.67
	HPC-4	5 h in mold	6.25	0.56
0.30	HPC-5	5 h in mold	5.75	0.58
	HPC-6	5 h in mold	5.50	0.50
	HPC-7	5 h in mold	6.75	0.50
	HPC-8	5 h in mold	5.25	0.59
	HPC-9	3 days moist	9.00	0.30
	HPC-10	3 days moist	12.50	0.18
	HPC-11 (SRA)	5 h in mold	134.00	0.03
	M-1	3 h in mold	1.25	1.33
	M-2	3 days moist	4.25	0.43
	M-3	3 days moist	79.25	0.02
	M-4	3 days moist	1.75	0.57

1.4.2 Simplified calculation of tensile stresses

For approaching the practical use of the inflating concrete, it is necessary to better know initially its mechanical properties by looking at all the possible components (such as creep, the capacity of the concrete to traction, etc.).

We can estimate, on the basis of calculation using BétonlabPro, the following properties for a standard road concrete:

- Total shrinkage of 700e-6
- Total creep of 70e-6/MPa
- Thermal dilation coefficient of 10e-6/°C
- Elastic modulus instantaneous of 40 GPa
- Tensile strength of 3,4 MPa (in general)
- Compressive strength from 35 to 40 MPa

We found that the length change due to thermal shrinkage is equal to

$$\Delta\varepsilon = (T - T_0) \times 10 \times 10^{-6}$$

With,

T_0 = *Concrete temperature during its hardening state*

T = *Ambient temperature*

Thus,

$$\Delta\sigma = E \times \Delta\varepsilon$$

Two extreme cases can be studied: a casting with T_0=5°C or T_0=40°C, with the surrounding temperature varies -10°C until 40°C. It is found that (T-T_0) can vary between 35°C and -50°C.

1. If T_0 = 5°C,

   Δε varies between -1,5^{e}-4 and 3,5^{e}-4

   Δσ varies between -6 MPa and 14 MPa

2. If T_0 = 40°C,

Δε varies between 5^e-4 and 0

Δσ varies between -20 MPa and 0

The differed elastic module is equal to 10,53 GPa. Thus the maximum constraint due to the withdrawal is -7 MPa.

At the worst case for,

T_0 = 5°C, varies between -13 MPa à 14 MPa

T_0 = 40°C, varies between -27 MPa à 0

In the first case if we compensate 11 MPa, the constraint oscillates between -2 MPa and 25 MPa. There won't be any cracking but buckling risk is pertinent.

In the second case if we compensate 25 MPa, the constraint oscillates between -2 MPa and 25 MPa.

It shows that thermal factor is dominating, thus these actions are necessary,

1. Have a more constant thermal variation (modify the bottom/base layer)
2. Have a weaker elastic module
3. Generate expansive force

The expansion of concrete makes it possible to have the 3rd point and probably the 2nd point. Moreover, the absence of cracking can develop only in the bottom/base layer.

CHAPTER 2

THE TREATED GRAVEL WITH HYDRAULIC BINDER OR THE LEAN CONCRETE

In the road construction field, the use of the treated gravel is well-known in the base layer or in foundation to improve the properties of the ground, or for better transferring the force from surface on the ground. There exist a certain number of the treated gravels which are defined in standards NF EN 14-227-1. These gravels are classified by their binders. It is also differentiated by its dry materials which are implemented by compaction.

- Gravel – Cement (NF P 98-116)
- Gravel – Pouzzolanes – Lime (NF P 98-117)
- Gravel – Slag (NF P 98-118)
- Gravel – Fly Ash – Lime (NF P 98-119)
- Gravel – Hydraulique Ash (NF P 98-120)
- Gravel – Special Road Binder (NF P 98-122)
- Gravel – Slag – Fly Ash – Lime (NF P 98-123)
- Compacted Road Concrete with Modified Treated Gravel (Hydraulic Binding) and High Performance Pouzzolanes (NF P 98-128)

2.1 Treated Gravel

Treated gravel with hydraulic binders are the mixture of gravel and the hydraulic binders, such as hydraulic cement, in this case we speak about "gravel - cement", or a road special binder, or a slag, or a slag-lime mixture, or fly ashes-lime, even pouzzolane-lime. The content of binding is about 5% (Gravel (Aggregate), 2006). The treated gravel with the hydraulic binder is specified to standard NF P 98-122 (treated gravel for road), replaced in February 2000 by NF P 98-116 (treated gravel with the hydraulic binder). We will also speak about the application of these products.

In the technical guide of the concrete roadway (France), the proportion of the lean concrete is following:

Table 5. Proportion of Lean Concrete

	Binder nature	Standard dosage
Traited gravel	Cement	3 – 4%
	Special Road Binder	3 – 5%
	Pre-Crush Slag + Activator	8 – 15%
	Granulated Slag + Activator	8 – 20%
	Pouzzolanes + Lime	15 – 25%
	Fly Ash Silico-Aluminate + Lime (80% Active Lime + 20% Passive Lime ou 86%	10 – 15%

	AL + 14% PL)	
	Hydraulic Ash	3,5 – 4%
Compacted Road Concrete	Cement and Road Special Binder	5 – 12%
	Activated Slags	10 – 20%
	Fly Ash Silico-Aluminate + Lime	13 – 20%

2.2 Lean Concrete

Lean concrete is implemented by vibration and is characterized by a weak cement proportioning compared to the surface's concretes. The following table proposes an example of lean concrete composition for road application.

Table 6. Lean Concrete Composition

Lean Concrete (Technical Guide : Concrete Roadways)	
Sand 0/5	860 kg (39%)
Gravel 5/25 silica calcaire	935 kg (42%)
Plastifiant	1,25 kg (0,05%)
Air entertainer	0,025 kg (0,001%)
Cement CPJ – CEM II/A 32,5	250 kg (11%)
Water	170 l (7%)

Compared to the problems of the cracking on the surface concrete, two principal conditions in the case which differ the lean concrete and the treated gravel is its mechanical performances and especially, from the weaker thermal variations since lean concrete is in the base courses or foundation.

The technical guide (FRANCE): Design and dimensioning of the structures of roadway proposes a value of resistance in traction in 360 days (Rt360) as the value used in the calculation of dimensioning (1994).

Table 7. Traction Resistance

Material	R_{t360} min (MPa)
Cement Gravel	1,15
Road Gravel	
Hydro-Ashes – Gravel	
Granulated Slag - Gravel	0,9
Pre-crush slag - Gravel (Lime)	
Pre-crush slag - Gravel (Sulfate activated or calcium)	1
Gravel – Silica Alumina Fly Ash - Lime	2,1
Compacted Concrete	2,8

This guide also proposes some typically elastic modules,

Table 8. Module of Elasticity for the Lean Concrete

Material	E (GPa)	E_{360} (GPa)
Cement Gravel Road Gravel Hydro-Ashes – Gravel	23	≤ 40
Granulated Slag - Gravel Pre-crush slag - Gravel (Lime)	15	≤ 20
Pre-crush slag - Gravel (Sulfate activated or calcium)	20	≤ 25
Gravel – Silica Alumina Fly Ash - Lime	30	≤ 45
Compacted Concrete	28	-

2.3 Analysis between Treated Gravel and Lean Concrete

As the thermal variation on the base courses is more constant, there will be probably the risk of cracking.

For the treated gravel, we have following values,

- Modulus of elasticity of 25 GPa
- Creep of 100^{e-6}MPa
- Complete shrinkage of 300^{e-6} MPa

For the lean concrete,

- Modulus of elasticity of 35 GPa
- Creep of 60^{e-6} MPa
- Shrinkage of 300^{e-6} MPa

For the thermal variation on the base courses, we consider a lower value. In some scientific journal the temperature during the placing of the concrete of surface road must between 10 and 35°C. A data sheet of transport makes by the ministry of Walloon (Belgium), proposes that the implementation is prohibited when the temperature of the air measured under shelter, to 1,5 m of the ground, is ≤1°C the morning and ≤-3°C the night. We thus fix a thermal variation going from -5°C to 15°C for the base courses.

Two extreme cases can be studied: a casting with T0=5°C or T0=30°C. It is found that (T-T0) can vary between -35°C and 10°C.

For the treated gravel, **If T_0 = 5°C,**

- Δε oscillates between -1^{e-4} and 1^{e-4}
- Δσ oscillates between -2,5 MPa and 2,5 MPa

If T_0 = 30°C,

- Δε oscillates between $-3{,}5^{e-4}$ and $-1{,}5^{e-4}$
- Δσ oscillates between -8,75 MPa and -3,75 MPa

The differed elastic module is equal to 7,14 GPa. Thus the maximum constraint due to the shrinkage is -2,14 MPa.

At the worst case for,

- T_0 = 5°C, we oscillate between -4,54 MPa with 2,5 MPa,
- T_0 = 30°C, we oscillate between -10,89 MPa with -5,89 MPa

In the first case if we compensate for 3,5 MPa, the stresses oscillate between -1,04 MPa and 6 MPa. In the second case if we compensate for 9,8 MPa, the stresses oscillate between -1,09 MPa and 3,91 MPa.

For the lean concrete, **If T_0 = 5°C,**

- Δε oscillates between -1^{e-4} and 1^{e-4}
- Δσ oscillates between -3,5 MPa and 3,5 MPa

If T_0 = 30°C,

- Δε oscillates between $-3{,}5^{e-4}$ and $-1{,}5^{e-4}$
- Δσ oscillates between -12,25 MPa and -5,25 MPa

The differed elastic module is equal to 11,29 GPa. Thus the maximum constraint due to the shrinkage is -3,38 MPa.

At the worst case for,

- T_0 = 5°C, we oscillate between -6,88 MPa with 3,5 MPa
- T_0 = 30°C, we oscillate between -15,63 MPa with -8,63 MPa

In the first case if we compensate for 5,8 MPa, the stresses oscillate between -1,08 MPa and 9,3 MPa. In the second case if we compensate for 14,5 MPa, the stresses oscillate between -1,13 MPa and 5,87 MPa.

In both cases, we compensate such a value of constraint to compensate the force of traction of the concrete. On the other hand, the compression force increases, and buckling risks is relevant. Hortet studied this problem in the case of the pre-stressed roadways (De l'Hortet 1963). The buckling of a beam curves (in the direction of the profile longitudinally) occurs when the bending moment (2nd order) generated by the compression of the beam exceeds the back moment, which is caused by self-weight, intervening with the separation of the beam. That can be given by curvature R:

$$R \leq R_{crit} = \frac{\sigma}{\rho g}$$

With,
σ = Compression constraint

The minimal radius of curvature in the longitudinal direction can be estimated by considering the plane defect that has a wavelength L=50 m by

$$R = \frac{L^2}{4\pi^2 a}$$

With $L=50$ m, $a=0,1$ m, $\rho = 2400$ kg/m3, $g=10$ m/s2, we thus find non buckling condition of $\sigma < 15$ MPa.

Thus a priori in the base courses, there is no risk of buckling; on the other hand in the surface concrete, there is a systematic risk of buckling if we completely compensate the risks of cracking by shrinkage. In this case, two solutions are possible: reducing the compensate force for the shrinkage and pre-cracking system. In the second case, it will not be interesting if the step of pre-cracking is definitely higher than what is usually made, which is usually in a step of 5 m maximum. This pre-cracking will have to be able to compensate the dissipation efforts of swelling/expansion and to allow shrinkage without new cracking or important opening of the pre-cracking.

CHAPTER 3
HOW TO INFLATE THE CONCRETE

In order to limit the risks of cracking, a certain number of solutions were developed which aims either at limiting the shrinking of the concrete, or straightforwardly to make inflate the concrete. In this chapter we will describe these solutions as well as the tests which make it possible to evaluate the deformations of the concretes.

3.1 Existing measurements

3.1.1 Free Deformation Test

The change of the concrete volume due to the shrinkage or expansive force in the free-state condition has, in general, the same testing method. The test which is known as “traditional mechanical test” uses a measuring device such as a *refractometer* to measure the change length in μm during a certain definite time.

There already exist standards to measure the change length of the concrete. French standard NF P 18427 described a free shrinkage test on concrete. The test consists in measuring using a comparator, the variation length between 2 opposite faces of prismatic test-tubes 7x7x28 cm or 10x10x40 cm equipped with studs drowned during the casting (cage system). The free shrinkage tests on mortar are described by standard NF P 15-433. French standard NF IN 12617-4 described later below explains briefly the determination of the shrinking and the expansion of concrete.

American standards such as, ACI (C157M-04 2004) also proposes a method on concrete test-tube of 75x75x279 (mm) and a comparator length which is specified by ACI 490.

The tests can be carried out as soon as it is possible to un-mould the test-tubes. The conditions of conservation (temperature and hygroscopic) can be adapted to the needs. In general 20°C and 50% relative humidity contractually are chosen.

It is thus important to specify at the result age presentation time from which measurements were made (because a certain quantity of shrinkage can take place before the first measurement) as well as the conditions of conservation.

<u>NF EN 12617-4 - Determination of the shrinkage and expansion</u>

This standard proposes a method of measuring of the dimensional stability (expansive/shrink) resulting from the variations of water content of the hydraulic mortars or hydraulics concrete (CC), or mortars or hydraulic polymer concretes cement (PCC). This method applies to the pastes, mortars, or with the products for concrete whose aggregate size does not exceed 10 mm (NF EN 12617-4 2002).

The determination of the shrinkage and expansion is carried out according to two different testing methods, for the products of CC and PCC. The first method measure the unconstrained linear movement coming from the immersion in water (expansion) or from dry conditions (shrinkage) of prismatic test-tubes 40 X 40 X 160 mm, from 24H until 56 days after casting.

The second method measure the loss of adherence and the evaluation of the tendency to cracking, when the product tested is applied to a support of 300 X 300 X 100 mm in the reference concrete and subjected to an immersion in water or dry conditions.

<u>Procedure for the unconstrained movement</u>

The preparation of the test tubes must be conditioned in the standard atmosphere before mixing, for 24H minimum. Mortars PCC and CC use mortar mixers regulated at low speed, by pouring the liquid in the container then the dry ingredients and mix them for two minutes in all. Preparation of the test tube must be formed with the requirements of the 4.5 of EN 196-1: 1994.

Table 9. 3 Chambers Mould

There are two types of test-tube's cage which we can use. Type 1 must be fixed at the mould using bolt through the bored hole with the center of the plates forming the bottom to be screwed on the threaded end of the cage, thus guaranteeing the centering of the specimen. Type 2 must be inserted in the bored holes with the center of the plates in the bottom of the moulds, in contact with the conical part of the hole, and while doing this, careful not to move them during the preparation of the test-tube.

The product must be carefully compacted in the moulds, using a small diameters solid-pipe to guarantee a complete compaction.

Measurement is made by the measurement of the calibration tube. It is necessary to have a point of alignment to mark the first measuring. When we make turn the calibration tube in the measuring device, the value posted by the apparatus should not vary ± 0,001 mm; the measured values must be noted with a margin of 0,001 mm.

Once the first measuring carried out, the test-tubes must be put on the triangular grid which does not prevent the expansion or the shrinkage of test-tubes. The room temperature after the release from the mould must be preserved of 21 ± 2 °C, with a relative humidity of 60 ± 10 %. The frequency of measurements is normally within 1,3,7,14,28, and 56 days after the release from the mould.

The value posted by the measuring device must initially be checked using the calibration tube according to the general method. At the end of a series of measuring, the value corresponding to the calibration tube must again be raised. If, at any age, the variation in the length of a test-tube in a set of three test-tubes at least, exceeds the most comparable test-tube more than 0,5 mm/m, it is appropriate to determine the cause of it (for example dust, insufficient contact, lack of fixity of the studs, etc.). If the problem cannot be solved, the test-tube must be eliminated.

The variation length must be calculated according to the initial value recorded (*Lo*) at the end of 24H. The variation in the length (ΔL) must be expressed in terms of deformation compared to the reference length (*Lg*), in mm/m, accuracy of 0,01 mm/m.

$$\text{Contrainte} = \frac{\Delta L \times 1\,000}{L_g} \text{ [mm/m]}$$

After each measuring, it is recommended to determine the change of the test-tube mass during the test, expressed in specific variation of mass (*m*). The test-tube must be weighed with a margin of 0,1gram, to determine the absorption or the loss of water. The variation of the specific mass can then be calculated starting from the variation of the mass (ΔM) given as follow

$$m = \frac{\Delta M \times 100}{M_0} \text{ [\%]}$$

3.1.1.1 American Standard

The standard of ASTM C490-04 measures the length change of the concrete or the mortar of the hydraulic cement base (C 490 1994). This standard defines the change length like the increase or the reduction in linear dimension of the specimen, while measuring according to the longitudinal axis, due to the causes other than the force applied. This standard specifies the requirements on the material, the conditioning and the number of specimens, the interpretation of the results and the precision of the test.

The principle of operation of the apparatus is,

1. Preparation of the mould having a dimension of 25x25x285 (mm). A smaller mould can be used (25x25x160 mm) with remarks in the event of argument.
2. Anti-sticking products, which don't have any serious effect to the specimen, can be used to cover the surface of the mould. The paste of cement is poured in two layers for the reason of compactness.
3. The relative humidity for the room of storage of the specimen is kept to 50% with a temperature of 23±4°C.
4. Measurement is done with a length comparator having a dial micrometer (accuracy of 0,0001 mm). Thus, we can calculate the change length,

$$L=,(,L-x.-,L-i.)-G.\times 100$$

With:

L : *length change in time x, %*

Lx : *speciment length in time x*

Li : *initial length*

G : initial length of the tube (250mm)

<u>The non standardized measurement of free expansion</u>

<u>Measuring device US7.240.545 B1</u>

This apparatus was developed to measure the cement grout deformations used to block the oil drainage pipes in wells of oil drillings. During drilling, it is necessary to have a good insulation between the solid mass ground and the metal pipe. Cement will be injected to block the development of the escapes of the fluids. It is thus necessary to make sure of the dimensional stability of these pastes. In order to represent of the real conditions, this test makes it possible to control the conditions of temperature and pressure imposed on the pastes.

The apparatus is as follow,

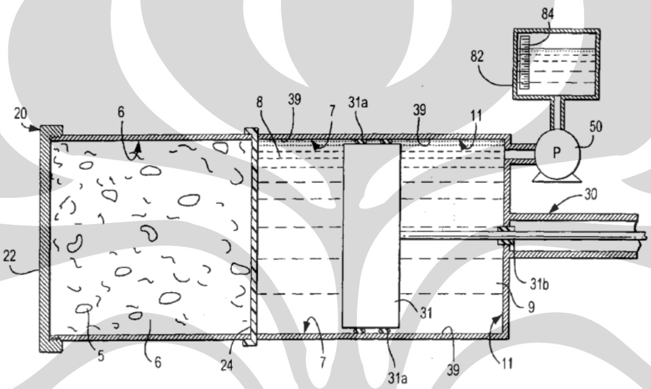

Figure 9. Oil Dedied Measuring Device

1. A reserve of pressure having two functions, to set up the test sample and to provide an exposed surface.
2. A flexible joint, which makes an isolating barrier to the sample from the fluid.
3. A sliding piston separating two rooms: in the first room is a pressurized incompressible medium in contact with the joint; the second room is connected to the tank.
4. An external reservoir provided with a pump.
5. A sensor system connected to the piston to measure the displacement of piston according to the change of volume of the test sample.

The principle of operation of the apparatus is the following:

1. The pump imposes by the means of the fluid a pressure on the piston, which in its turn imposes the pressure on the mixture via the fluid and the flexible joint.
2. When the material undergoes a change of volume, the piston moves, and the pump adjusts the pressure in the tank to keep it constant.
3. We measure then using a LVDT by the displacement of the piston, which translates the deformation of material in time function.

4. It should be noted that the temperature of the test could be controlled by immersion in oil bath, radiant sources, and electric rollings.

The measurement expansive forces

Subauste and Odler propose an automated measuring device to find the force exerted when the concrete inflates (Colan Subauste and Odler 2002). A mould is composed of a room having a dimension of 15x15x60 (mm) and a block of measurement connected to a signal amplifier to measure the force generated by the concrete expansion.

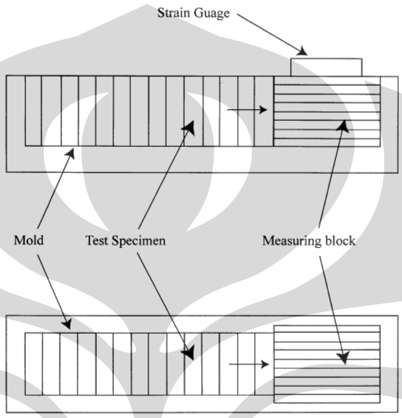

Figure 10. Subauste and Odler Measuring Device

The mould is manufactured in high rigidity steel (Steel C60 CK60 DIN 17200, Rm = 780-910 MPa, Re 490 MPa), on the other hand, the block of measurement (here the "measuring block") is manufactured in low rigidity steel, which makes it possible to have measurable deformations during expansion (Steel X5 CrNi 189, DIN 17440). A sensor of deformation (standard 3/120 LY11 Hottinger), is put at the top of the block of measurement. The captured signal is amplified by Semmeg 9000 (type 97202 to amplify the signal, and type 97302 to display the result).

The relation between the force applied and the deformation of the blocks of measurement is calibrated using a hydraulic press. It also important to check the rigidity of the moulds, which is rigid compared to the blocks of measurement to not interfere the results.

3.1.2 Essay of restrained deformations

The test of prevented deformations can be divided in two terms, the test of the prevented shrinkage and the test of prevented expansion. Those are different from the test of free deformations which has almost the same method for the shrinkage and expansion.

The prevented shrinkage test

The free shrinkage test is not directly related to the tendency of material to fissure. Indeed, cracking utilizes the evolution of the shrinkage but also the evolution of the mechanical performances. The withdrawal will be detrimental if only it is restricted and if the concrete has a sufficient module to generate tensile stresses.

This is why the measures of prevented shrinkage were proposed. We can find a presentation of test principle, such as (AASHTO PP34 1998; Mokarem 2002), This method creates concrete ring around an instrumented steel ring.

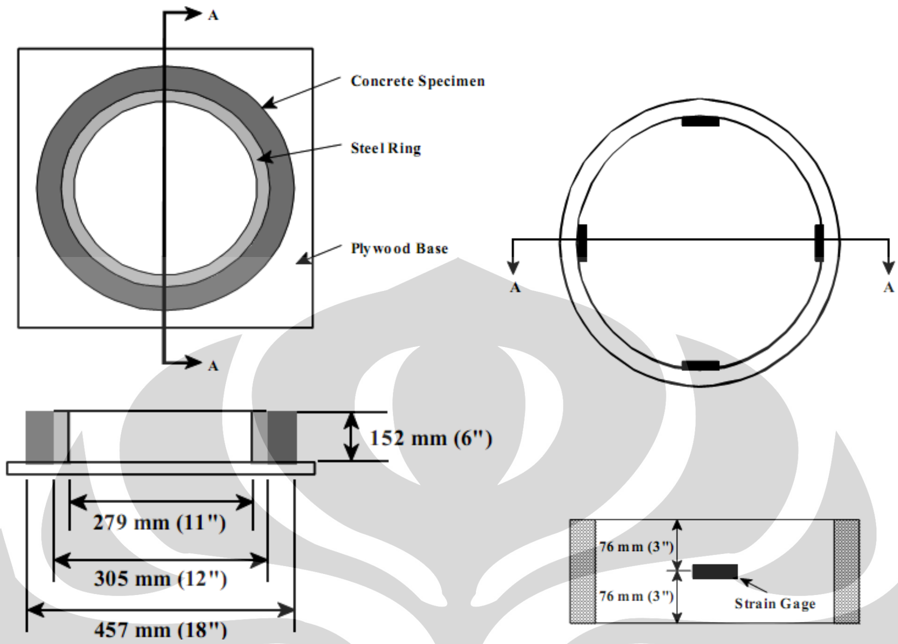

Figure 11. Ring Test

When the concrete narrows, a compressive force appears in the ring, which is, normally, equalizes with the force of traction of the concrete. If the crack appears on the concrete, the constraint on the ring minimizes. This test takes into account the mechanical effects of the shrinkage just after the casting. The time of appearance of a macro crack in the concrete can be used as indicator of susceptibility to cracking. As for the free shrinkage tests, the environmental conditions can be adapted to the needs.

The shrinkage test in young age

At the time cement is mixed with water, there exists continuation of chemical reactions, which are accompanied by a chemical shrinkage leading to the endogenous shrinkage. Pigeon et al. showed that the deformations observed as of the first 24 hours are not negligible whereas in general the shrinkage tests do not start normally before 24H (Pigeon, Toma et al. 2003).

A testing device was proposed to measure the shrinkage in young age. This apparatus comprises a simple dilatometer which making it possible to measure the free endogenous shrinkage from time t=0 (just after the casting), as well as a device with a mobile head to measure from the same moment when the stress generated by the prevented shrinkage.

The apparatus is composed of a mould of 50x50x1000 (mm). After mixing, paste concrete is placed directly on the mould and immediately sealed to avoid any exchange of water. At the beginning, in the assembly with mobile head, the engine is controlled so that the constraint remains zero and the test-tube becomes deformed freely (in shrinkage or expansion) until the recorded deformation reaches a predetermined value. At this time, the system applies to the test-tube the force which is necessary to bring it back to its original. The test-tube then continues to become deformed, while supporting the load applied, until the deformation reaches again the predetermined value. At this time, the force is again increased in order to bring back the test-tube to its original. These ways allow:

Measuring the evolution of the constraint according to time in the test-tube subjected to the prevented shrinkage.

Evaluate the viscous deformation (or creep) in this test-tube, by dividing at the moment T the cumulative sum of the deformations in the test-tube subjected to the prevented shrinkage the value of the measured shrinkage in the test-tube simply subjected to the free shrinkage.

Another method of measurement of LCPC, known by the project of BTJADE, which is being studied by Boulay (Boulay 2008), proposes a device of measurement of the shrinkage for the fresh concrete. The device allows the measurement of the endogenous deformation with a little gap of time before the starting of measurements and the casting.

Figure 12. Boulay Measuring Devices

<u>The test of prevented expansion</u>

There exist two American Standards which describe the phenomenon of prevented expansion, ASTM C806-04 is dedicated for the mortar and ASTM C878 is dedicated for the concrete.

The principle of ASTM C806 is to use a retaining cage in the middle of the specimen, which causes the constraint on the concrete. One can associate this condition like the case of the reinforced concrete. The mould used has a dimension of 50x50x250 (mm).

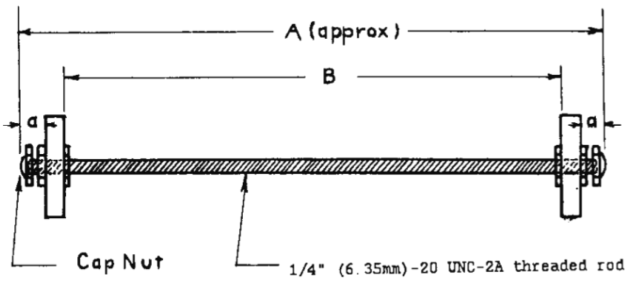

Figure 13. ASTM C878 Retaining Cage

The proportion of the mortar is 1: 2,75 between cement and the sand (which conforms ASTM C878). The installation of the concrete is done in two layers, the first layer covers the retaining cage, and the second layer slightly filled the mould. The specimen should be homogeneous. The cure condition is done with a polyethylene paper so that it can reduce the effects of hydration. Paper must be in contact with the surface of the mortar. When the hardened mortar (6±1/4h), we take out the specimen and put it in the lime saturated water at the 23±1,7°C until age of 7 days. Measurement can be done since the mortar hardened (normally at the age of 6H) by using a measuring device.

To calculate the expansion of the concrete this formula is used,

$$E_x = \frac{L_x - L_i}{10\ (250)} \times 100$$

With,

Ex : expansion at age x (%)

Lx : comparator length at age x (mm)

L_i *: initial length (mm)*

ASTM C 878/878M 2003 has the same testing method like ASTM C806 (C 878/C878M 2003). The dimension of the mould used is larger (76x76x250 mm), with more solid retaining cage which resists traction up to 2800 kN.

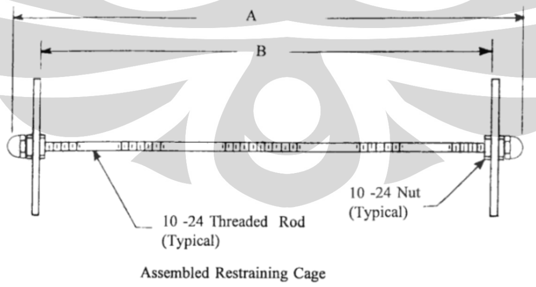

Figure 14. ASTM C806 Retaining Cage

These two standards make only the measurement of the expansion of concrete or the hardened mortar. There exist also American standards which describe the specification of the expansive cement.

Normalizes ASTM C845-04 (Specification of expansible hydraulic cement)

ASTM C845 specifies the hydraulic composition and cements which inflate for some period during hardening after the casting. This standard details the use of the expansive cement, the definition and the use of the expansive cement (C 845 2004).

1. Standard chemical condition

Table 10. Standard Chemical Condition of Expansive Cement

	Percentage
Magnesium oxide	6,0
Insoluble residue	1,0
Loss in lighting	4,0

2. Facultative chemical condition

Table 11. Facultative Chemical Condition of Expansive Cement

	Percentage
Alkalis (Na_2O + 0,658 K_2O)	0,60

3. Physical Characteristic

Table 12. Physical Characteristic of Expansive Cement

Catch time (min. minutes)	75
Air content (max. volume %)	12
Mortar Restrained Expansion	
7 days (%)	0,04 – 0,10
28 days (% de 7 days)	115
Compression force (minimum)	
7 days (MPa)	14,7
28 days (MPa)	24,5

3.1.3 Standard ACI 223-98 (Standardized Technique for the use of the concrete resistant to the shrinkage)

Some important remarks concerning the concrete resistant to shrinkage (ACI 223 1998).

The process of hydration

Two basic essential factors of the concrete expansion volume development are the suitable quantity of the soluble sulfates materials and the availability of sufficient water for the hydration. The ettringite starts to form almost immediately when water is present and its formation is accelerated by the mixture. However, to be relevant, a major part of the ettringite must be formed after the achievement of a certain degree of force; otherwise the expansible force will absorb in the plastic deformation of the concrete. For this reason, the increase in the time of mixing to ensure a uniform mixture is not recommended since the ettringite formed during the prolonged mixture will reduce the quantity of later expansion.

Specific surface

Specific surface has an important influence on expansion as well as the strength of the concrete in the young age. When specific surface increases above the optimum value (2800-5000 cm2/g)(Béton 2006), the formation of ettringite accelerates, thus, less expansion will be obtained in a hardened concrete.

The formulation of the concrete

The formulation of the shrinkage resistance concrete appropriate with desired resistance and conditions of expansions must be based on the results of the preliminary tests. If the data of the tests of shrinkage resistance cement are not yet available, the following table can be used as a guide to establish a formulation of concrete,

Table 13. Usual W/C Ratio for Expansive Concrete Design

Compression resistance at 28 days (MPa)	W/C Ratio	
	Without air entrainer	With air entrainer
41,4	0,42 - 0,45	-
34,5	0,51 - 0,53	0,42 - 0,44
27,6	0,60 - 0,63	0,50 - 0,53
20,7	0,71 - 0,75	0,62 - 0,65

Water contents

The water contents for the shrinkage resistant concrete can be 10 to 15% with the standard Portland cement 1 or 2. Increased volumes of water can be allotted to the variations of the hydration rates which are influenced by the chemical composition of cement and some physical properties like the cement smoothness, the concrete temperature, etc.

Effects of the aggregates

Satisfactory aggregates for concretes Portland cement can also be used for the cement of shrinkage resistant concretes. Good performances can be obtained with the light or heavy aggregates with normal density. The type of aggregate used has a significant influence on the characteristics of expansion and the drying shrinkage. For example, the laboratory test results show that a shrinkage resistant concrete r which elaborate with limestone had an expansion of 0,03%, whereas one obtained a withdrawal Net of 0.02% when sandstone was employed (Klieger 1971).

The aggregates containing the gypsum or other sulfates can increase the rate of expansion or delay the expansion of concrete. Chlorines in granular found normally on beach sands tend to decrease expansion.

Effects of the additions

The additions such as the air-entraining agent, water reducer, the retarder, and the accelerator can have positive or negative effects on the expansion. Special tests must be made to examine the effective effect.

In general,

1. The air-entraining agent is effective to improve resistances to gel in the presence of the defrost chemicals and the rate of expansion.
2. The water reducer and the retarder can be incompatible with the shrinkage resistant concrete due to the acceleration of the reaction of ettringite. This decreases the expansion of concrete.
3. The calcium chlorine reduces expansion.
4. The fly-ashes and other pozzolan can improve expansion and also influence resistance and other physical properties of the concrete.

Formulation of the concrete

An optimal formulation of the shrinkage resistant concrete is necessary for,

1. The installation and the placement of the concrete
2. The force of expansion necessary (adequate)
3. The materials at the minimal cost

In general, the formulations of the concrete, which function well with Portland cement, will produce the same quality for the expansive cement, although a small increase in report/ratio E/C can be necessary to produce the required expansion.

The depression of the paste of cement

Good performances can be obtained by using the cone test (ACI 211.1). The following values can be used, (with the concrete temperature of 24°C and without the use of the water reducer):

Table 14. Cone Test Setting

Construction type	The cone test (mm)
Foundation connected to wall	125
Underground wall	100
Reinforced wall	150
Building Column	150
Pile Cap	100
Grand Project Construction	100

Installation of the concrete and conditions of cure

In general, the concrete resistant to the shrinkage is more cohesive than the concrete with Portland cement, thus it has less tendency to separate. Shrinkage Resistant Cement is often used without difficulty in the manufacture of the prefabricated pipes and also the roadways.

The characteristics of the Shrinkage Resistant Cement require good fabrication in order to ensure adequate expansion and the satisfactory results.

4. The place where the concrete will be in contact with an absorbing material such as the dry ground or the no-slump concrete previously placed, must be saturated with water.
5. Under conditions of hot, dry, and windy field of works, the concrete tends to lose moisture and can develop the plastic shrinkages. We can decrease the effects of drying by using a vapor barrier.
6. If the plastic shrinkage is probable, the use of cover such as molecular mono films and the water spray pulverizes can be used.
7. The environment temperature of the concrete and the time of the mixture are two big factors for expansion. For the temperature above 30°C, the practical duration of use is limited to 1H. On the other hand for the temperature below 30°C, the practical duration of use is limited to 1H30

The shrinkage resistant concrete, like all the Portland cement concrete, requires a cure at the moderate temperatures during several days to develop resistance, durability, and other properties. The typical effects of various methods of cure on the expansion are presented in the following table,

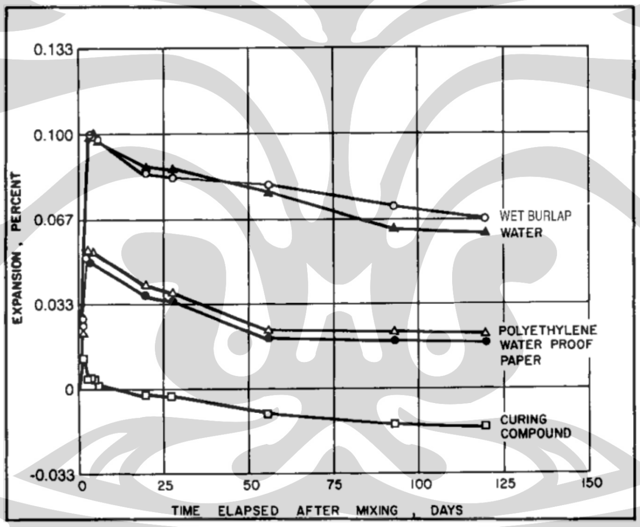

Figure 15. Effects of Curing in Expansion of Concrete

3.1.4 Conclusions on the tests

The following table summarizes information on the various standardized tests which we identified adequate with our research

Table 15. Summary of Tests and Standards

Standard	Summary	Adaptation with our research
C490-04 The use of a measuring device to determine the change	This standard explains only the standardized use and procedures for measurement of the concrete expansion.	The application of the C490 standard could be useful for our research to make the concrete sample. It gives us

in hardened paste cements length, mortar or concrete.		standards of measurements.
C806-04 Standardized testing method for the prevented expansion of the expansive cement mortar	The derivation of the standard C490, ASTM C806 is adapted for the tests of the mortar in the restrained expansion	the testing device proposed by ASTM C806 and C878 is adapted than C490, because it measures expansion in the restrained state. But, we also interested to measure expansion in the young age.
C878/C878M-03 Standardized testing method for the restrained expansion of the shrinkage resistant concrete	the identical standard of C806, but instead of the mortar, this standard is applied to the concrete	
C845-04 Specification of hydraulic expansive cement	This standard explains all what are correspond with the definition, and specification of the expansive cement, such as its chemical and physical properties	C845 standard gives the comparison of our test result. The mechanics properties mechanics concrete which we will have would have at least equal to this standard
C223-98 Standardized technique of the shrinkage resistant concrete	This standard details all the elements of the expansive cement, concerning its chemical reaction, until its use. It also explains the method of measurement for the concrete expansion, by using existing theorems (see Appendix A)	This standard does not propose any testing device. On the other hand, he proposes a standard of use of expansive cement.
NF EN 12617-4 Determination of the shrinkage and expansion	The method of measurement is identical like ASTM C490	This standard is not completely adapted to our needs. Like ASTM C490, we can use it to do pilot concrete (preliminary test) if there are excessive reactions.

All the standards and the not-standardized tests describe above are important for the base of our research on the inflating concrete. Compared to the application in the field road, the tests above are not enough the research objectives. The existing tests, except the oil apparatus, measure only the hardened concrete. Moreover, it is necessary to have measurements on the state while the concrete is in young age in the prevented state. It is why a new testing device is necessary.

3.2 Testing device proposal

The catch of the concrete plays a big role in the mechanical properties of the hardened concrete. Before the catch, we already observe phenomena of shrinkage and expansion. This is why, it is essential to make the measurement of the concrete in the young age. The tests suggested by the existing standards make only the measurement of the length change of the hardened concrete, which in our case is not enough. The measurement of expansion in the young age is also difficult because the modulus of elasticity (E) of the cement paste is still zero because it is still in the fluid form.

In spite of the conditions above, the measurement of expansion in young age is not impossible with the development of measuring device of the shrinkage in young age. The idea to put the apparatus in compression (Pigeon, Toma et al. 2003) to find the effects of the shrinkage at the time the concrete's catch was already studied. The change of the pressure inside the apparatus due to the chemical reactions can be measured (Boulay 2008) according to time, to find the modulus of elasticity of the concrete, the change of volume (even expansion).

We then propose to implement a testing device modeling the conditions of the roadway. The idea is to manufacture a hollow tube having a diameter of 200 mm and a height of 200 mm. Manufacturing was proposed by the company *Metro Measures* which suggests the use of stainless steel 316L.

3.2.1 Technical specification of stainless steel 316L

- Density : 7990 kg/m^3
- Elastic module : 193 GPa (Module Young)
- Shear Module : 77 GPa
- Specific heat : 500 J/Kg°C
- Thermal Expansion : 1,6^e-5 1/°C
- Poisson ratio : 0,3
- Elasticity limit : 290 MPa
- Ultimate force : 558 MPa

The goal of this modeling is to find the effective thickness of the cylinder which has single ends (the extreme part is thicker than the medium part) so that displacement, the constraint, and the deformation are equal even the specimen is sealed or not.

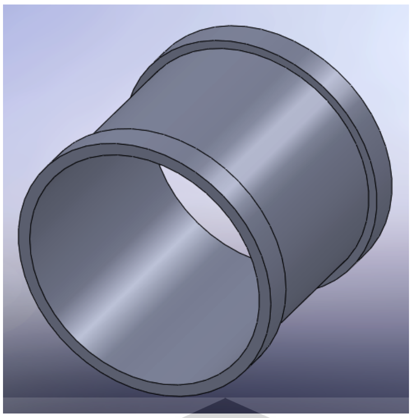

Figure 16. Model of Tube

Modeling is made in two parts. Firstly the design is made with the assistance of the software Solidworks 2008 (Version ECN), and in continuation the modeling of finite element by using software ALGOR Design Check (License ECN). Software ALGOR is preferable than other software (such as the SAMCEF software Field, CESAR LCPC, Abaqus), because it simplicity, even with variations of the values of pressure.

3.2.2 Case study

The presentation on Solidworks is made in mm, and this does not impose any problem. On the other hand, the studies on ALGOR are more complicated than expected, because there is not much documentation on the use of the software. Following important remarks were made to guide the step of modeling,

1. The expansion of concrete studied by Collepardi and Troli showed that the expansion of concrete is about 700 µm/m and 800 µm/m. It is thus necessary to find a thickness, which is sensitive to these values.
2. The concrete has coefficient of traction of about 7 MPa (see preceding calculation). One associated this value as the force with pressure of the concrete on the model. Furthermore, we make the simulation of 1 to 10 MPa.
3. The plastic deformation of stainless steel 316L is 290 MPa. It is thus necessary to find a value of constraint smaller than that.
4. There exist 4 important points (see figure) on the cylinder whose deformation is as weak as possible, so that the cylinder won't deform enormously.

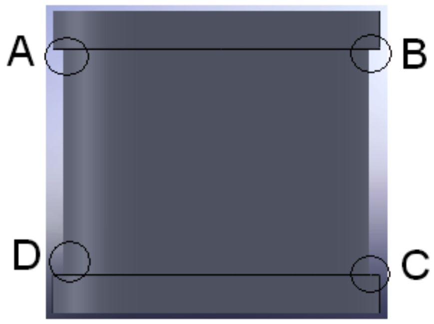

Figure 17. Important Points - Models

The first priority is to model the end, and then the thickness of cylinder. The two ends are important because we would model the condition on the restrained concrete (when the cylinder is closed).

Table 16. Models Dimension

Model	a	b	c
ModA (5mm)	110	25	105
ModB (3 mm)	110	25	103
ModC (2mm)	110	25	102
ModD (2,5mm)	110	25	102,5

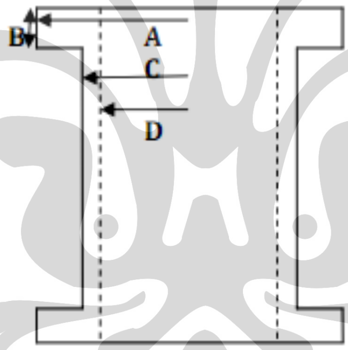

Figure 18. Models Cross Section

The following results show that the deformation of the closed cylinder is almost the same as the open cylinder.

Table 17. Result of the Opened Cylinder

Pression (MPa)	Deformation (mm/mm)	Constraint YY (MPa)	Displacement Y (mm)
1	1,07E-04	21,64	0,01045
2	2,15E-04	43,29	0,0209
3	3,32E-04	64,945	0,0313
4	4,31E-04	86,594	0,0418
5	5,39E-04	108,243	0,0522
6	6,47E-04	129,891	0,0627
7	7,55E-04	151,54	0,0731
8	8,63E-04	173,18	0,0836

9	9,70E-04	194,84	0,094
10	1,07E-03	216,486	0,104

Table 18. Results of the Closed Cylinder

Pression (MPa)	Deformation (mm/mm)	Constraint YY (MPa)	Displacement Y (mm)
1	1,05E-04	21,071	0,0104
2	2,11E-04	42,23	0,0208
3	3,17E-04	63,357	0,0313
4	4,20E-04	84,47	0,042
5	5,28E-04	105,56	0,0521
6	6,34E-04	126,714	0,0625
7	7,39E-04	147,83	0,0729
8	8,45E-04	168,95	0,0835
9	9,51E-04	190,07	0,0939
10	1,05E-03	211,19	0,104

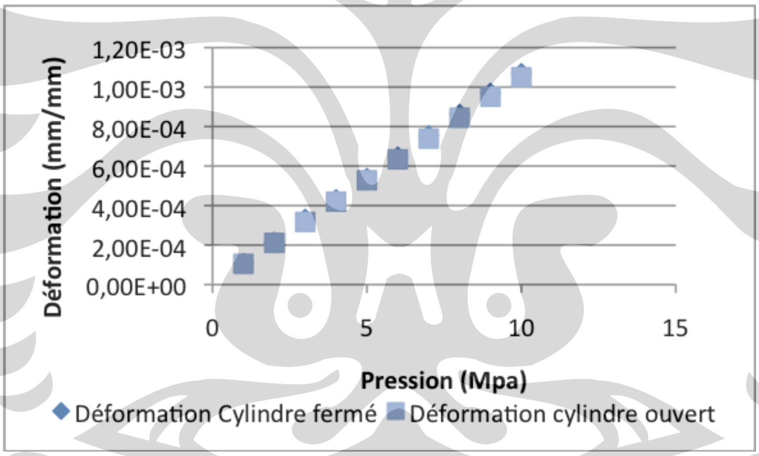

Figure 19. Deformation and Pression Relationship

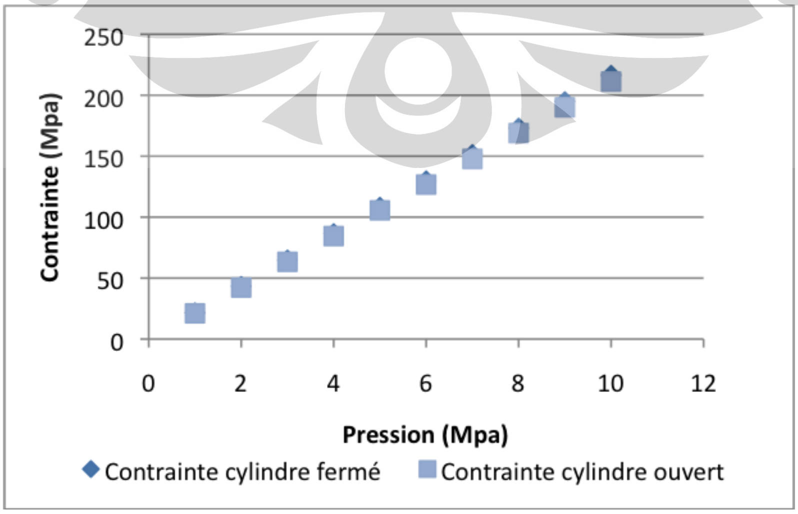

Figure 20. Constraint and Pression Relationship

The thickness of the extensions of 10 mm and height a 25 mm are the optimal values. We then calculate the thickness of the cylinder. 4 various thicknesses were made. For each thickness we vary the pressure of 1 - 10 MPa to follow the mechanical properties of the cylinder

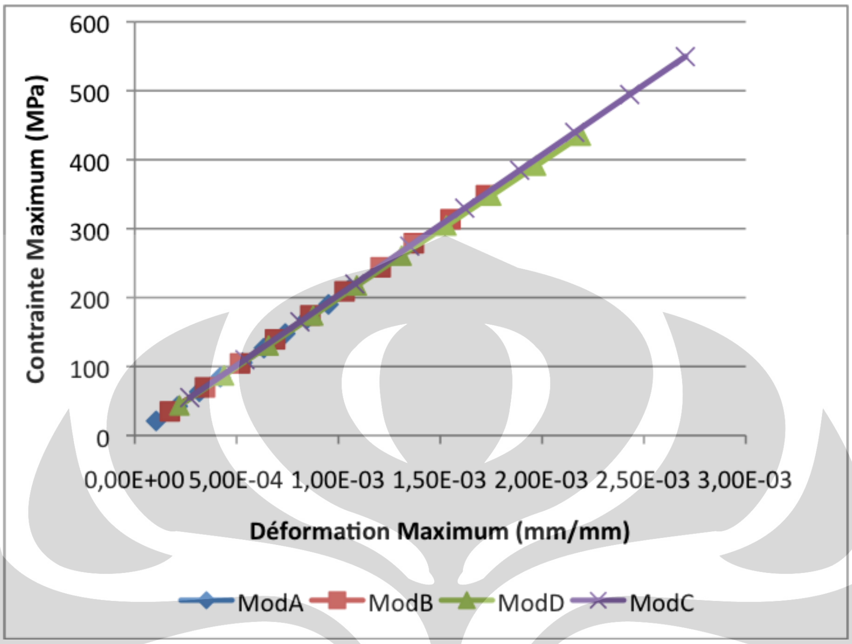

Figure 21. Constraint and Deformation Maximum for each Models

By using the curve of stress-strain, we observe that all the models follow the same points, which means the values are coherent.

We notice in all the Models, there are only ModA (5mm thickness) which does not exceed the yield stress of stainless (290 MPa). With the pressure of 10 MPa, the maximum constraint is 211,19 MPa. On the other hand, if the concrete imposes only one small value of pressure, the deformation will not be remarkable. If the pressure of the hardened concrete goes from 1 MPa to 5 MPa, the imposed constraint is 21,071 - 105,56 MPa, with the value of displacement of 0,0104 - 0,0521 mm, and a deformation of 1,05e-4 - 5,28e-4 (mm/mm). The value of deformation on the other hand does not seem interesting if we compare it with the maximum deformation concrete (800e-6 mm/mm).

With the finest thickness (2mm), we finds that the maximum constraint is 549,49 MPa for a pressure of 10 MPa, which is much larger than the yield stress and close to the ultimate force (558 MPa). To the level of the material resistance, the 2 mm thickness is too weak and led to the deformation of the measuring device, if we always work with a pressure of 10 MPa or more.

With a 3 mm thickness, we resist the value of 10 MPa to the pressure. Wee obtain a maximum constraint of 348,439 MPa, with a deformation of 1,72e-3. So in this case, if the pressure of the concrete varies from 1 - 5 MPa, we find that the deformation is also significant (1,72e-4 - 8,62e-4 mm/mm).

3.2.3 Assessment of modeling

It is preferable to use a 3 mm thickness (or 2,5 mm) for the cylinder, because the value of imposed deformation is rather important and measurable and the exerted constraint does not reach the ultimate value of force.

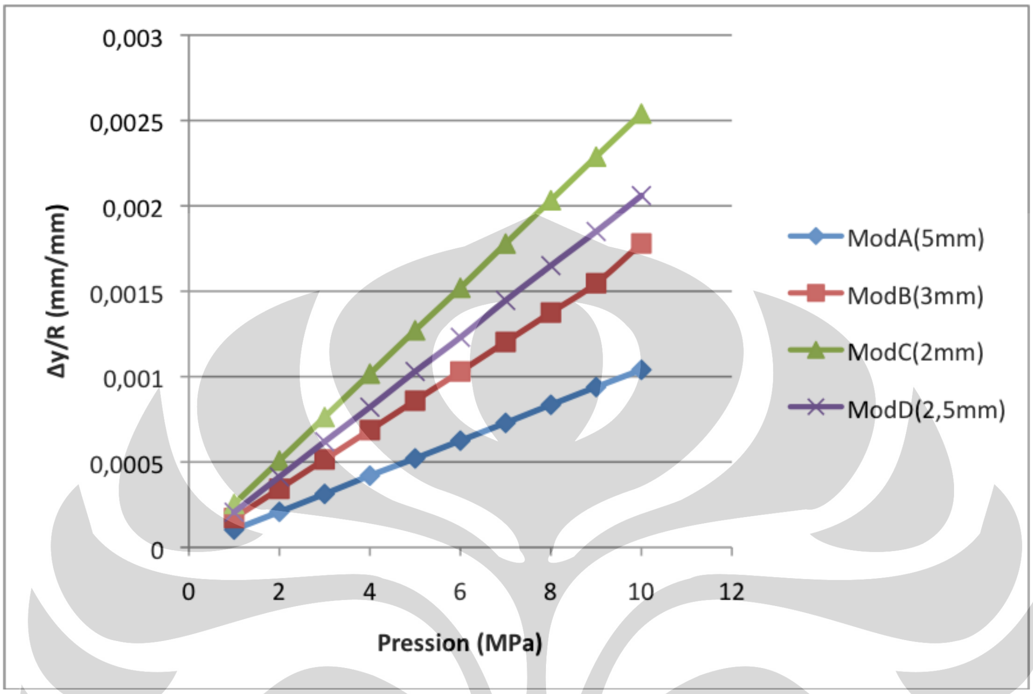

Figure 22. Displacement along Pression for Each Models

For the study of the sensitivity, the cylinder with a 5 mm thickness is already sufficient to impose the deformation of the cylinder to be measured for such a value on the gauge of measurement (for example LVDT). But, it is preferable to take a 3 mm thickness, because it gives a more important deformation.

3.3 Various existing techniques to inflate the concrete

Existing products which inflate the concrete, such as the expansive cement and the expansive additives, are alternatives to compensate the phenomenon of shrinkage. We can find three expansive principal materials in the Portland cement, which are (Vénuat 1989):

- Free lime (CaO)
- Free magnesium (MgO)
- The excess gypsum SO4Ca.2H20 (formation of a sulfo aluminate calcium)

3.3.1 Expansive cement

The expansive cement is cement which once mixed with water forms a paste which tends to inflate for such a volume with a degree appreciably larger than the Portland cement paste.

1. Type K

   Cement of the type K is the mixture between Portland cement, "anhydrous tetra-calcium tri-aluminate sulfates - C_4A_3S", "calcium sulfates - $CaSO_4$", and lime "CaO".

2. Type M

   Cement of the type M is the mixture between Portland cement, cement of calcium aluminates, calcium sulfate, in suitable proportions.

3. Type S

   The Portland cement which contains a great tri-calcium aluminate content "C_3A" and a small content of calcium sulfates (with the above normal quantity found in Portland cement).

Table 19. Expansive Cement

Expansive cement	Principal constituent	Reactive alumina
type K	Portland cement	C_4A_3S
	Calcium sulfate	
	Modified Portland Cement with C_4A_3S	
type S	Portland cement	CA et $C_{12}A_7$
	Calcium sulfate	
	Cement with calcium alumina (CA et $C_{12}A_7$)	
type M	Portland cement (with C_3A)	C_3A
	Calcium sulfate	

3.3.2 Expansive additives

1. Anti-shrinkage (Shrinkage Reducing Admixtures)

The product which we present is "ECLIPSE SRA", one of the products of GRACE (2006). The effectiveness of this product depends on the content of water, the fraction of the paste of mortar, the types of cement and its quantities, and the aggregates used.

In practice, it is initially necessary to select good proportioning by preliminary measurements according to test ASTM C157 (test of mould 76x76x286 mm). Selected proportioning is not always linear from 1 to 2,5% of the cement weight. Thus, measurements with varied proportions (low, medium, and high) are essential. The following result can be used to see the evolution of the concrete,

Table 20. Sample of Concrete Expansion

	Reference		Low Eclipse		High Eclipse	
	CRD (avg. 3 bars)	ΔL (%)	CRD (avg. 3 bars)	ΔL (%)	CRD (avg. 3 bars)	ΔL (%)
1 day	0.1735	—	0.1808	—	0.1843	—
7 day	0.1741	-0.006	0.1813	-0.005	0.1850	-0.007
14 day	0.1723	0.012	0.1801	0.007	0.1845	-0.002
21 day	0.1710	0.025	0.1792	0.016	0.1834	0.009
28 day	0.1701	0.034	0.1788	0.020	0.1830	0.013
35 day	0.1696	0.039	0.1784	0.024	0.1827	0.016
56 day	0.1691	0.044	0.1778	0.030	0.1823	0.020
90 day	0.1688	0.047	0.1777	0.031	0.1822	0.021
365 day	0.1685	0.050	0.1776	0.032	0.1821	0.022

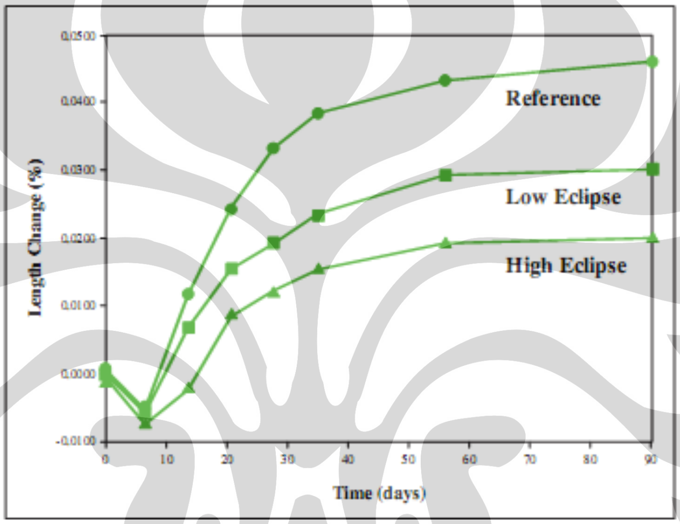

Figure 23. Length Change Using Expansive Additive

The product anti-withdrawal is generally a mixture of chemicals based on *Neopentil Glycol*, *$(CH_2)_2$-C-(CH_2OH_2)* (Collepardi, Borsoi et al. 2004). This product does not affect the evaporation of water, even if the concrete is placed in the unsaturated air. But it decreases the tension of water surface, which thus reduces the capillary tension due to the formation of the water meniscuses developed in the capillary pores.

2. Ca0 based Additives

Collepardi et al. propose the use of the CaO based additives. The CaO is already known for its expansive reactivity at the time of catch of cement. The expansive agent is a special product which can increase the volume of the concrete due to the chemical reactions. We present here an expansive agent which is composed of CaO, which is given by following chemical reactions (Collepardi, Borsoi et al. 2004),

$$C_4A_3S + 6C + 8CS + 96H \rightarrow 3C_3A.3CS.H_{32}$$

$$C + H \rightarrow CH$$

Considering that expansion is due to the reaction of the transformation of lime to the calcium hydroxide.

Collepardi carried out tests by comparing the CaO, the product of anti shrinkage, and mix between the two products, to see the effectiveness of these products.

Table 21. Collepardi's Material Composition

Material	Compositions		
	A/B	*C*	*D*
Cement (II 42,5 N – kg/m^3)	350	350	350
CaO (kg/m^3)	35	35	-
Sand (0-5 mm) (kg/m^3)	980	980	1015
Small Gravel (5-20 mm) (kg/m^3)	860	860	860
Water	160	156	156
Acrylic – Super plastifiant (kg/m^3)	3	3	3
Propylen Glycol – Anti Shrinkage (Kg/m^3)	-	4	4
Slump (mm)	180	190	200
Compressive strength			
1 day	16	13	11
3 days	37	36	36
28 days	45	44	43

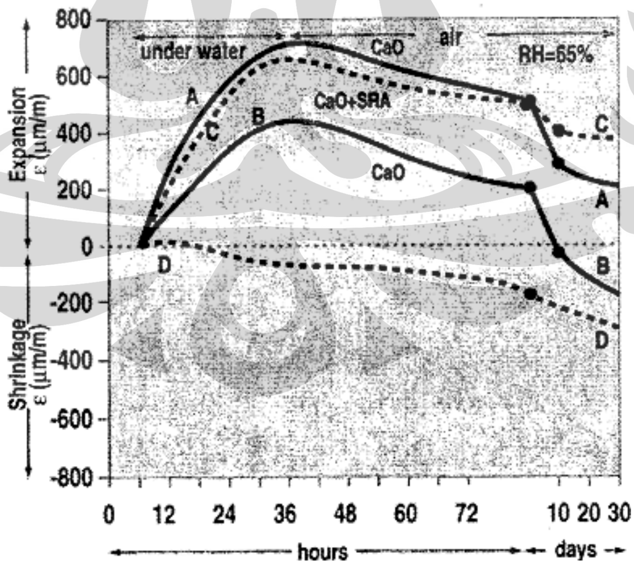

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Figure 24. Collepardi's Experiment Based for Expansive Concrete

We noticed that the use of the expansive agent in CaO and the anti shrinkage behave very well with the shrinkage (sample C), but the use of the product anti shrinkage alone does not enormously compensate the phenomenon of the shrinkage.

The use of the expansive agent to inflate the concrete still needs thorough studies. The expansive reaction during the first hours in the plastic state of the concrete does not produce any development of compression in the hardened concrete (no rigidity). On the other hand, expansion of the concrete must be accompanied by the prolongation of the cure.

The basic reaction of lime occurs around 1 to 2 days whereas the ettringite needs normally 5 to 7 days to reach its potential of expansion. The cure also gives important effects to the withdrawal. We notice that the use of the layer of polyethylene during 6 - 36 H of cure has an important effect on the effect of swelling. This remark is also valid for the cure in water (Collepardi, Borsoi et al.).

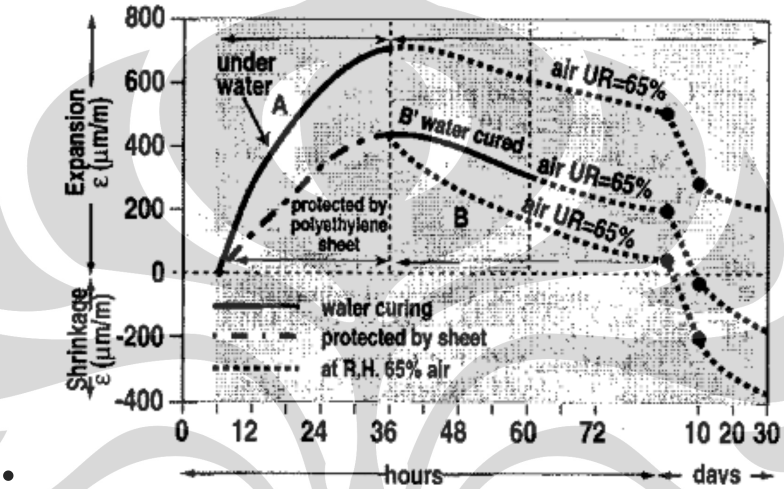

Figure 25. Effects of Curing (Collepardi's based experiment)

CHAPTER 4
THE APPLICATION IN THE ROAD FIELD

The use of the concrete as construction material is already known for its reliability. To fight against the problems of cracking two approaches are generally used: the use of discontinuous road or the utilization of continuous reinforcements (continuous reinforced concrete). The first technique requires maintenance of the joints whereas the second requires a lot of investment. The compensation of the withdrawal could thus prove to be a technique economically attractive. (Sedran 2007)

4.1 Construction of the viaduct on the highway Turin-Savone, Italy

The construction of the new way on the highway Turin-Savone includes the construction of a viaduct using a mixed structure with steel beams and reinforced concrete roadways which is cast in place (Troli, Sforza et al.). It is a roadway with a width of 11 m and a thickness of approximately 20 cm. Moreover, the viaduct as follows has an overall length of 1100 M. the concrete used are:

- R_c : 50 MPa
- Class : XF1
- w/c : $\leq$ 4,5
- Cement : CEM IV / A 42.5 R

A preliminary study was taken to anticipate the possibility of defect during and after construction. A special attention was subjected to the problem of the shrinkage since construction uses mix system between the steel beams and the concrete surface.

Indeed in this case, the roadway has more susceptibility to fissure. The constraint with the traction generated by the prevented shrinkage, the additional force with the traction of statics, and also low moisture, causes the cracking of the roadway easily. The solution is to put an additive anti-shrinkage.

4.2 The Use of Expansive Agent

The additive used is the mixture of expansive agent (EXPANCOLL) with special additive (GINIUS). Ginius is a super modified plasticizer which reduces the effect of withdrawal. The formula used for construction is according to,

Table 22. Turine-Savone Viaduct's Material Compositions

Material	Quantity
CEM IV A 42,5 R	470 kg/m^3
Sable	868 kg/m^3
Small Gravel (4-8mm)	300 kg/m^3
Medium Gravel (20-31,5mm)	580 kg/m^3
Expancoll	25 kg/m^3
Eau	179 kg/m^3
Ginius RM 20 SCC	2,6% of water
E/C	0,38

Which thus brings following results,

Table 23. Turin-Savone Viaduct's Slump Results

Slump (minute)	Loss in slump (cm)
0'	24
30'	23
60'	23

And compressive strength of,

Table 24. Turin-Savone Viaduct's Compressive Strength

Jour(s)	R_C (MPa)
1	25,2
4	44,4
7	47,2
14	52,3
21	-
28	61

The laboratory result shows that the combination of the two additives (Expancoll and Ginius), allows an expansion of concrete of 800 µm/m for the first day, and at the end of a few weeks a residual value of 300 µm/m, although the shrinkage continued to develop.

The use of the expansive agents made it possible to reduce the constraints between the roadway and the steel beams, therefore to reduce the risk of cracking. Moreover it gives advantages on the durability of construction. The increase in the concrete size causes a pre-compression in steel. The method of construction is also simple, with less labor for the installation and the normal cure with a covering plastic during the first 24 hours.

With all of the advantages, there are also disadvantages, which they are necessary to note, as this method requires a constant wet material during approximately a week to allow the development of expansion (cure condition). It is also difficult to ensure the expansion of concrete.

CHAPTER 5
CONCLUSION

The expansive cement gives a promising result in the term of shrinkage. Some additive and expansive agents used on this research give a different result, but the expansion of the concrete itself would maybe restraint the effect of shrinkage. Unfortunately in this limited time, we haven't yet the result of how much the expansion of the concrete will compensate the effect of shrinkage.

Some advance research is obligatory to prove the hypothesis that "the expansion of the concrete would compensate the effect of the shrinkage itself". Some researches that will carry on in the future should provide:

1. The compensating value of shrinkage
2. The effect of expansion would reduce the shrinkage of the concrete itself
3. Application in the roadway

With all of the advantages, there are also disadvantages, which they are necessary to note, as this method requires a constant wet material to allow the development of expansion (cure condition). It is also difficult to ensure the expansion of concrete.

Bibliography

(1994). *Guide technique: Conception et dimensionnement des structures de chaussée*. Paris, Le Laboratoire Central des Ponts et Chaussées.

(2006). *Eclipse Shrinkage Reducing Admixtures.* Concrete. Cambridge, England, W. R. Grace & Co.-Conn.

AASHTO PP34 (1998). *Standard Practice for Estimating the Crack Tendency of Concrete*, AASHTO Publication.

ACI 223 (1998). *Standard Practice for the Use of Shrinkage-Compensate Concrete*, American Concrete Institute.

ACI, -. (1983). *Building code requirements for reinforced concrete*. Detroit, Michigan, American Concrete Institute.

ACI committee (1993). *Prediction of creep, shrinkage, and temperature effects in concrete structures (ACI209R-92)*. Detroit, American Concrete Institute.

Baroghel-Bouny, V. (1996). *Texture and Moisture Properties of Ordinary and High Performance Cementitious Materials.* Beton: du Materiau a la Structure, Arles, France, Proceedings of Seminaire RILEM.

Béton, C. (2006). *Fiches Techniques, Tome1: Les constituants des bétons et des mortiers*. Paris, Collection Technique CIMBETON.

Boulay, C. (2008) LCPC.fr. *Laboratoire central des ponts et chausées*

Byfors, J. (1980). *Plain Concrete at Early Ages, Swedish Cement and Concrete Research Institute*.

C157M-04, A. (2004). *Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete*. ACI Manual of Concrete Practice, ACI Publication.

C 490 (1994). *Standard Practice for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete*. West Conshohocken, ASTM Internationl.

C 845 (2004). *Standard Specification for Expansive Hydraulic Cement*. West Conshohocken, ASTM International.

C 878/C878M (2003). *Standard Test Method for Restrained Expansion of Shrinkage-Compensating Concrete*. West Conshohocke, ASTM International.

CEB-FIP (1990). *Model Code for Concrete Structures*. Bulletin d'information N°195.

Colan Subauste, J. and I. Odler (2002). *Stresses generated in expansive reactions of cementitious systems*. Cement and Concrete Research **32**(1): 117-122.
The authors built an experimental assembly that enabled to measure the expansive stresses generated in cementitious systems in the course of hydration. The assembly was used to measure stresses generated in the hydration of pastes consisting of tricalcium silicate, acting as the cementitious matrix, and gypsum, in combination with CA, C3A, C4A3s, C4AsH12 (AFm) and Al2(SO4)3·18H2O, acting as the expansive component. Also measured were stresses generated in the hydration of hard-burnt CaO combined with tricalcium silicate.

Collepardi, M., A. Borsoi, et al. *Effects of Shrinkage Reducing Admixture in Shrinkage Compensating Concrete*. Kenji Sakata Symposium on Properties of Concrete.

Collepardi, M., A. Borsoi, et al. (2004). *"Effects of shrinkage reducing admixture in shrinkage compensating conrete under non-wet curing condition."* Science Direct.

De l'Hortet, R. (1963). *"La chaussée en béton très mince, fortement Pré Contrainte est-elle la chaussée de demain?"*: 101-115.

FDOT (2002). *Structural design guidelines for load and resistance factor design*. Florida, Structural Design Office.

Hedlund, H. (1996). *Stresses in High Performance Concrete Due to Temperature and Moisture Variations at Early Ages*. Luleå, Sweden, Licentiate Thesis, Luleå University of Technology.

Holt, E. E. (2001). *Early Age Autogenous Shrinkage of Concrete*, VTT Publications.

Japan Concrete Institute, T. c. o. A. S. o. C. (1999). *Committee report, Autogenous Shrinkage of Concrete*. London, E&FN Spon.

Jokela, J., H. Kukko, et al. (1980). *Kovettuneen Betonin Perusominaisuudet (Basic Properties of Hardened Concrete)*, Research Notes 74. Espoo, Finland, VTT.

Klieger, P. (1971). *Shrinkage-Compensated Concrete: A Review of Current Technology*. Silver Spring, NRMCA Publication.

Kosmatka, S. and W. Panarese (1988). *Design and Control of Concrete Mixtures, 13th edition*. Skokie, Portland Cement Association.

Mehta, P. K. and J. M. Monteiro (1993*). Concrete: Stuctures, Properties and Materials, 2nd edition*, Prentice Hall, Inc.

Mindess, S. and J. F. Young (1981). *Concrete*, Prentice-Hal, Inc.

Mokarem, D. W. (2002). *Development of Concrete Shrinkage Performance Specifications, A Dissertation*. Virginia, Virginia Polytechnic Institute And State University.

Neville, A. M. (1992). *Properties of Concrete, 4th*. London, Pittman Publishing.

NF EN 12617-4 (2002). *Méthodes d'essai, Partie 4: Détermination du retrait et du gonflement* Saint-Denis La Pleine, Association française de normalisation.

Pigeon, M., G. Toma, et al. (2003). "*Etude expérimentale du retrait endogène restreint au jeune âge.*" Materials and Structures, Vol. 36, December: 666-672.

Sedran, T. (2007). *Projet R2GC - Thème 1E, Infrastucture de transport*. Nantes, Laboratoire central des ponts et chaussées.

See, H. T., E. K. Attiogbe, et al. (2003). "*Shrinkage Cracking Characteristics of Concrete Using Ring Specimens.*" ACI Materials Journal, Vol.100 No.3, May-June 2003: 239-245.

Toledo Filho, R. D., K. Ghavami, et al. (2005). "*Free, restrained and drying shrinkage of cement mortar composites reinforced with vegetable fibres.*" Cement & Concrete Composites, Vol.27: 537-546.

Troli, R., G. Sforza, et al. *Realizzazione del nuovo impalcato sull'autostrada Torino-Savona con calcestruzzo a ritiro nullo*. Enco Journal.

Vénuat, M. (1989). *La pratique des ciments morties et bétons: Tome 1 (Caractéristiques des liants et des bétons, Mise en oeuvre des coulis et mortiers)*. Paris, Editions du Moniteur.