RESEARCH ARTICLE OPEN ACCESS

Mechanical Behavior of Reinforced Concrete Sleepers on a Railway Line: The Case of the National Railway Company of Congo (SNCC)

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Abstract

This study focuses on the mechanical behavior of the concrete of the sleepers of the SNCC rails. The objective is to make the concrete durable for the case of SNCC rail sleepers, in order to highlight the elements entering into the constitution of this concrete by referring to the standards prescribed by Eurocodes 2.

To achieve these objectives, Compressive strength tests for 7 days, 14 and 28 days, the particle size analysis of the aggregates (0/5; 7/15; 15/25), were carried out, the sagging and the " analysis of the mixing water, which gave the following results: RCavg at 7 days: 29.4431 MPa with a mass of 862g, Fmoy = 652.24 kN, RCavg at 14 days: 35.45 MPa with a mass of 862g, RCavg at 28 days: 42.44 MPa with a mass of 862g, Fmoy = 661.34kN.

We then notice that the mixing water contains high amounts of Cl- and SO4- this influences the durability and permeability of the concrete. From where we suggest to the SNCC to use, the water-repellent additive of mass in order to improve the tightness of the concrete by blocking the pores created by the occluded air and to take into account the chemical treatments of this water to modify chlorides and sulphates which negatively influence the durability of concrete.

Keywords: Mechanical behavior, sleepers, reinforced concrete, railway

1. INTRODUCTION

The empirical nature of the study and design of rail base structures is due to the typology and complexity of the materials used (Mansouri & Bensafi, 2000). To withstand loads, the components of the superstructure have evolved and become very efficient. Sleepers have evolved thanks to prestressed concrete, and now have a lifespan three times longer than those made of wood (Paderno, 2010). The main functions of sleepers can be summarized in particular: (i) transmission of loads from the rails to the ballasts; (ii) maintaining the gauge and inclination at 1/20 of the two rails; (iii) sufficient mechanical strength in vertical and horizontal directions. Sleepers, initially made of wood or metal, were made increasingly heavy and stable following the invention of reinforced concrete. The solution of concrete is a priori attractive: sand and gravel are found everywhere, and the small quantities of iron and cement required for its manufacture do not pose a problem.

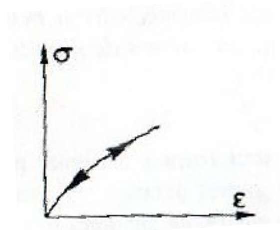
The only disadvantages of concrete are its low vibration damping capacity and its high weight. Whatever arrangements are made to meet the defined conditions and the rules of the art, the result achieved on concrete depends above all on the action of those who make it and those who put it in place. Knowledge of the quality of the seat structure and its ability to accept a given load (identical, increase in axle load and / or speed) is essential to make Track Renewal and Ballast operations more reliable (Calon, 2016). This article is an analysis of the mechanical behavior of reinforced concrete sleepers on the SNCC railway line. This will allow the implementation of volume models and the study of the influence of sleepers on the behavior of the rail bed structure. The remainder of the article is devoted to the description of the behavioral laws and the methodology used, followed by the presentation of the results and the discussion and finally a brief conclusion will close this article.

2. LAWS OF BEHAVIOR

The constitutive laws are relations between the stresses and the deformations in formations according to the characteristics of the material or the medium.

2.1. Reversible behaviors

Linear elasticity: The burst behavior is that of a material which caused them. These materials are therefore characterized by the absence of residual deformations after removal of the load. The shape of the curve of such a material is given in figure 1.



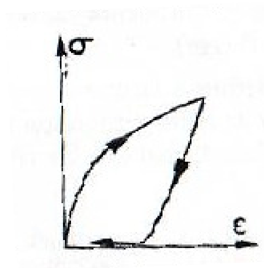


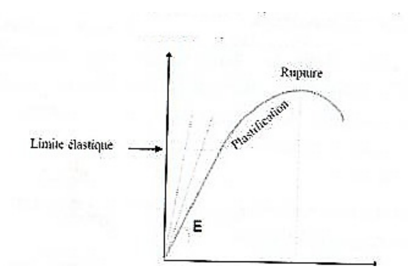
Figure 1- Linear elastic flow Figure 2 -Viscoelastic flow

2.2. Viscoelasticity

The material undergoes reversible deformations but in this case the reversibility is not instantaneous, it is delayed only to intervene after a sufficiently long time (figure 2).

Non-reversible behaviors

a. Plasticity: This kind of behavior is characterized by the existence for the stresses of a state threshold below which there are no persistent deformations which quickly become much more important than persistent non-persistent deformations. Beyond the elastic limit, the deformation is like a flow.



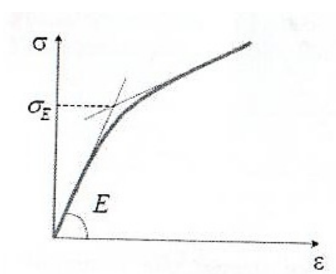


Figure 3- Plastic behavior. Figure 4- Work hardenable elastoplastic behavior

If the behavior is not perfectly elastic, the material will undergo either hardening or a decrease in ductility: this is hardening. We will then speak of a perfect elastoplastic or strain-hardenable elastoplastic behavior (figure 4).

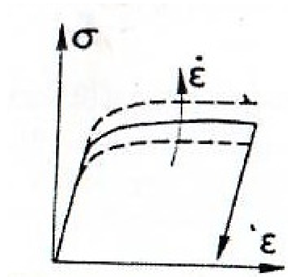


Figure 5- Elastic behavior not perfectly viscoplastic

b. Viscoplasticity: Contrary to the plastic behavior where the strains are instantaneously stable and in equilibrium under load in viscoplasticity the material undergoes a flow of creep according to time (figure 5).

Identification of constitutive laws

One calls identification any work which consists in presenting the functions which intervene in the models and to find the numerical values of the coefficients which define them for each material. This is hard work that does not follow strict rules and where experience and the "art" of the role model play a big role in moving between theory and experience.

To determine the behavior of a rock, we postulate the existence of a thermodynamic potential from which derive the state laws which describe the behavior of the medium, as well as the dissipation potential which describes the evolution of internal variables (dissipative processes). The equations thus obtained are fitted to the experimental data to find the values of the parameters which intervene in the model.

Determining the complete mechanical behavior of a material will require the performance of three characteristic tests:

The strain hardening test: in which the stress is increased to see the influence on the strain and vice versa

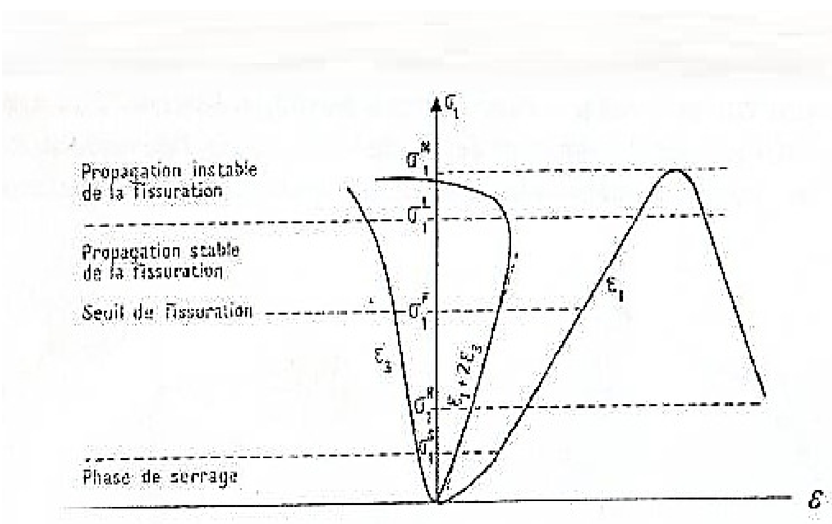
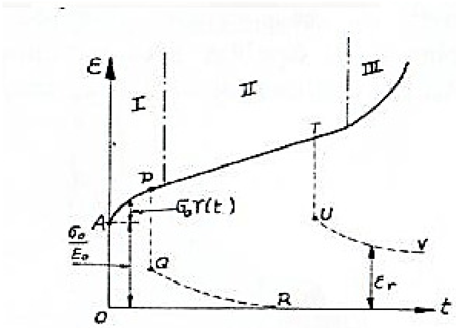


Figure 6- Work hardening test

The creep test: in which we impose a stress that we keep constant and we study the evolution of the strains over time.

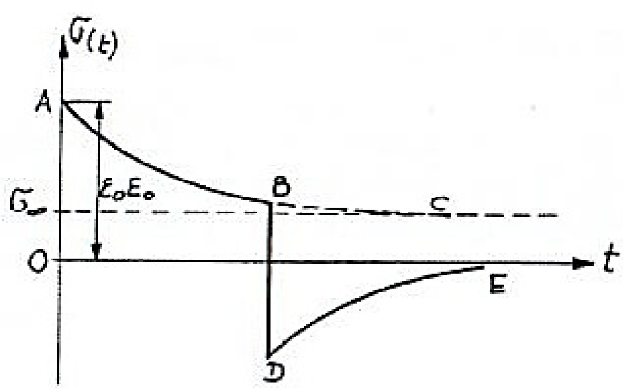


$$\varepsilon(t)=\varepsilon(0)+\varepsilon_p(t)=\frac{\sigma_0}{E_0}+\sigma_0\gamma(t)$$

$$f(t)=\frac{1}{E_0}+\gamma(t)=f(0)+\gamma(t)$$

Figure 7 - Creep test

- *The relaxation test*: in which a strain is imposed (constancy over time) and the study of the evolution of stresses over time is studied.



$$\frac{\sigma(t)}{\varepsilon_0}=r(t)$$

$$\sigma(t)=\sigma(0)+\varepsilon_0\theta_r(t)$$

$$r(t)=E_0+\theta_r(t)$$

Figure 8 -Relaxation test

3. METHODOLOGY

3.1. Simple compressive strength and flexural strength tests

3.1.1. Simple compressive strength test.

The essential characteristic of a hardened concrete is the mechanical compressive strength at the age of 28 days. Concrete is a material that works well in compression. Knowledge of its mechanical properties is therefore essential for the sizing and calculation of structures. The mechanical compressive strength of concrete is measured by axial compression on cylindrical specimens with a diameter of 16 cm and a height of 32 cm.

The specimens must remain in the mold and be protected against shocks and vibrations for a minimum of 16 hours and a maximum of 3 days [NF EN 12390-2]. After demoulding, the test pieces should generally be stored in water until the time of testing at a temperature of 200c ± 20c and a relative humidity ≥ 95%. The crushing test must be carried out according to standard [NF EN 12390-3 / 4]. The machine used for the compression test in this study is shown in Figure 9.

Figure 9- SNCC compression testing machine

Concrete is characterized by a stress-strain curve (σ,ε) both in tension and in compression, presenting an elastic linear phase for low loadings and then a non-linear phase up to the peak of resistance and finally a non-linear phase. -linear until failure (figure 10). In compression, the stress-deformation curve is almost linear up to 40% while in tension concrete behaves in the same way up to 90%. The elastic modulus of concrete in compression which corresponds to the slope of the stress-strain curve up to 40% of fc.

One can graphically estimate the elastic modulus Ec by dividing the stress applied to the concreteσ_c by the strain presented by the latter $\varepsilon_c$in the field of elastic linear behavior.

The elastic modulus Ec of concrete in compression can also be calculated by:

$$Ec = \frac{\sigma_c}{\varepsilon_c} \text{ ou } \varepsilon_c = \frac{\sigma_c}{E_c} \qquad \text{(Eq. 1)}$$

or

Ec : modulus of elasticity in MPa.

fc : compressive strength in MPa

ε : linear strain in µm/m

σ : stress in MPa.

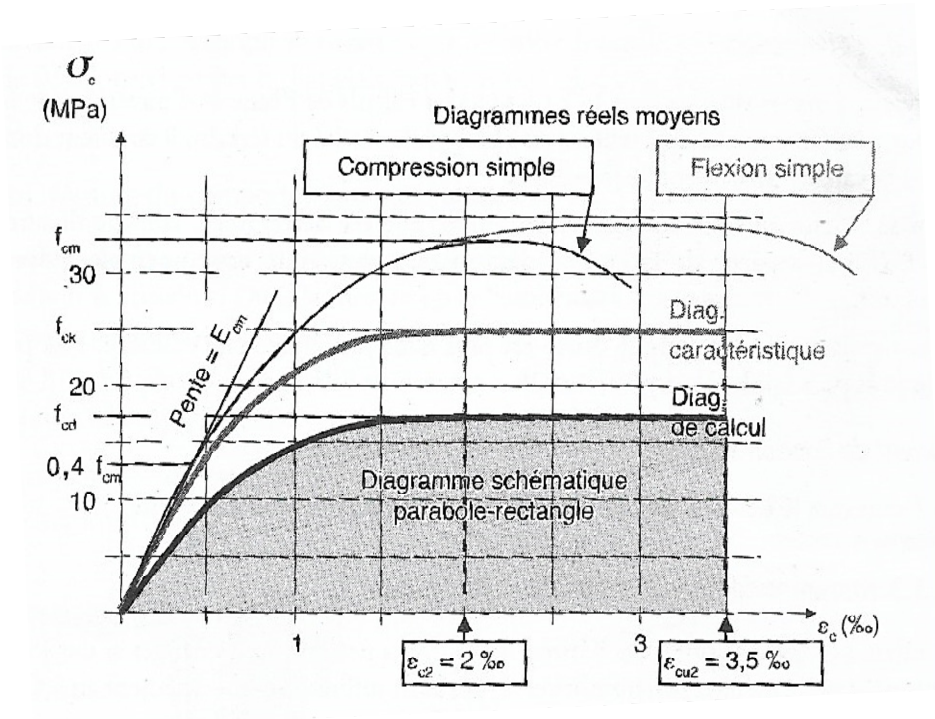


Figure 10- mean experimental stress-strain diagram of concrete compression calculation

(Source: Granju, 2014).

3.2. Flexural strength test

The following standard bending test set-up was chosen (Figure 11).

1) Lower articulated support
2) Upper articulated support
3) Elastic sole
4) 1 / 20th take-up wedge
5) Blochet VDH-600 / SNCC

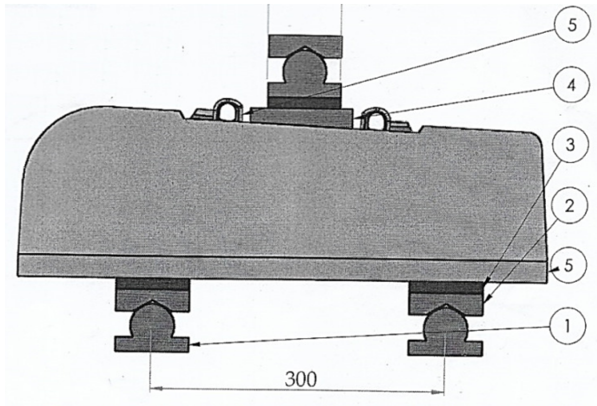


Figure 9 - Bending test setup

Serial test procedure:

The verification procedure on the crosshead block will confirm the value of the cracking below, measured with the press during a positive static test with the following parameters:

Center distance between supports = 300 mm

Strengths:

P1 = 209 kN

P2 = 376 kN

Maximum loading speed = 120 kN / min

The progressive loading of the tested block makes it possible to detect a first crack or the initial crack for which the applied force P0 is to be indicated in the table of the file bending crosses. The load is then gradually increased to reach P1 = 209 kN after 2 minutes. At this load, the crack observed cannot exceed 0.1 mm. The load is then gradually increased to reach P2 = 376 kN. At this value, there is no longer a limit set for the opening of the crack. The load is then gradually reduced to P3 = 0. The residual crack observed must then be a maximum of 0.05 mm when removing any force on the cross member.

A sleeper is refused if, at the load of 209 kN, it exhibits a >15 mm crack which propagates during the addition of 10 kN to the load, held for 10 seconds.

Initial crack: crack, regardless of its width, which occurs on the tensioned face of the sleeper and the concrete support and the length of which reaches 15 mm on one side or the other of said sleeper and support, and which s' lengthens with increasing load (figure 12).

The measurements are taken approximately 15 mm from the tensile face on both sides of the concrete element.

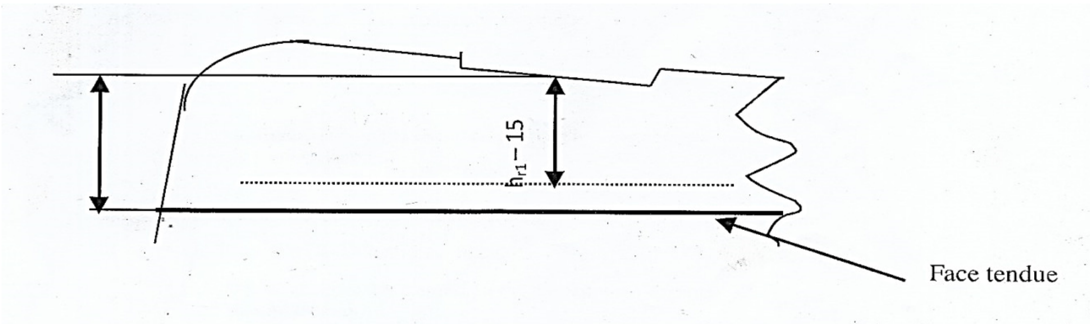


Figure 12- Initial crack

4. RESULTS AND DISCUSSION

4.1. Simple compression tests

Table 1 shows the measurement of the concrete stress at 28 days for the 20 samples.

Table 1- Stress of concrete at 28 days

Sample number	Stress (MPa)	Deviation / mean value	Square Value
1.	28.91	2.345	5.499
2.	34.96	-3.705	13.727
3.	35.60	-4.345	18.879
4.	26.73	4.225	20.475
5.	32.01	-0.755	0.570
6.	33.03	-1.775	3.150
7.	29.10	2.155	4.644
8.	32.78	-1.525	2.325
9.	27.86	3.395	11.526
10.	35.11	-3.875	14.276
11.	31.70	-0.445	0.198
12.	28.32	2.935	8.614
13.	30.40	0.855	0.731

14.	33.90	-2.645	6.996
15.	31.36	-0.105	0.011
16.	28.45	2.805	7.868
17.	29.78	1.475	2.175
18.	34.16	-2.905	8.439
19.	28.78	2.475	6.125
20.	32.16	-0.905	0.819

The total of the measurements of the 20 samples equals 625.1

The mean = 625.1 / 20 = 31.255

For each sample we extract the distance between the mean and the measurement of the sample (sample N ° 1 → difference value = 31.255 - 28.91 = 2.345

Each deviation value on the average is then squared (sample N ° 1 → 2.345 squared = 5.499) to constitute the last column of the table (squared value)

The total squared values of 137.747

The variance = 137.747 / 20 = 6.887

The dispersion = square root of 6.887, or 2.624

1.6 times dispersion = 2.624 x 1.6 = 4.198

Limit value = 31.255 - 4.198 = 27.057 <30, so sample # 4 is not acceptable.

This leads to the conclusion that the quality of the concrete is acceptable.

4.2. Bending test results

Table 2 shows the results of the bending stress.

Table 2- Measurement of the bending stress of a block of sleepers for the 20 samples.

Sample number	Measurment daN / cm²	Deviation / Average	Square value
1.	536	-8.65	74.8225
2.	537	-9.65	93.1225
3.	490	37.35	1395.0225
4.	535	-7.65	58.5225
5.	534	-6.65	44,2225
6.	482	45.35	2056.6225
7.	532	-4.65	21.6225
8.	537	-9.65	93.1225
9.	535	-7.65	58.5225
10.	536	-8.65	74.8225
11.	530	-2.65	7.0225
12.	529	-1.65	2.7225
13.	531	-3.65	13.3225
14.	532	-4.65	21.6225
15.	530	-2.65	7.0225
16.	534	-6.65	44.2225
17.	495	32.35	1046.5225
18.	540	-12.65	160.0225
19.	535	-7.65	58.5225
20.	537	-9.65	93.1225

For bending the total of the measurements of the 20 samples was 10547, this led to an average of 10547/20 = 527.35.

For each sample the distance between the mean and the sample measurement was extracted, of which for sample No. 1 the difference value = 527.35 - 536 = -8.65

Each mean deviation value was then squared, for the sample we had 74.8. The total of the squared values of 5424.55. The variance = 5424.55 / 20 = 271.23. The dispersion = square root of 271.23 or 16.47. The dispersion times 1.6 = 1.6 x 16.47 = 26.35. This leads to a limit value = 527.35 - 26.35 = 501.00 > 500, so the 3 samples No. 3, 6 and 17 are not acceptable. For bending, the limit value is 501.00> 500, so samples 3, 6 and 17 are acceptable. The application of this rule makes it possible to accept, under conditions, certain concrete samples whose measured value is however less than 500 daN / cm² (Paderno, 2010). This difference in resistance between samples has several sources. We want the concrete to be homogeneous at different points in a batch so we need adequate mixing (Richard, 2010) and methods that can prevent segregation and bleeding phenomena and a good proportion of the constituents must also be taken into account. in the mix (Kostiantyn, 2010). The time of day during which the concrete mix is made, so it is room temperature without forgetting the curing and ripening of the concrete.

5. CONCLUSION

This study focused on the mechanical behavior of the concrete of the sleepers of the SNCC rails. This by giving the granulometric curves of the aggregates, the subsidence of concrete as well as the values of compressive strength at the age of 28 days.

To achieve these objectives, a need to collect data has emerged from the site laboratory, the mixing water, sands, gravel, and the characteristics of the concrete in the fresh and hardened state. Compressive strength tests for 7 days, 14 and 28 days, particle size analysis of aggregates (0/5; 7/15; 15/25), were performed, sagging and analysis of mixing water, which made it possible to obtain the following results:

RCavg at 7 days: 29.4431 MPa with a mass of 862g, Favg = 652.24 kN, RC avg at 14 days: 35.45 MPA with a mass of 862g, RCavg at 28 days: 42.44 MPa with a mass of 862g, F avg = 661.34kN.

The mixing water which contained the high amounts of Cl- and SO4- which influences the durability and permeability of the concrete. From where we suggest to the railway company of Congo by its responsibility to be able to use, following the poor quality of its mixing water, the water-repellent additive of mass which improves the tightness of the concrete by blocking the pores created by the occluded air and take into account the chemical treatments of this water to modify the chlorides and sulphates which have a negative influence on the durability of the concrete. The results of this article open a door to future research in the near future. A study will be made on the implementation of volume models and the study of the influence of sleepers on the behavior of the rail bed structure.

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