PRE-DESIGN AND MODELLING OF A QUALITY CONTROL DEVICE TO TEST TILES MECHANICAL CHARACTERISTICS

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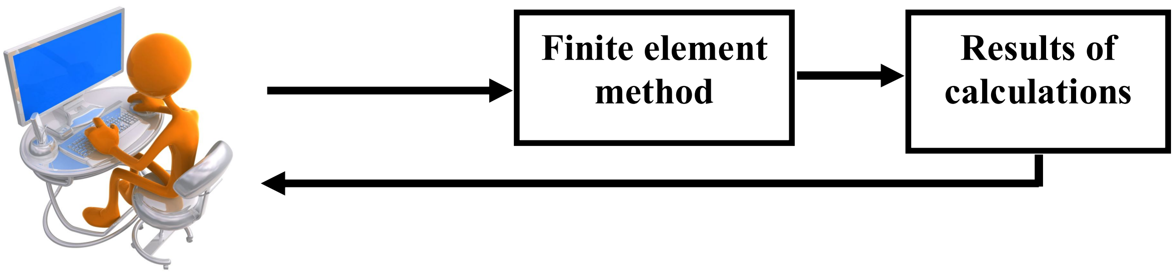
The aim of this study was to develop an original device to provide an improved quality control testing technology for a 3- or 4-four point-flexure tests, the impact resistance and tensile strength of the heel. To achieve this aim, we firstly reported about the devices for quality mechanical characteristics control testing for the broad nomenclature of sizes for tiles, used in West Africa. A conceptual approach based on Newton's 3rd law (the well-known "principle of action and reaction") and structures calculation with use of finite elements method. This method was adopted to modeling, analyse and evaluation the new device, that complies with the recommendations and requirements of the normative documents in Benin. With this device we made various tests to monitor (research) the mechanical characteristics of tiles. After that we compared the results from numerical simulations by finite elements to the real test for the validation of the device. The results showed a suitable concordance between the two approaches.

Keywords: micro-concrete, tile, quality control, mechanical characteristics, finite elements, modelling, real tests, results comparing

Graphical annotation (Графическая аннотация)

Original design of roof

Alternation of gray and red tiles



УДК 004.94:[666.6+620.1]

ПРЕДВАРИТЕЛЬНАЯ РАЗРАБОТКА И МОДЕЛИРОВАНИЕ УСТРОЙСТВА ДЛЯ КОНТРОЛЯ КАЧЕСТВА ТЕСТИРОВАНИЯ МЕХАНИЧЕСКИХ ХАРАКТЕРИСТИК ЧЕРЕПИЦЫ

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Цель исследования – разработка оригинального устройства для улучшения технологии тестирования при контролее качества плиток черепицы в трех или четырех точках (при испытаниях на изгиб, ударную прочность и предел прочности на разрыв). Для достижения этой цели, мы, в первую очередь, рассмотрели устройства для контроля качества испытаний механических характеристик микробетонных плиток различных размеров, которые используются в Западной Африке. Концептуальный подход, основывается на третьем законе Ньютона («принцип действия и реакции») и расчете конструкций методом конечных элементов для целей моделирования, анализа и оценки точности нового устройства. Его параметры должны соответствовать рекомендациям и требованиям нормативных документов, используемых в Бенине. С помощью этого устройства авторы провели различные тесты для контроля механических характеристик исследуемых объектов. Для проверки эффективности разработки результаты численного моделирования (на основе метода конечных элементов) были сравнены с результатами реальных испытаний. Сравнение показало хорошее соответствие результатов при использовании этих двух подходов.

Ключевые слова: микробетон, плитка, контроль качества, механические характеристики, конечные элементы, моделирование, реальные испытания, сравнение результатов

Introduction. Tiles are widespread material, used in constructions of various buildings. Therefore, characteristics of tiles have to be tested by different parameters. For this purpose can be used different approaches and devices. The aim of this article have been comparison of approaches, based on finite element modelling of tiles and their real testing.

Used variables and their symbols

First of all we give a table with symbols, which used for main parameters in this article

Table 1 – **Symbols, used for main parameters in this article**

Nomenclature			
A_X	The cross-sectional area relative to the axis OX (cm²)	M_1	Bending moment on the Node 1 (kNm)
E	Young's modulus (kN/cm²)	M_2	Bending moment on the Node 2 (kNm)
E_1	Element N°1 of the bar	M_3	Bending moment on the Node 3 (kNm)
E_2	Element N°2 of the bar	M_4	Bending moment on the Node 4 (kNm)
E_3	Element N°3 of the bar	N_1	Normal effort on node 1 (kN)

Continuation of the Table 1

F	Allowable load (kg)	N_2	Normal effort on node 2 (kN)
$\{F\}^S$	Torsor of the efforts	N_3	Normal effort on node 3 (kN)
F_Z	Allowable load relative to the axis OZ (kg)	N_4	Normal effort on node 4 (kN)
G	Shear modulus or Coulomb modulus (MPa)	$[P]$	The transition matrix Global landmark local landmark
I_1	Moment of inertia of the element 1 (cm^4)	$[P]^T$	Transpose of the matrix [P]
I_2	Moment of inertia of the element 2 (cm^4)	R_e	Yield point (MPa)
I_3	Moment of inertia of the element 3 (cm^4)	$Sigf_v$	Yield point (MPa)
I_X	Moment of inertia about to OX (cm^4)	T_1	Shear force on the node 1 (kN)
I_Y	Moment of inertia about to OY (cm^4)	T_2	Shear force on the node 2 (kN)
I_Z	Moment of inertia about to OZ (cm^4)	T_3	Shear force on the node 3 (kN)
$[K]^{1\,Global}$	Stiffness matrix in the global coordinate system of the element 1	T_4	Shear force on the node 4 (kN)
$[K]^{2\,Global}$	Stiffness matrix in the global coordinate system of the element 2	U_1	Moving the node 1 next X (cm)
$[K]^{3\,Global}$	Stiffness matrix in the global coordinate system of the element 3	U_2	Moving the node 2 next X (cm)
$[K]^{1\,Local}$	Stiffness matrix in the local coordinate system of the element 1	U_3	Moving the node 3 next X (cm)
$[K]^{2\,Local}$	Stiffness matrix in the local coordinate system of the element 2	U_4	Moving the node 4 next X (cm)
$[K]^{3\,Local}$	Stiffness matrix in the local coordinate system of the element 3	$\{U\}^S$	Displacement matrix
$[K]^{S_1}$	Stiffness of sub-matrix (6 x 6)	V_1	Moving the node 1 next y (cm)
$[K]^S$	Assembly of the structural stiffness matrix	V_2	Moving the node 2 next y (cm)
L	Length of the elements 1 and 2 (cm)	V_3	Moving the node 3 next y (cm)
l	Length of element 3 (cm)	V_4	Moving the node 4 next y (cm)
Greek symbols			
ν	Poisson's ratio	θ_2	Rotation of the node 2 (rad)
ρ	Density (kg/m^3)	θ_3	Rotation of the node 3 (rad)
θ_1	Rotation of the node 1 (rad)	θ_4	Rotation of the node 4 (rad)

General characteristic of the problem, analysed in this article. In West Africa, particularly in Benin, the tile makers produce large quantity of micro-concrete tiles with different sizes with local materials (sand + cement) suitable proportion without adding amiant (Figure 1). The development of this product is less energy intensive. Advantages of tiles usage are good thermal insulation, the acoustic comfort, the simplest production with little investment, better resistance tiles to wind storms, to shock and point loads [2]. Besides the implementation of broad size tiles is easier.

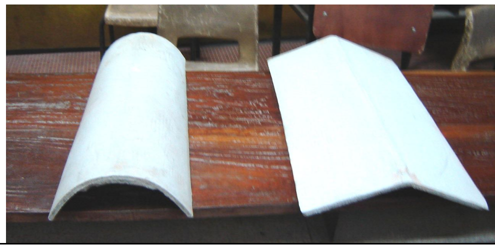
Type tile products in Benin Republic		
		
Flamande large tile	**Ridge tile**	**Romania tiles**

Figure 1 – Typical samples of tiles, produced in Benin Republic

However, during the laying of the tiles or maintenance work, there is a relatively high risk of their breakage [5]. That raises a question: are the quality control tests made in appropriate conditions? An observation of the strengths of control tests in some local workshops, pointed out that test devices need to be improved.

Indeed with the bending resistance tester, we see that in most cases, the tiles are defectively supported and poorly loaded. This result in the absence of flatness although three flexion or four-point tests must be made with details (distance between supports, transmission point loads to the supports, displacement measurement in some points). Regarding the impact resistance tests, there is no suitable device to our knowledge. Usually to measure the impact resistance a spherical steel ball of 200 g is dropped in free fall from 20 cm height on the convex undulation of the tile. As for the tensile tests of the tile heel the situation is similar: there is no adequate test device. To carry out the test of resistance to traction of the heel, a load of 20 kg is applied cantilevered at the distance of 50 mm between the axis of the load and the device that holds the tile. Therefore to contribute to the solution to all difficulties mentioned above, we have developed a new device. Characteristic of this device give opportunities to measure simultaneously the flexural strength, impact strength and tear resistance of the heel. That way, the results of tests can comply with strict requirements to the normative documents [7, 10].

Material and Methods, used in this article

Conceptual approach

The scheme of experimental device for testing tiles is shown at figure 2.

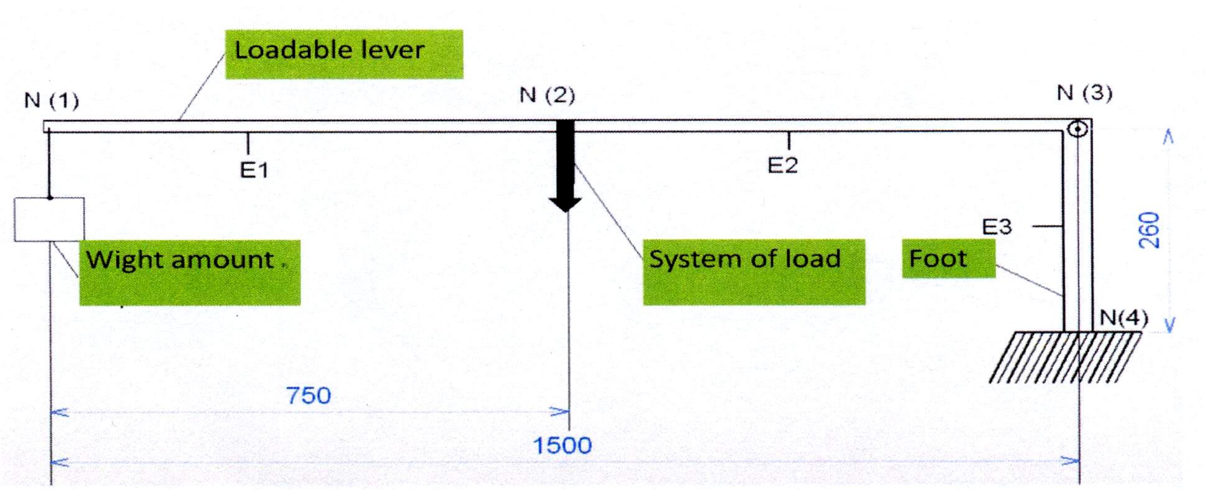


Figure 2 – Pre dimensioning of the device for the 3- and 4-points flexural strength tests

For finite element method (FEM) are used such parameters.

A full bar and a profile UUAP 80 – as structural elements (Figure 3).

For figures 2 and 3:

• Number of nodes: 4 (N°1, N°2, N°3, N°4).
• Number of elements (bars) 3 (E_1, E_2, E_3).
• Finite elements per unit length: 3 (E_1, E_2, E_3).
• Finished Surface elements: 0.
•Volumetric finite elements: 0.
• Number of degrees of freedom: 6.
• Load case: 8.

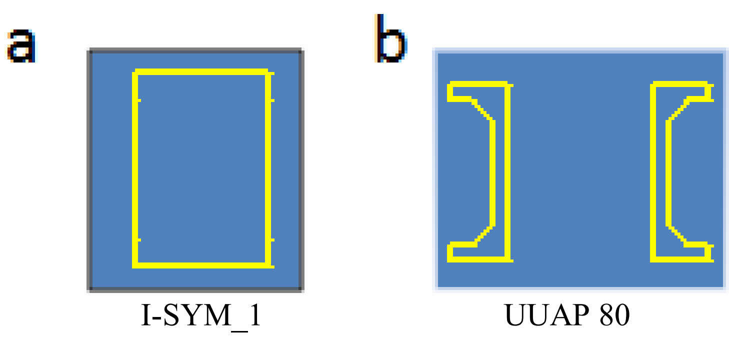


Figure 3 – Profiled lever arm (a) and gallows full bar (b)

The structural elements and characteristics of used materials are shown in Tables 2 and 3.

Table 2 – **Characteristics of the profiles sections**

Section Name	Element	A_X (cm²)	I_X (cm^4)	I_Y (cm^4)	I_Z (cm^4)
I-SYM_1	E_1 et E_2	08.000	4.839	10.667	02.667
UUAP 80	E_3	21.350	0.396	214.000	98.070

Table 3 – **Material Specifications**

Material	E (Mpa)	G (Mpa)	ν	ρ	R_e (Mpa) or $Sigf_y$
Acier E24	210000	80800	0.30	77.00	235

A concept of approach, used in this article, based on the structure calculation by the FEM with the Robot Millennium 17.0 software and Newton's third law: "The principle of action and reaction". The results of calculating experiments have been compared with results, received with new three- and four-point bending test device usage. For the design of this device, the CM66 rules governing metal constructions have been used. Figures 2, 4, 5 respectively show the flexural strength tests, the impact strength (impact resistance test) and the tear strength of the heel (traction heel resistance test).

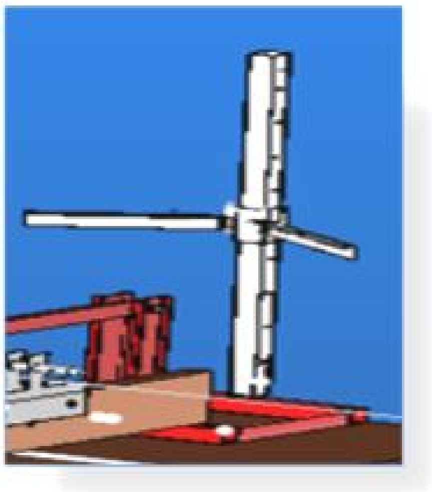


Figure 4 – General view of the impact resistance test device

For scheme on figure 4 a loose ball sliding system on a graduated vertical rod is attached to a flush mounted on the table. We ensure that the requirements of the normative documents are respected [8]. As this test is destructive, it's carried on the small tiles $500 \times 250 \times 8$ mm^3.

A piece of wood in which was made a cut of 10 cm depth (see figure 6 below) is fixed on the table in order to maintain the tile on the latter. Then normative loads have been applied to the heel of the tile at 5 cm from the edge of the table [8]. The tests are performed on small tiles with dimensions $500 \times 250 \times 8$ mm^3. These 3 different devices (flexural strength, impact and tensile strength of the heel) are combined into one – on a table that can withstand tiles of 2 m long and 1.6 m wide (see Figure 6).

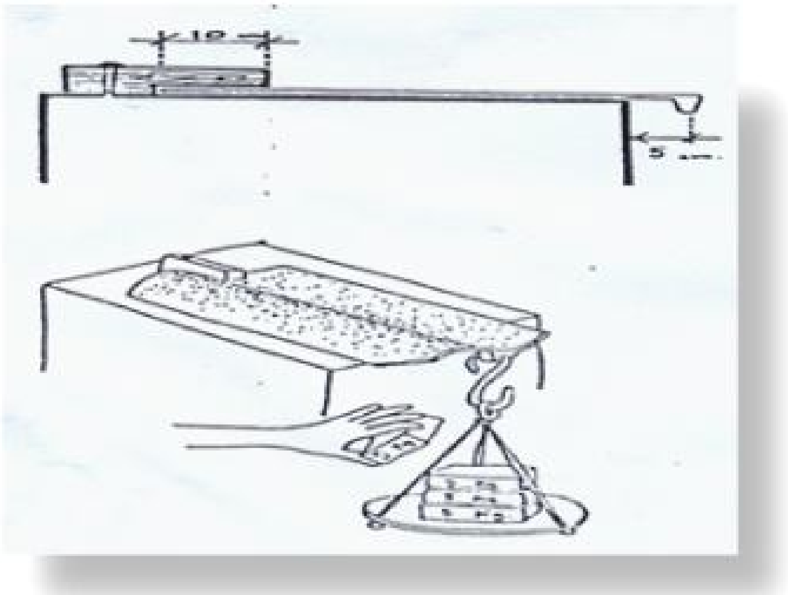


Figure 5 – A traction heel resistance test [1], [8]

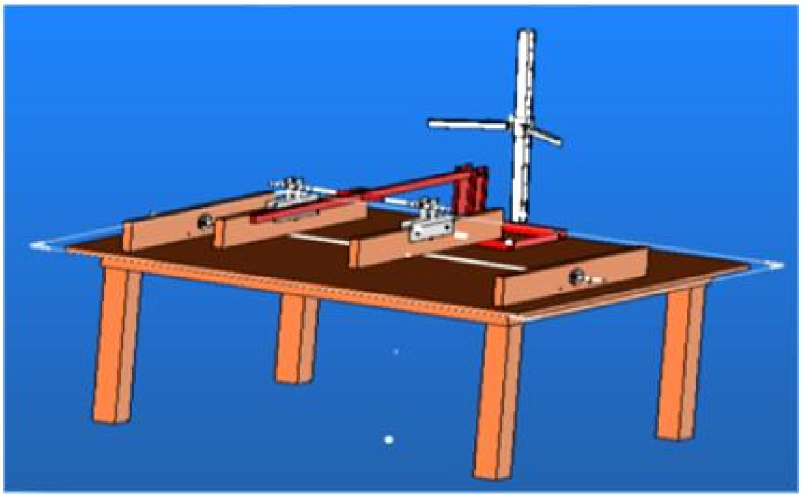


Figure 6 – Overview of the designed device for tiles mechanical strength tests

Modelling and Analysis of flexural strength testing of device

Modelling the structure

We launch the Millennium Version 17.0 Robot software. A "Wizard" dialog box opens and allows us to choose from the following list, the type of structure that we want to study: Portico plan space frame, lattice plane, spatial mesh, mesh, plate, shell, etc. In our case it is a gantry plane (XZ) consisting of such objects.

- A steel lever length 1.5 m and dimension rectangular 0.02 m × 0.04 m.
- A foot high steel and 0.6 m section UUAP 80.

The lever is articulated on the foot (node №3) and the foot in turn is built on a fixed support (node № 4). A window "View" consists of a grid and the horizontal and vertical rulers on the screen. We then define the construction lines 1, 2, 3 and along the axis «A», following the «B» axis to position the various elements of our device, supports and loads. Support is also defined: joint (bbl) to the node N°3 between the lever and the foot; Recessed (bbb) to the node N°4 between the foot and the support and finally a single tap (lbl) at the node N°2 middle lever. Finally, expenses are declared and defined to apply to the N°1 lever node; loads (cases: 0 kg, Case 2: 5 kg, Case 3: 10 kg, Case 4: 15 kg, Case 5: 20 kg, Case 6: 25 kg, Case 7: 30 kg, Case 8: 35 kg) representing the equivalent weight of the minimum allowable load are respectively applied to the node N°1 of the device and the reactions are determined in N°2 node for each load case.

Modeling of the device is illustrated at figure 7.

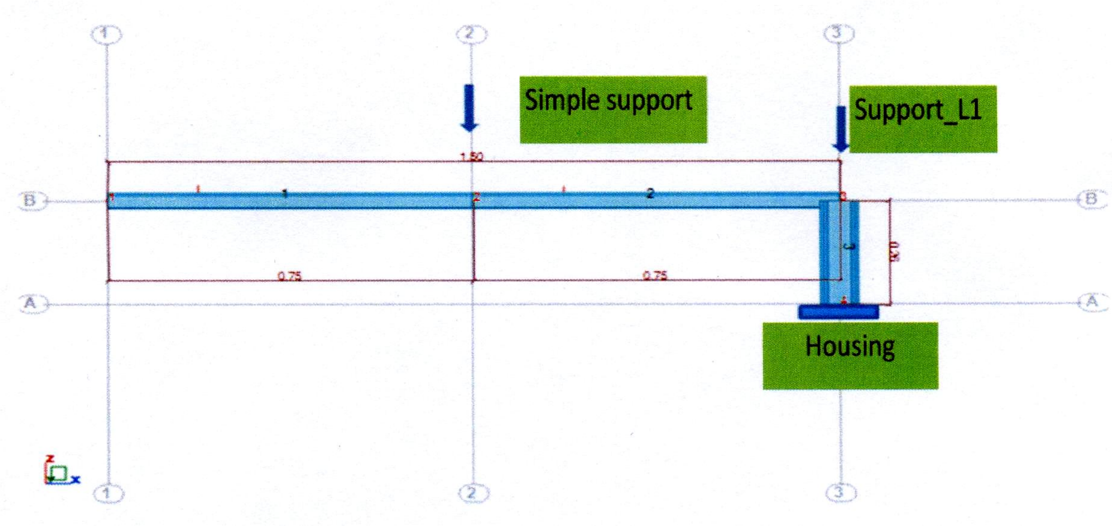


Figure 7 – Device Modelling in Robot Bat View window

Analysis of the structure

❖ The analysis of the device structure starts with a manual verification. After comparing the first manual results (support reactions) with those, calculated with the computer) modelling program). If the results are the same, the analysis can continue further with the Millenium 17.0 Robot software to avoid miscalculations and to gain time. This software is very user-friendly and can be installed on microcomputers unlike the large computing code that requires great space capacity details of FEM usage.

From all information which we have gathered during the modelling, FEM appears as the ideal method among those that we have previously tested during the manual analysis of the device structure. Indeed, the structure works in the XZ plane.

It consists of a lever hinged on one foot and the connections are:

- a single tap (N°2 node): a (01) unknown (T_2);
- a joint (node N°3): two (02) unknown (N°3 and T_3);
- recessed (N°4 node): three (03) unknown (N°4, M_4 and T_4).

In the XZ plane, there have only three equations to determine the six above unknowns. The system is therefore indeterminate. Applying the FEM, the structure can be divided into three separate linear elements numbered E_1, E_2 and E_3. These elements works as simple beams when applying a load T_1 = –0.35 kN to the node N°1 (see Figure 2).

<u>Element N°1</u>

Its stiffness matrix in the local space reference is:

$$[K]^{1Local} = \frac{EI_1}{L^3}\begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^2 & -6L & 2L^2 \\ -12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L^2 \end{bmatrix} \quad (1)$$

With E = 21000 kN/cm², $I_1 = I_2$ = 10.667 cm^4; L = 75 cm.

Between the local coordinate system of the element N°1 and the global coordinate system of the structure occurs the following link:

$$\begin{cases} \vec{x}_1 = \vec{X} \\ \vec{z}_1 = \vec{Z} \end{cases}, \quad (2)$$

$$\begin{Bmatrix} \vec{x}_1 \\ \vec{z}_1 \end{Bmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\begin{Bmatrix} \vec{X} \\ \vec{Z} \end{Bmatrix} \quad (3)$$

The transition matrix [P] from the overall mark (size 6) to the local landmark is therefore equal to

$$[P] = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}. \quad (4)$$

Let us write the stiffness matrix in the local coordinate system, using the following principle: when a planar structure has a beam bending element working only flat, the latter is characterized in general in the global coordinate by three (3 degrees of freedom per node and six degrees of freedom per element [3]). Then we obtain:

$$[K]^{1Local} = \frac{EI_1}{L^3}\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 12 & 6L & 0 & -12 & 6L \\ 0 & 6L & 4L^2 & 0 & -6L & 2L^2 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -12 & -6L & 0 & 12 & -6L \\ 0 & 6L & 2L^2 & 0 & -6L & 4L^2 \end{bmatrix}. \quad (5)$$

In the global coordinate system, the stiffness matrix of element «1» is written as

$$[K]^{1Global} = [P]^T.[K]^{1Local}.[P] \quad (6)$$

$$[K]^{1Global} = \frac{EI_1}{L^3}\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 12 & 6L & 0 & -12 & 6L \\ 0 & 6L & 4L^2 & 0 & -6L & 2L^2 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -12 & -6L & 0 & 12 & -6L \\ 0 & 6L & 2L^2 & 0 & -6L & 4L^2 \end{bmatrix}. \quad (7)$$

<u>Element N°2</u>
Same item

$$[K]^{1Global} = [K]^{2Global}. \quad (8)$$

<u>Element N°3</u>
Its stiffness matrix in the local reference is:

$$[K]^{3Local} = \frac{EI_3}{L^3}\begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^2 & -6L & 2L^2 \\ -12 & 6L & 12 & -6L \\ 6L & 2L^2 & 6L & 4L^2 \end{bmatrix} \quad (9)$$

With E = 21 000 KN/cm², I_3 = 214 cm^4, l = 26 cm.

Then the following relationship can be observed between the local coordinate system of the element N°3 and the global coordinate of the structure:

$$\begin{cases} \bar{x}_3 = -\bar{Z} \\ \bar{z}_3 = \bar{X} \end{cases}, \quad (10)$$

$$\begin{Bmatrix} \vec{x}_3 \\ \vec{z}_3 \end{Bmatrix} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}\begin{Bmatrix} \vec{X} \\ \vec{Z} \end{Bmatrix}. \quad (11)$$

There is a gap of «90°» between the two references. That way, the transition matrix [P] from the global coordinate system to the local one is equal to:

$$[P] = \begin{bmatrix} 0 & -1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}. \quad (12)$$

Its transponate writes:

$$[P]^T = \begin{bmatrix} 0 & -1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}. \quad (13)$$

The stiffness matrix in the local coordinate system can be expressed in the same manner as for the element N°1:

$$[K]^{3Global}=\frac{EI_3}{L^3}\begin{bmatrix}0&0&0&0&0&0\\0&12&6L&0&-12&6L\\0&6L&4L^2&0&-6L&2L^2\\0&0&0&0&0&0\\0&-12&-6L&0&12&-6L\\0&6L&2L^2&0&-6L&4L^2\end{bmatrix}. \tag{14}$$

In the global coordinate system, the stiffness matrix of the element 3 becomes:

$$[K]^{3Global}=[P]^T[K]^{3Local}[P], \tag{15}$$

$$[K]^{3Global}=\frac{EI_3}{L^3}\begin{bmatrix}12&0&6L&-12&0&6L\\0&0&0&0&0&0\\6L&0&4L^2&-6L&0&2L^2\\-12&0&-6L&12&0&-6L\\0&0&0&0&0&0\\6L&0&2L^2&-6L&0&4L^2\end{bmatrix}. \tag{16}$$

Once the stiffness matrixes are defined, one proceeds to their assembling to obtain the stiffness matrix of the device structure (as a whole device). So, we will work in the global coordinate system. The assembly of the three elementary matrices $[K]^{1Global}$, $[K]^{2Global}$ and $[K]^{3Global}$ of the three finite elements of the device structure provides the global matrix of $[K]^S$, whose dimension is «12 x 12». Indeed, for a simple bending element in plane, each node has three degrees of freedom and each node bears three degrees of freedom. The structure has four (4) nodes, that justifies the degree of freedom obtained for the whole device. For convenience the matrix $[K]^S$ is represented in tabular form (Table 4).

Table 4 – **Matrix [K]^S**

0	0	0	0	0	0	0	0	0	0	0	0
0	$12\frac{EI_1}{L^3}$	$6\frac{EI_1}{L^2}$	0	$-12\frac{EI_1}{L^3}$	$6\frac{EI_1}{L^2}$	0	0	0	0	0	0
0	$6\frac{EI_1}{L^2}$	$4\frac{EI_1}{L}$	0	$-6\frac{EI_1}{L^2}$	$2\frac{EI_1}{L}$	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	$-12\frac{EI_1}{L^3}$	$-6\frac{EI_1}{L^2}$	0	$24\frac{EI_1}{L^2}$	0	0	$-12\frac{EI_1}{L^3}$	$6\frac{EI_1}{L^2}$	0	0	0
0	$6\frac{EI_1}{L^2}$	$4\frac{EI_1}{L}$	0	0	$8\frac{EI_1}{L}$	0	$-6\frac{EI_1}{L^2}$	$2\frac{EI_1}{L}$	0	0	0
0	0	0	0	0	0	$-12\frac{EI_3}{l^3}$	0	$-6\frac{EI_3}{l^2}$	$-12\frac{EI_3}{l^3}$	0	$6\frac{EI_3}{l^2}$
0	0	0	0	$-12\frac{EI_1}{L^3}$	$-6\frac{EI_1}{L^2}$	0	$12\frac{EI_1}{L^3}$	$-6\frac{EI_1}{L^2}$	0	0	0
0	0	0	0	$-6\frac{EI_1}{L^2}$	$-6\frac{EI_1}{L}$	$-6\frac{EI_3}{l^2}$	$-6\frac{EI_3}{L^2}$	$4\frac{EI_1}{L}+4\frac{EI_3}{l}$	$-6\frac{EI_3}{l^2}$	0	$-2\frac{EI_3}{l}$

Once the overall stiffness matrix is established, it's necessary to take into account the loading conditions of the support. The behaviour in the global coordinate of the structure can be put in the form:

$$\{F\}^S=[K]^S\{U\}^S \tag{17}$$

with :

$$\{F\}^S = [N_1, T_1, M_1, N_2, T_2, M_2, N_3, T_3, M_3, N_4, T_4, M_4]^T$$

and

$$\{U\}^S = [U_1, V_1, \theta_1, U_2, V_2, \theta_2, U_3, V_3, \theta_3, U_4, V_4, \theta_4]^T$$

Considering the correlation between «Machine and Degree of Freedom» [3] we obtain the following relationships:

Node 1: Free

$N_1 = 0$; T_1 = weight equivalent «P» variableis from 0 to -0.35 kN; $M_1 = 0$

U_1 =? V_1 =? θ_1 = ?

Node 2: single press

$N_2 = 0$ T_2 =? $M_2 = 0$

U_2 =? $V_2 = 0$ θ_2 =?

Node 3: joint support

N_3 =? T_3 =? $M_3 = 0$

$U_3 = 0$ $V_3 = 0$ θ_3 =?

Node 4: support installation

N_4 =? T4 =? M_4 =?

U_4 =0; V4 = 0; $\theta_4 = 0$

The relation (16) is a linear system of twelve equations whose resolution requires the creation of two sub-system.

Sub-system 1:

It is obtained after removing from the equation (17) the lines corresponding to zero degrees of freedom and the columns of the same rank. In the resulting sub-system appears only unknown nodal displacements (degree of freedom free) and the nodal known actions. After simplification, $[K]^S$, $\{F\}^S$ and $\{U\}^S$ become respectively.

0	0	0	0	0	0
0	$12\frac{EI_1}{L^3}$	$6\frac{EI_1}{L^2}$	0	$6\frac{EI_{12}}{L^2}$	0
0	$6\frac{EI_1}{L^2}$	$4\frac{EI_1}{L}$	0	$2\frac{EI_1}{L}$	0
0	0	0	0	0	0
0	$6\frac{EI_1}{L^2}$	$2\frac{EI_1}{L}$	0	$8\frac{EI_{12}}{L}$	$2\frac{EI_1}{L}$
0	0	0	0	$2\frac{EI_{12}}{L}$	$4E\left(\frac{I_1}{L}+\frac{I_3}{L}\right)$

With:

$$\{F\}^S = [N_1 = 0, T_1 = -0.35, M_1 = 0, N_2 = 0, M_2 = 0, M_3 = 0]^T$$

and

$$\{U\}^S = [U_1 = ?, V_1 = ?, \theta_1 = ?, U_2 = ?, \theta_2 = ?, \theta_3 = ?]^T$$

The relation (16) becomes a «6 ×6» dimension relationship. This sub-system cannot reasonably be reversed by a conventional manual procedure. We must use a computer algebra utility or a pocket calculator to obtain the components of $\{U\}^S$. Introducing the components of the stiffness of sub-matrix $[K]^{S1}$ and those of $\{F\}^S$ = [$N_1 = 0$, $T_1 = -0.35$ kN, $M_1 = 0$, $N_2 = 0$, $M_2 = 0$, $M_3 = 0$] in a calculator TI – 89 for example. After processing and calculation, the components of $\{U\}^S$ are affordable.

Sub-system 2

It is obtained by returning to previously deleted rows and eliminating zero terms. After simplification, $[K]^S$, $\{F\}^S$ and $\{U\}^S$ write :

0	$-12\frac{EI_1}{L^3}$	$-\frac{EI_1}{L^3}$	0	0	$6\frac{EI_1}{L^2}$
0	0	0	0	0	$6\frac{EI_3}{L^2}$
0	0	0	0		$-6\frac{EI_1}{L^2}$
0	0	0	0	0	$-6\frac{EI_3}{L^2}$
0	0	0	0	0	0
0	0	0	0	0	$2\frac{EI_3}{L}$

With

$$\{F\}^S = [T_2 = ?,\ N_3 = ?,\ T_3 = ?,\ N_4 = ?,\ T_4 = ?,\ M_4 = ?]^T$$

and

$$\{U\}^S = [U_1, V_1, \theta_1, U_2, \theta_2, \theta_3]^T.$$

By adopting the same calculation as in the system1, the components of $\{F\}^S$ are obtained.

❖ Process of calculations

After the modelling stage, the «Calculation» and the «Analysis» phases follow. The Millennium robot software automatically establishes the mathematical model calculations that best reflects to the actual structure of the device (figure 8): the discretization of the finite element structure. We can modify the mathematical model created automatically by the software by clicking on the command «generate model» of the «Analysis» menu. We can do a static analysis (default) or dynamic (modal) of the structure. [9]. For each finite element, the software determines the order, the interpolation matrix connecting the displacements of an inner point of the element to the nodal displacements, establishes the relationship between deformation and displacement, establishes the relationship between stress and strain, calculates elementary matrices (stiffness or mass) and finally proceeds to the assembly of the elementary matrices. With all the information gathered, the software calculates finally the values of internal and external nodal displacements, reactions to the nodes of support, effort, strain and stress in the entire structure. From all these results, only two types of information are important for the following study.

- Reactions to the nodes N°2 (load case N°1-8) for determining the equivalent weight *P* to a minimum allowable load *F*.
- The highest stresses, obtained in the elements N°1, 2 and 3, necessary for their dimensioning.

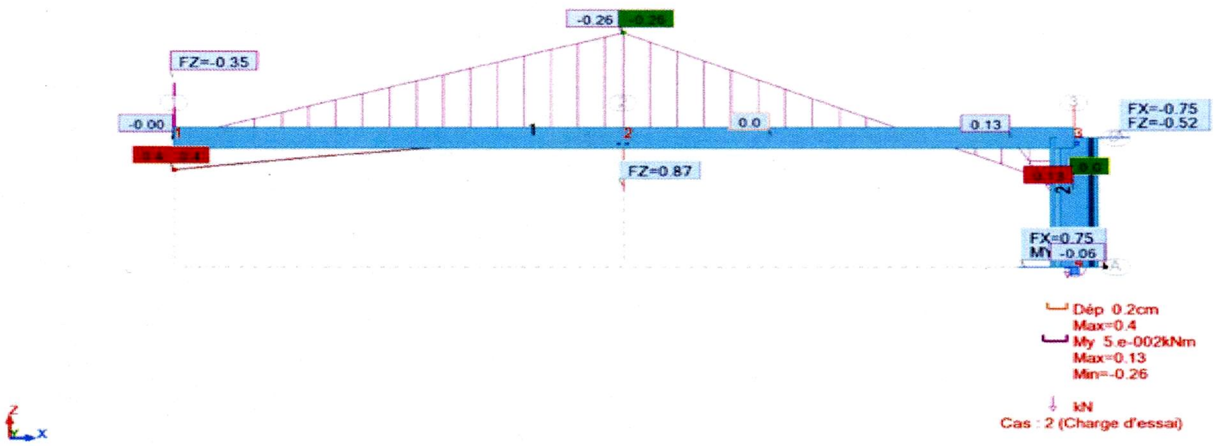


Figure 8 – Forces and Moments reactions (Load case 8, $F_Z = -0.35$ kN)

Results and discussion

Analytical results

- Sub-system 1

The constants used for the calculations are summarized in Table 5.

Table 5 – **Elastic constant and geometrical parameters**

E (kN/cm^2)	L (cm)	l (cm)	I_1 (cm^4)	I_2 (cm^4)	I_3 (cm^4)
21000	75	26	10.667	10.667	214

After calculation and treatment the components of $\{U\}^S$ have been obtained (Table 6).

Table 6 – **Components of $\{U\}^S$ (nodal displacements)**

$U_1 = 0$	$V_1 = \frac{(6lI_1 + 7LI_3)L^3 T_1}{[3EI_1(3lI_1 + 4LI_3)]} = -0.3852\,cm$	$\theta_1 = \frac{-(5lI_1 + 6LI_3)L^2 T_1}{[2EI_1(3lI_1 + 4LI_3)]} = 0.0068\,rad$
$U_2 = 0$	$V_2 = 0$	$\theta_2 = \frac{-(lI_1 + LI_3)L^2 T_1}{[EI_1(3lI_1 + 4LI_3)]} = 0.0022\,rad$
$U_3 = 0$	$V_3 = 0$	$\theta_3 = \frac{L^2 l T_1}{[2EI_1(3lI_1 + 4LI_3)]} = -1.8741 \times 10^{-5}\,rad$
$U_4 = 0$	$V_4 = 0$	$\theta_2 = 0\,rad$

- Sub-system 2

After treatment and calculating the components of $\{F\}^S$ is obtained (Table 7).

Table 7 – **Manual calculation results (reactions) for the load case 8 (35 kg)**

$N_1 = 0$	$T_1 = -0.35\,kN$	$M_1 = 0$
$N_2 = 0$	$T_2 = 6\frac{EI_1}{L^3}\left(-2\frac{V_1}{L} - \theta_1 + \theta_3\right) = 0.825\,kN$	$M_2 = 0$
$N_3 = 6\frac{EI_3}{l^2}\theta_3 = -0.748\,kN$	$T_3 = -6\frac{EI_1}{L^2}(\theta_2 + \theta_3) = -0.521\,kN$	$M_1 = 0$
$N_4 = 6\frac{EI_3}{l^2}\theta_3 = 0.748\,kN$	$T_4 = 0\,kN$	$M_4 = 2\frac{EI_3}{l}\theta_3 = -0.065\,kNm$

Incidentally, these results are obtained by assuming negligible weight of the lever.

Numerical results

The results obtained with the millennium robot software are presented in Table 8.

Table 8 – **Numerical results**

Reactions	N_1	T_1	M_1	N_2	T_2	M_2	N_3	T_3	M_3	N_4	T_4	M_4
Software	0	0.35	0	0	0.873	0	–0.748	–0.523	0	0.748	0	–0.065

After getting the results analytically and numerically, it is obvious to compare them to appreciate the difference between the two methods (Table 9).

Table 9 – **Comparison of results obtained through manual calculations and software**

Réactions	Manual	Software	Difference
N_1	0	0	0
T_1	0.35	0.35	0
M_1	0	0	0
N_2	0	0	0
T_2	0.825	0.873	0.048
M_2	0	0	0
N_3	–0.748	–0.748	0
T_3	–0.521	–0.523	0.002
M_3	0	0	0
N_4	0.748	0.748	0
T_4	0	0	0
M_4	–0.065	–0.065	0

The differences are relatively low. So we can superimpose the two models: this implies that there is convergence despite the reduced number of elements.

Study of multiple load cases

The above results are obtained for a single load case. The use of the device may take several load cases, when a guide has been established to help the user (Table 10).

Table 10 – **Summary allowable minimum loads *F* based equivalent weight *P***

Case load	equivalent weight *P* (kg) in the node **N°1**	Reaction of tile kg [Action of *P* + (10 kg = lever weight)]	Min. allowable Load *F*(Kg) in the node **N°2**
1	0	10	–10
2	–5	22	–22
3	–10	35	–35
4	–15	47	-47
5	–20	60	-60
6	–25	72	–72
7	–30	85	-85
8	–35	97	–97

If hypothetically we assume that the relationship between the reaction of the tile and the equivalent weight P is linear, we can draw the curve that provides the equivalent weight when the minimum allowable load is known (Figure 9).

In annexes, a copy of the forms, related to mechanical stress tests for tiles is joined – to help reader of the article understand the usage of these results.

Validation of the device

For the dimensioning of the device of the flexural strength tests, analysis of the structure gives such results (they reproduced in the form, close to the form displayed at the monitor) – figure 10, table 11.

Table 11 – **Validation of the device**

Type of tile		Flamane Small format ($500 \times 250 \times 8$ mm^3)	Flamande Large format ($1200 \times 500 \times 8$ mm^3)	Plate Small format ($500 \times 250 \times 8$ mm^3)	Plate Small format ($1200 \times 500 \times 8$ mm^3)
Maximum deflection (mm)	Simulation	0.078	0.093	1.436	9.865
	Comparator	0.071	0.089	1.501	9.810

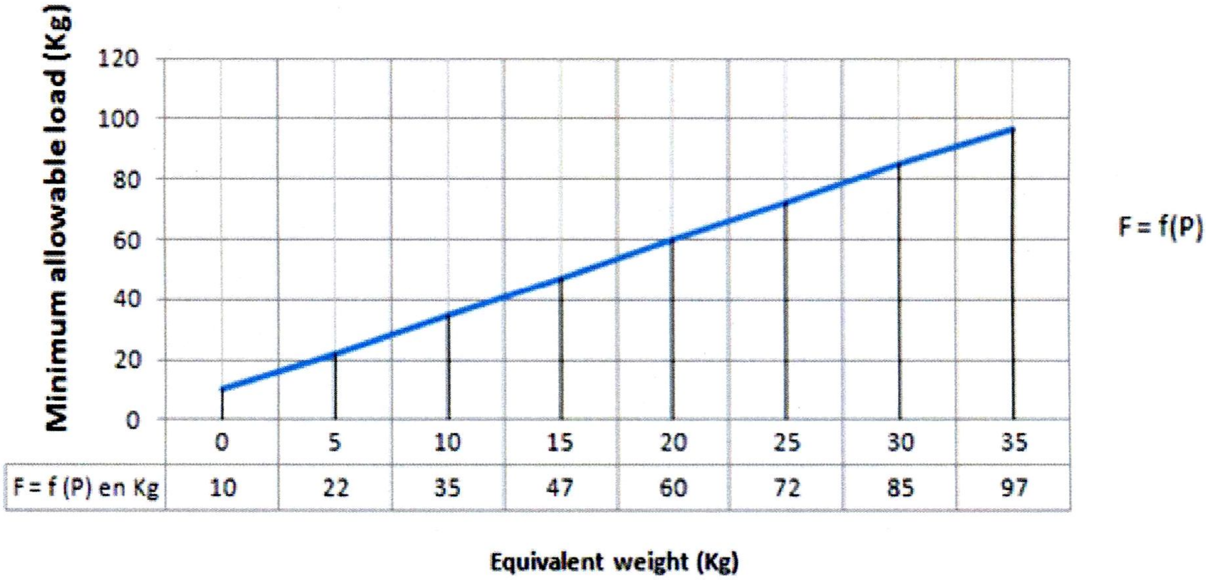


Figure 9 – Curve minimum allowable load *F* – weight equivalent *P*

Standard: CM66
Type of analysis: Static
allowable loads: F = 97 kg, P = equivalent weight 35 Kg.
Material Steel E24: Sigfy = 235,000 Mpa

Element E_1 and E_2: lever
Constraints Sigfy = -0,280 / 5,333 = -52,468 Mpa
discharge parameters: kD = 1.00
verification formulas:
*** SigFy kD = 1.00 * 52,468 = | 52 468 | <235,000 Mpa (3,611)**
*** = Tauz 1.54 | 1.54 * -0660 | = | 1 017 | <235,000 Mpa (1,313)**
The profile is correct!

Element E_3 foot

Constraints Sigfy = 0,134 / 53,500 = 2,502 Mpa
verification of formulas:
Sigfy = 2.502 < 235,000 Mpa (3212)
*** = Tauz 1.54 | 1.54 * -0965 | = | 1 486 | <235.000 Mpa (1,313)**
The profile is correct!

Figure 10 – Results of computer calculations

Using the extension gauges, resistors, the Wheatstone bridge and accessories, we were able to check that the load *F* transmitted to the tile in the flexural strength testing, the fixed charging system in the middle of the lever is substantially equal to the theoretical load *F* calculated above for each equivalent weight *P*. Therefore, it is appropriate that the lever effectively transmits a load *F* to the tile. In the bending strength test, each tile which rests on the adjustable supports, receives the load transmitted by the lever. Displacements (arrows) arising from such different stresses are recorded by two comparators placed in the middle and below the loaded tile [4]. On average, the results of surveys on travel 2 comparators and finally we compare these results (arrows) with those obtained by numerical simulation. As the two results are substantially equal for the various tested tiles, it is concluded that the device is well-dimensioned.

Conclusion. In Benin, some devices tests for the mechanical characteristics of the tiles remained in the state of indications of the normative documents. Moreover, in most workshops control devices rely on no scientific nor technical reality. Their assembly is subjected to criticism. As this theme is specially adapted to a complete educational study and considering the need of an analytical approach to solve the problem, the study and the implementation of the new system, we propose through this work, follow the procedures described below:

- ✓ A simulation approach based on the FEM;
- ✓ An experimental approach: the device is constructed and instrumented to measure the mechanical strength of the tiles control tests (flexural, impact, heel tearing);
- ✓ For the validation of the device, the use of the comparators and strain gauges is available;
- ✓ With the Robot Millennium 17.0 software was made the simulation of the mechanical behaviour (variation of field trips and changes in stress fields) of small and wide format tiles.

We hope this work will contribute to make reliable quality control tests for small and wide format tiles, and micro-concretes.

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<u>ANNEX 1</u>: Copy of a form for mechanical stress tests tiles.

IDENTIFICATION FEATURES MECHANICAL TILES IN MICRO-CONCRETE

Type: Date:

Dimensions: L = L 7/10 x T = B = m m m H

<u>ANNEX 2</u>: Copy of a form for mechanical stress tests tiles.

IDENTIFICATION CHARACTERISTICS MECHANICAL TILES IN MICRO-CONCRETE

Sample ID:

Operator Name:

Type:
Date:
Color:
Company:
Dimensions :
$L^{1} = 7/10 \times L^{2}_{T}$ = m B = m H = m

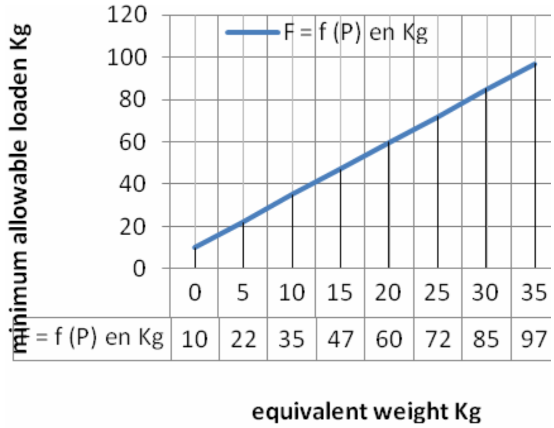
bending strength

Three (3) points : $F(Kg) = \frac{35BH^2}{3L}.10^5$

P =
Max resistance. :

Four **(4) points** : $F\ (Kg) = \frac{35BH^2}{3(L-l)}.10^5$

P = Max resistance. :



Impact resistance	
N° Série	Height **Max. in cm**

Peel strength of the heel
P = 20 daN Max resistance.

<u>Example</u>: provides a tile with dimensions:
Width B = 0.4 m;
Thickness H = 0.006 M;
Lt = length 1.4 m.

You are asked to determine the equivalent weight *P* to perform the test three flexion (3) points, and the test of bending four (4) points.

Bending test three (3) points :
Determining the support spacing L = 7/10 x Lt = 1 m.

Calculating the minimum allowable load F = 35BH² / 3L ⟦10⟧ ^ 5 = 16.8 Kg.

Calculating the equivalent weight P using the diagram Figure 6: Curve minimum allowable load F Weight Kg equivalent P, linear interpolation is determined by the value of P = 2.83 ≅ 2.8 Kg.

Bending test four (4) points:
Determination = L / 3 = 0,33 m;

35BH² F = / (3 (L-l)). ⟦10⟧ ^ 5 = 25,1 Kg.

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[1] Espacement des appuis.
[2] Longueur de la tuile.