ANALYSIS OF PLUVIAL FLOW IN METALLIC TILES

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Abstract. *The steel is being a quite important constructive element in the building site of Brazil. This is due to the advantages that it presents such as: high constructive efficiency, relief of the foundations in comparison with the structures done in concrete, reduction of the time of construction and many architectural possibilities that it offers. In the Brazilian market several types of metallic tiles are appearing, that being chosen appropriately during the project phase, for each climatic area of the country, they will be a solution really economical and efficient and more compatible with the industrialized construction. In relation to the system of closing of a construction the roof, that it is exposed to the solar radiation during a larger period along the day, it has an important paper inside of the evaluation of the thermal acting of a construction. Of a good roof selection it is waited not only a good thermal acting as well as a good barrier in relation to the rain. It also stands out that in the developed countries the most efficient material is it used in the coverings, in the case metallic tiles. In the present work it is studied the flow of the rain for the several drawings of channels of metallic tiles presented at the market and that are appearing now. A mathematical modelling simplified for the flow in cope in tiles is presented, being considered a flow one-dimensional, for some drawings of metallic tiles already found at the national market. It is also made a numeric simulation being considered a two-dimensional flow being used the program Ansys. Results are shown for the variation of the height of the liquid layer and for flow speed in transient regime for channels with simple geometries, but with variable section and inclinations of different roof. Starting from the presented results it is observed that the variation of the liquid layer (rain) is influenced by the inclination of the channel (roof). The overflow can happen for channels with constant traverse section and smaller inclination than* 30^0. *Like the barrier, besides the thermal isolation, is also an important parameter in a roof selection, this result is important during the definition of the drawing of the roof with this tile type.*

Keys words:. *Metallic tile, pluvial flow, open channel, industrialized construction.*

1. Introduction

1.1. The industrialized construction

The industrialized constructions are conceived looking for a larger reduction in the time of execution of the work, optimization of costs, acting improvement and quality. With that, a great variety of materials, equipments and practices technological innovators have been imported to the market of the building site. However, to reach a real technological innovation, it is not enough to introduce isolated components in a work, or to import functional systems no adapted to the reality in subject. It is necessary that the components are properly associated to the production process, and this is in keeping with the real conditions of execution. A sistemical vision of the process should be had, in other words, the construction should be faced as a group of systems to they be mounted and connected as a puzzle. A promise of that constructive type is the constructions in metallic structure and efficient complemental systems, being included the metallic tiles (Sales et al., 2001a, 2001b).

Of the physical-constructive point of view, the constructions have been being lighter and slender, as well as its execution has if shown faster, due to new technologies of the constructive process. However, the connections between the subsystem of the construction and the warranty of its efficiency still represent a practical problem in the daily of the works and of the market when no analyzed previously.

The metallic structure possesses an own constructive methodology, and not to have knowledge of that technology implicates in adopting a solution that can be incompatible with the structural system. They are few the professionals of the middle, of servants, going by masters of works, for engineers and for architects, that possess a minimum level of technical knowledge to build and to conceive constructions in steel, in way the if it avoids typical problems of that constructive modality (Castro, 1999; Sales et al., 2001c).

The coming of new construction materials and of new insulating materials it has been possible the appearance of new project alternatives for the coverings with the appearance of metallic tiles in substitution the conventional ones in ceramic and asbestos. The current tendency is the growth of the use of metallic tiles and the appearance of new models, colonial type for residential use, in substitution to the conventional tiles in function of the following factors: a) environmental pressure, with the collection of the recomposition of the cultivated beds and of the firewood that is used for the production of the ceramic tile; (b) the subject of the quality that is quite prejudiced in the production of conventional tiles where most of the ovens is inadequate and tiles are produced with characteristics differentiated in a same ovenned. Besides these factors the chronic technical problems exist with the high absorption of water, unstandardisation and feathering , etc., of the conventional tiles in ceramic.

1.2. The metallic tiles

Looking for complemental constructive systems more compatible with the whole industrialized construction, the metallic tiles, present a lot of advantages, mainly for they be very light, to reduce the cost of the work hand in the assembly of the roof and also for not presenting break indexes in the transport, to resist great impacts, in the storage or even in the execution of the covering. Another important point is in the execution of the projects of coverings, because, the metallic tile being lighter is possible to use less weight in the roof batten metallic or wood, providing like this a very smaller cost for square meter for work. Besides that, the metallic tile presents a very high durability compared to the conventional tiles in ceramic.

For its praticily allied to a great resistance and lightness, the metallic tile can be used in curved roofs, and when done in panel form, it can be used as lateral covering, facade of buildings and industrial hangars. Now, besides the great range of panels of vertical and horizontal closings prefabricated existent in the market and that are compatible with the industrialized construction, a lot of options of metallic tiles, besides the already traditional in ceramic and asbestos, they are appearing in new models each one presenting a color pattern, style and durability, Fig. 1. For a good selection of those new models of tiles in steel, besides knowing all of the existent options, it should be known their advantages and disadvantages and style.

Now the use of the metallic tiles is more industrial, in the type panel plane or curved, and the residential use, where the colonial style is needed, it is not still easily available in the market. They are still few the national manufacturers of metallic tiles, colonial type, but with the progress of the industry of the national steel, this tile type beging to enlarges at the market for all of the advantages mentioned previously. The metallic tiles allow curved roofs, besides the conventional ones, in cupula form, as shown in the Fig. 2. This is due to their small dimensions, lightness, geometric forms (scales, losangular and rectangular) and appropriate fitting that provide lighter and slender structures.

(a) Gutter type (b) Panel type

Figure 1. Types of metallic tiles. Source: Technologies, 2002.

a) Intern view of the roof   b) Extern view of the covering

Figure 2. Forum of Recife, covering and roof in natural copper. Source: Revestalic, 2004.

2. Methodology

The analysis of pluvial flow in metallic tiles consists of verifying the variation of the height of the layer of water of the flow along the channel of the tile, in function of the inclination and geometry of the channel. The solution of this problem type is only possible through numeric simulation once the ruling equation is complex. In this work, this analysis will be made in two ways. The first approach includes an analytical solution of the developed mathematical models more easily being considered hypotheses simplificatives, that allow to obtain the solution, through simple algorithms of numeric solution. In the second approach the study is made, through numeric simulation using specific software and it allows the analysis in transient regime of the height of the liquid layer and of the flow speed.

2.1. Flow in opened channel

The flow in opened channels very important, however, their characteristics and the complexity of the same ones vary plenty and they are different from those in condutes. Usually the flow in open channel are due to the own weight of the fluid and they present a free surface among the fluid that it flows and the fluid above and that it can be altered of a configuration no disturbed (relatively plane) and to form waves that move through the surface with a speed that depends on its size (weigh, length) and of the properties of the channel (depth, speed of the flow, etc.) (Munsom et al., 1997; White, 2002).

In the flow in opened channel the pressure gradient is not relevant, because the inertia and the viscous effects in the gas above the liquid are despicable. In a lot of situations, the depth of the flow is not constant along the channel (variable section, obstruction in a portion of the channel) turning complex its analysis. The flow is three-dimensional, sometimes no permanent and frequently complex due to the geometric effects (Jones, 2002; Thomas, 2002).

2.2. Mathematical modelling

In the mathematical approach it comes a model simplified unidimensional of a flow in opened channel, Fig. 3, being considered the following hypotheses: steepness of the channel varying slowly, depth of the water varying slowly, simple geometry, distribution of speed unidimensional and pressure distribution approximately hidrostatic.

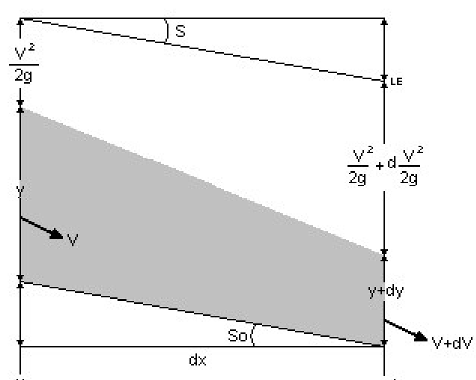

Figure 3. Control volume among two sections in an opened channel. Source: WHITE, 2002.

The equation of the balance of energy for the flow is given by the expression, Eq. (1),

$$y+\frac{V^2}{2\cdot g}+S_0\cdot dx=y+dy+\frac{V^2}{2\cdot g}+d\,\frac{V^2}{2\cdot g}+h_l \quad (1)$$

where h_l is the loss of load due to the viscous effects of the flow, V is the speed of the flow, g is the acceleration of the gravity, S_0 is the inclination of the channel and LE is the line of energy. When it is written the load loss in function of the inclination of the line of energy, $S = h_l/dx$, the Eq. (1) it is reduced the, Eq. (2),

$$dy=\frac{V\cdot d(V)}{g}+(S_0-S)\cdot dx \quad (2)$$

Being considered the equation of the continuity (Q = cte. = V.A) and differentiating it in relation to x, it is had, Eq. (3):

$$\frac{dQ}{dx}=A\cdot\frac{dV}{dx}+V\cdot\frac{dA}{dx}=0 \quad (3)$$

As A = b.y, and consequently dA = b.dy, being b the width of the channel, it is obtained, Eq. (4):

$$\frac{dy}{dx}\cdot\left(1-\frac{V^2}{g\cdot y}\right)=S_0-S \quad ou \quad \frac{dy}{dx}=\frac{S_0-S}{1-Fr^2} \quad (4)$$

where Fr is the number of Froude, given by the expression, Eq. (5),

$$Fr=\frac{V}{(g\cdot y)^{\frac{1}{2}}} \quad (5)$$

being S the inclination of the line of defined energy for, Eq. (6):

$$S=\frac{f}{D_h}\cdot\frac{V^2}{2\cdot g}=\frac{V^2}{R_h\cdot C^2}=\frac{n^2\cdot V^2}{\alpha^2\cdot R_h^{\frac{4}{3}}} \quad (6)$$

where C is the coefficient of Chézy (White, 2002), n is the rugosidad parameter (fixed), α is the parameter same result 1, for the international system and R_h it is the hydraulic ray, given by the division among the area of traverse section (A) and the wet perimeter (P_m).

3. Case studies

3.1. Mathematical approach

In this stage, with the application of the theory of flow in opened channels, it comes a mathematical modelling for the flow of the rain in different geometries of channels of metallic tiles and inclinations of roofs, being adopted hypotheses simplificatives, such as: steepness of the channel varying slowly, depth of the water varying slowly, simple geometry, unidimensional distribution of speed, pressure distribution approximately hidrostatic and permanent regime. Starting from these simplified models algorithms were developed, through code FORTRAN and MAPLE, for obtaining of the variation of the height of the layer of water in the channels.

3.1.1. Tile with channel of constant rectangular section

The tile, with channel of constant rectangular section shown in the Fig. 4, it is the simplest model to model mathematically, because the hydraulic ray just depends on the height of the liquid layer of the flow.

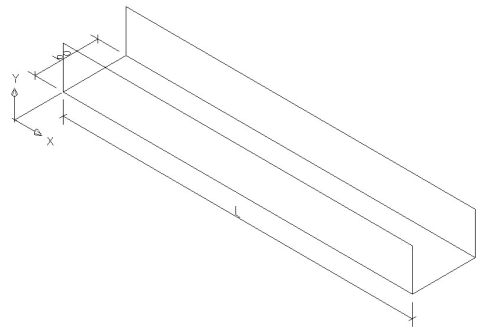

Figure 4. Model three-dimensional of a tile with channel of constant rectangular section (Channel 1).

For this channel the wet perimeter, P_m, it is given by the expression, Eq. (7),

$$P_m = 2 \cdot y(x) \cdot b_0 \tag{7}$$

the area of traverse section, A, for, Eq. (8):

$$A = b_0 \cdot y(x) \tag{8}$$

and the hydraulic ray, R_h, for, Eq. (9):

$$R_h = \frac{y(x)}{1 + \frac{2}{b_0} \cdot y(x)} \tag{9}$$

where y(x) it is the height of the liquid layer of the channel and b_0 it is the width of the channel.

3.1.2. Tile with channel of variable rectangular section

The tile with channel of variable rectangular section, Fig. 5, it differs of the tile with channel of constant rectangular section because it possesses an angle of opening of the channel, increasing its traverse section.

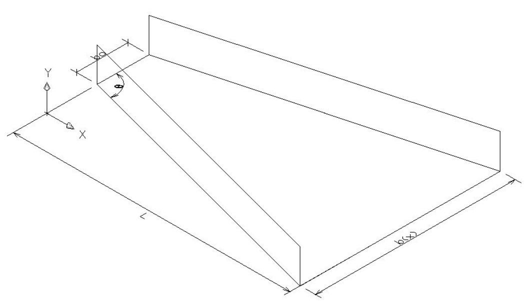

Figure 5. Model three-dimensional of a tile with channel of variable rectangular section (Channel 2).

For this channel the wet perimeter, P_m, it is given by the expression, Eq. (10),

$$P_m = 2 \cdot y(x) + 2 \cdot \tan(\theta) \cdot x + b_0 \tag{10}$$

the area of traverse section, A, for, Eq. (11):

$$A = (2 \cdot \tan(\theta) \cdot x + b_0) \cdot y(x) \tag{11}$$

and the hydraulic ray, R_h, for, Eq. (12):

$$R_h = \frac{\left(2 \cdot \tan(\theta) \cdot x + b_0\right) \cdot y(x)}{2 \cdot y(x) + 2 \cdot \tan(\theta) \cdot x + b_0} \tag{12}$$

where y(x) it is the height of the liquid layer of the channel, b_0 is the initial width of the channel and θ angle of opening of the channel.

3.1.3. Tile with channel of variable section

The tile with channel of variable section, Fig. 6, it is the analyzed most complex model and that more it approaches the real model, because, besides varying the width along the channel it also possesses the sloping lateral walls.

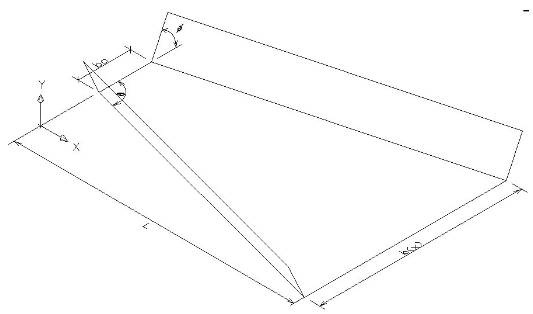

Figure 6. Model three-dimensional of a tile with channel of variable section (Channel 3).

For this channel the wet perimeter, P_m, it is given by the expression, Eq. (13),

$$P_m = \frac{2}{\mathrm{sen}(\phi)} \cdot y(x) + 2 \cdot \tan(\theta) \cdot x + b_0 \tag{13}$$

the area of traverse section, A, for, Eq. (14):

$$A = \left(\cot g(\phi) \cdot y(x) + 2 \cdot \tan(\theta) \cdot x + b_0\right) \cdot y(x) \tag{14}$$

and the hydraulic ray, R_h, for, Eq. (15):

$$R_h = \frac{\left(\cot g(\phi) \cdot y(x) + 2 \cdot \tan(\theta) \cdot x + b_0\right) \cdot y(x)}{\frac{2}{\mathrm{sen}(\phi)} \cdot y(x) + 2 \cdot \tan(\theta) \cdot x + b_0} \tag{15}$$

where y(x) it is the height of the liquid layer of the channel, b_0 is the initial width of the channel and θ angle of opening of the channel and ϕ angle of inclination of the wall of the channel.

3.2. Numeric approach

Being used of specific software, Ansys, a model of a metallic tile is elaborated for the analysis in transient regime of the flow of the rain, for different inclinations of roofs, being adopted a model bidimensional. Being used this model was made numeric simulations for obtaining of the variation of the height of the layer of water and of the flow speed in the channels.

3.2.1. Description of the numeric element.

The software Ansys uses the numeric technique of finite elements. For the description of the model, the element of bi-dimensional fluid, was called FLUID141. The element FLUID141, Fig. 7, is a constituted plane element of 4 knot. The element has three degrees of freedom for knot: speed, pressure and temperature. To obtain the speeds the beginning of the conservation of the momentum it is used and the pressure is obtained through the beginning of the conservation of the mass and if it needs of the temperature, this is obtained through the law of conservation of energy. A system of derived head offices of the discretization of the ruling equations is created for each degree of freedom, and solved separately by the program Ansys (ANSYS,2001).

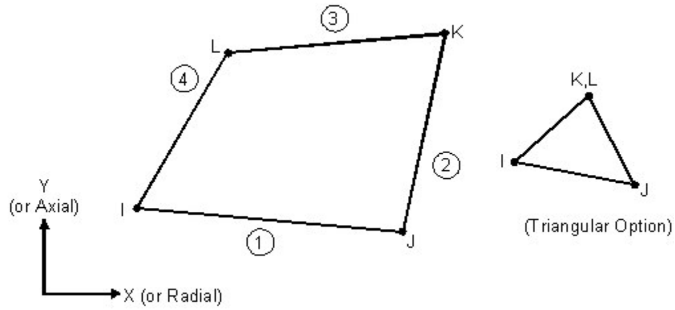

Figure 7. Outline of the element FLUID141 – Source: ANSYS, 2001.

The element FLUID141 needs as entrance data the specifications of the knots (I,J,L,K) that will define the mesh, and the values of the properties thermophisical of the fluid (density, viscosity, specific heat and thermal conductivity).

3.3. Results

The analysis of pluvial flow in metallic tiles was accomplished being considered three geometries different from channel: channel with constant rectangular section (Channel 1), channel with variable rectangular section (Channel 2) and the channel with variable section (Channel 3), varying the inclinations in 10^0 and 45^0.

In the Figures 8 and 9 the results are presented being considered the different configurations in relation to the geometry and inclination of the channel. For this analysis a same flow was considered for all of the configurations.

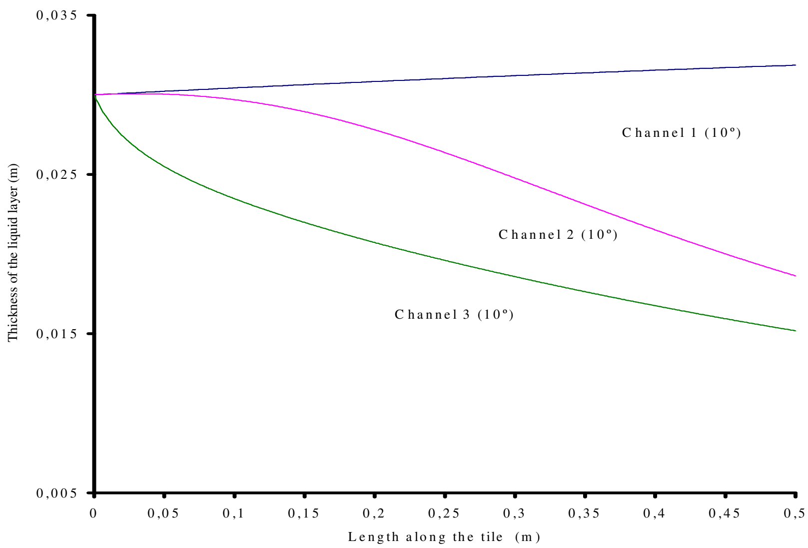

Figure 8. Variation of the height of the liquid layer along the channel in function of the geometry, for the channel with inclination of 10º.

The efficiency of any roof configuration is analyzed starting from the variation of the height of the layer of the rain along the channel. To The types of analyzed channels they present different flow capacities for the rain. This associated flow the different inclinations can form a roof configuration (channel + inclination) more or less efficient, regarding a good banning for the rain. It is observed, for the results, that the capacity of flow of a channel is proportional to the inclination of the same. This result is shown through the profile of the variation of the height of the liquid in function of the geometry, Fig. 8 and 9.

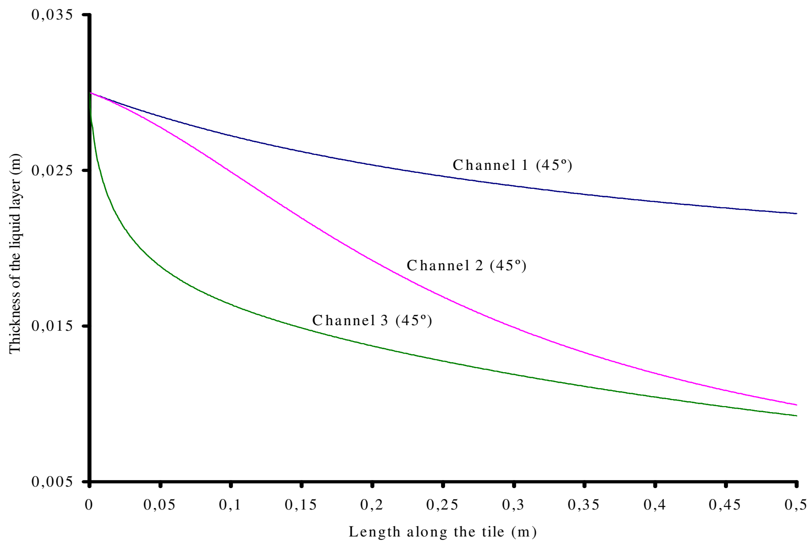

Figure 9. Variation of the height of the liquid layer along the channel in function of the geometry, for the channel with inclination of 45º.

It is observed that for Channel 1, with a small inclination, 10º for exemple, it happens the overflow of the rain. That is observed by the positive inclination of the height of the liquid layer shown in the Fig. 8, for Channel 1. This fact is justifiable also for the hypotheses imposed simplificatives, as permanent flow, unidimensional and constant outflow. In a real situation that overflow is minimized by the real characteristics of the flow (tri-dimensional and transient) and outflow variable.

The numerical analysis of pluvial flow in metallic tiles was accomplished being considered a two-dimensional model in finite elements, varying two inclinations, one in the horizontal and other with 45^0 of inclination, because these are the maxims and low inclinations of a roof. In the Figures 10 and 11 the results are presented being considered the different inclinations of the channel. For this analysis a same outflow was considered for all of the simulations.

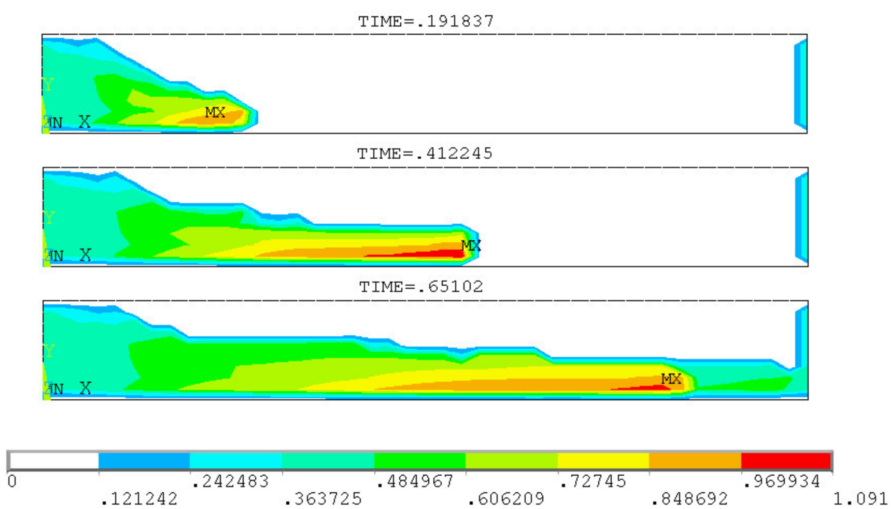

Figure 10. Evolution of the profile of the height of the liquid layer and of the speed of the flow in three instants for a tile in the horizontal.

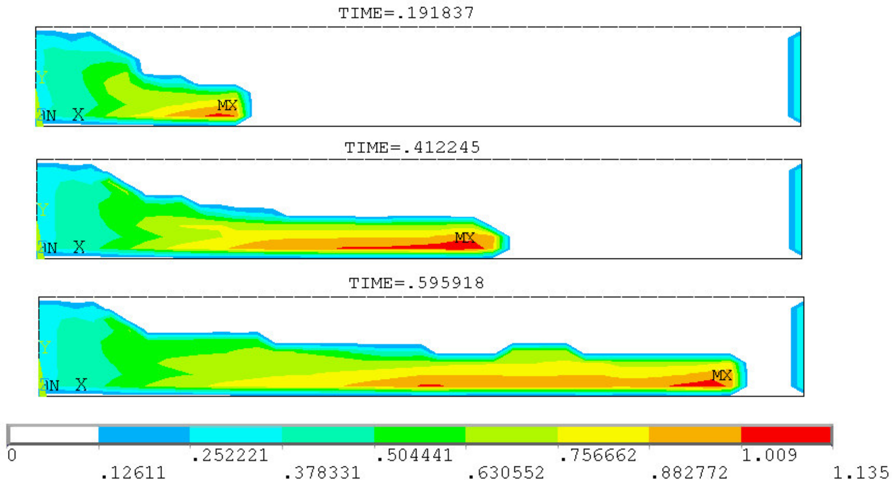

Figure 11. Evolution of the profile of the height of the liquid layer and of the speed of the flow in three instants for a tile with inclination of 45º.

In the Table 1 the values of the height of the liquid layer are shown in function of the time and distance along the channel, for the analyzed inclinations.

Table 1. Values of the height of the liquid layer (y) in function of the time and distance along the channel (x).

Inclination					
0º			45º		
Time (s)	x (m)	y (m)	Time (s)	x (m)	y (m)
0,13	0,11	0,04	0,13	0,11	0,03
0,32	0,24	0,03	0,32	0,24	0,025
0,68	0,48	0,02	0,59	0,48	0,019

4. Final considerations

It is observed by the evolution of the profile of the height of the liquid layer, shown in the Fig. 10 and 11, and also in the table of values of the height of the liquid layer in function of the time and distance along the channel, Tab. 1, that the height of the liquid layer decreases in the end of the channel in function of the inclination of the same. That result confirms the profile obtained for permanent analysis, figure 8. In way similar to the speed of the fluid it also increases with the inclination of the channel for the condition of considered constant flow, Fig. 10 and 11.

5. References

ANSYS 6.0, 2001, " User's Manual, version 6.0", SAS IP Inc., Canonburg, PA.

Castro, E. M. C. de, 1999, "Patologia dos edifícios estruturas metálicas", Dissertação de mestrado, Universidade Federal de Ouro Preto UFOP, 184 p., Ouro Preto.

Gerard Roofing Technologies. Disponível em: Site:<www.gerard roofing technologies>. Acesso em 20 de nov. 2002. Atas International Inc.

Jones, R. W., 2002, "A method for comparing the performance of open channel velocity-area flow meters and critical depth flow meters", Flow Measuremment and Instrumention, Vol. 13, dec. 2002, pp. 285-289.

Munson, B.R., Young, D. F and Okiishi,T.H., 1997, "Fundamentos da Mecânica dos Fluidos", Trad. da 2ª edição Americana, Vol.1and Vol2, Editora, Edgard Blücher, Ltda.,1997.

N. Didini Revestalic. Disponível em: Site:<www. n. didini revestalic >. Acesso em 20 de ago. 2004.

Sales, U.C., Souza, H.A. and Neves, F. A., 2001a, "Interfaces entre Sistemas de Vedação e Estruturas Metálicas, Problemas Reais", Téchne, São Paulo, Vol. Ago, No. 53, pp. 98-102, 2001.

______, 2001b, "Mapeamento de problemas na construção industrializada em aço", Revista da Escola de Minas de Ouro Preto, Ouro Preto, Vol. 54, No. 4, pp. 303-309, 2001.

______, 2001c, “Avaliação Comparativa do Desempenho Vibratório de Pisos Pré-fabricados para Construção Metálica”, In: Iv Seminário Internacional – O Uso de Estruturas Metálicas na Construção Civil e I Congresso Internacional da Construção Metálica, São Paulo. Anais eletrônicos. SME/MG.

Thomas, F., 2002, “Open channel flow measurement using international standards: introducing a standards programme and selecting a standard”, Flow Measuremment and Instrumention, Vol. 13, Dec. 2002, pp. 303-307.

White, F. M., 2002, “Mecânica dos fluidos”, 4a edição, Mc Graw-Hill, Rio de Janeiro, 2002. ISBN 85-86804

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