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Fire Spread across a Fuel Break in a Ridge

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Abstract
The size of a fuel break in a top of the ridge with several different configurations of slope is studied on this work.
Laboratorial tests were performed to simulate the same geometric conditions of a fire occurred in centre of Portugal and that was extinguished by itself due to the special configurations of slope and geometric barrier to fire spread that correspond to a fire break. Based on this fire other configurations were tested to measured their impact on the probability of the fire crossing the geometric barrier of a gap.

1. Introduction

It is observed that in some instances a fire spreading upslope, without wind and in the absence of spotting, stops when it reaches the ridge even with a relatively narrow fire break at the ridge top. Referring to fire fighter safety in Green (1977) it is assumed that a fire spreading along a slope of 35º, in heavy brush fuel, with low humidity, and heavy winds, flames with 15 m long flames a fuel break with 60 m is efficient. But if a sharp ridge marked the centre of a fuel break, protection from radiation would be afforded by crouching in the lee of the ridge top, and somewhat less than 60 m would be needed. Indeed a forest road or a maintained right-of-way such as a power or telephone line often serves as a firebreak (Brown and Davis 1973). In Butler & Cohen (1998) a general rule in wich a safety zone radius must be equal or greater than four times the maximum flame height is proposed. This situation was observed for example at fires in Segade (Coimbra) in 2001 and in Sardinia in 2010. In order to analyse this phenomenon and to assess the effectiveness of fire breaks placed at the ridge tops in general the present research was performed.

2. Experimental Study

2.1. Physical problem

We consider a ridge formed by two planar slopes making an angle α_A in face ***A*** and α_B in face ***B*** and assume that there is a fuel break with a width equal to *c* at the ridge top (Figure 1). A fire spreading upslope on face ***A*** in the absence of wind will reach its top with a ROS R_1, a flame length L_1 and will either spread across the fuel break or not.

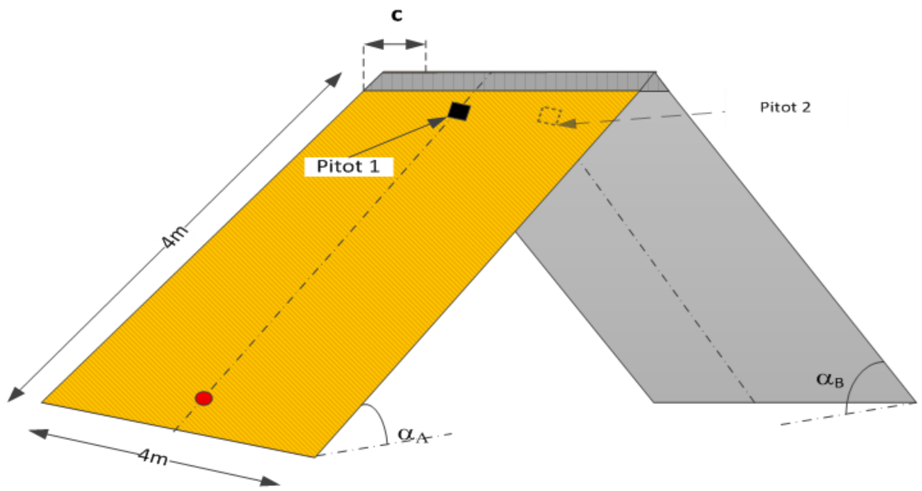

Figure 1. Schematic view of the ridge and the fuel break.

3. Laboratory Experiments

In the present study an experimental research was carried out at the Forest Fire Research Laboratory of the University of Coimbra on the Dihedral Table that has two faces of 4x4m^2 each that can be inclined independently between -45º and +45º in relation to the horizontal reference (figure 2a).

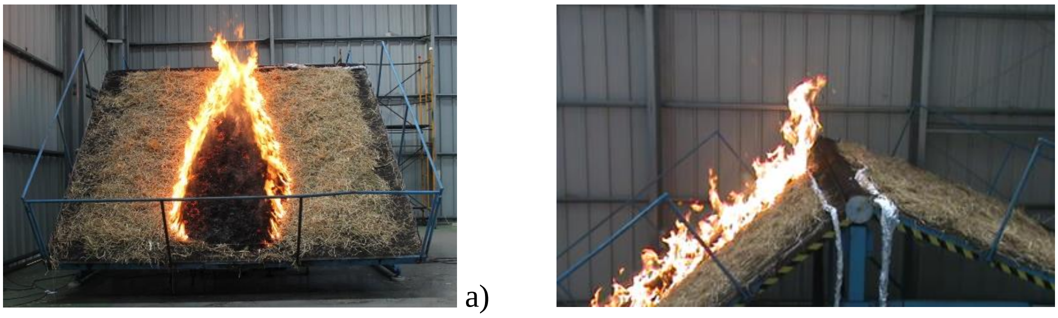
a) b)

Figure 2. Picture of the test SE11 with parameters: α_A=40º, α_B= -20º, c=0.30m. a) Front view, b) Side view with detail of the ridge and fuel break.

The fuel bed was made with straw with a fuel load of 0.6 kg/m^2 (dry basis) and the fire was ignited at a point in the centre line of face A 0.25m above its lower edge. The fuel covered the entire face A and only 1.6x4 m^2 on face B. The ROS of the head fire was measured using strings of cotton placed across the fuel bed with a gap of 20cm between them. A pair of S Type pitot tubes equipped with thermocouples was placed near the ridge top to measure flow velocity even inside the flames at the positions indicated in figure 2a). A video camera was used to record and analyse the flame front near the ridge top to capture a side vew of the fire front when it approached the ridge line (figure 2b)). Several tests were performed with various combinations of slope angles αA and αB with fuel break widths in the range of 0 to 0.3m. The main parameters of the tests are given in Table 1.

Table 1. Set of experiments and main parameters.

Ref.	α_1	α_2	C (m)	M_c (kg/m^2)	m_f (%)
SE 1	30	30	0,00	0,6	8,46
SE 2	30	-20	0,00	0,6	8,10
SE 3	30	-30	0,00	0,6	8,10
SE 4	30	-40	0,00	0,6	7,29
SE 5	30	-40	0,00	1	7,64
SE 6	30	-30	0,30	0,6	8,70
SE 7	30	-20	0,30	0,6	8,30
SE 8	30	-10	0,30	0,6	13,89
SE 9	30	0	0,30	0,6	9,89
SE 10	30	10	0,30	0,6	9,76
SE 11	40	-20	0,30	0,6	14,41
SE 12	40	-10	0,30	0,6	9,53
SE 13	40	0	0,30	0,6	9,53
SE 14	40	0	0,15	0,6	8,58
SE 15	40	10	0,15	0,6	9,80
SE 16	30	10	0,15	0,6	9,80
SE 17	30	20	0,15	0,6	13,10
SE 18	30	30	0,15	0,6	13,10
SE 19	30	40	0,15	0,6	11,96
SE 20	30	0	0,15	0,6	11.10
SE 21	30	-10	0,30	0,6	13,00
SE 22	30	20	0,30	0,6	13,00
SE 23	40	10	0,30	0,6	9,00

4. Results and Discussion

4.1. Probability of fire crossing

In figure 3 a plot of the cases in which the fire went or did not go across the fuel break as a function of c/L_1 is presented. The value one in this graph indicates that the fire passed the fuel break while the value zero indicates the contrary. Only for cases in which the slope angle α_B was positive we had passage of the fire. The terrain configuration in such cases is not really a ridge. As can be seen in this figure a relatively small value of c/L_1 of the order of 0.2 seems to be sufficient to stop the fire which is much smaller than the value of c/L_1 =4 presented in Green, (1977) for the case described above.

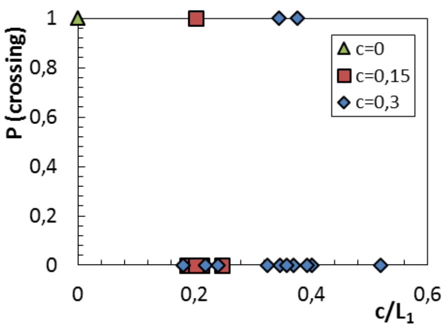

Figure 3. Probability of fire crossing as a function of c/L_1 for all tests.

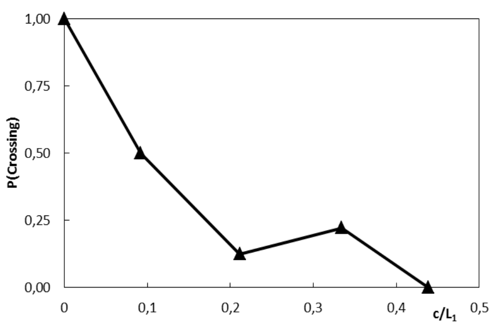

Figure 4. Average probability of fire crossing as a function of c/L_1 for classes with a step of 0.13 between them.

In figure 4 the average probability of crossing for different classes of values of c/L_1 is presented. The range of values were split in groups of values of c/L_1 with a length of 0.13 between them and the correspondent value of the probability for each class of c/L_1 was plotted. In agreement with the previous data a sharp decrease of the probability of the fire crossing with the increase of relation c/L_1 is clear. For $c/L_1 > 0.2$ the probability of crossing becomes constant with a small increase for c/L_1 close to 0.36. Comparing figure 3 with the data of the figure 4 it is possible to relate this small increase with the occurrence of two crossings of the fire to the face B. After this occurrence no more crossings were registered with the increase of c/L_1 making the value of the probability of crossing to decrease to zero for $c/L_1=0.4$.

Radiation

Using a simple model based on principles of radiation presented in Wong (2003) was estimate the radiation flux from a vertical flame with constant height to an infinitesimal element of area, with an area of $0{,}05 \times 0{,}05 m^2$, placed on face B at the centreline at a distance c from the base of the fire (figure 5) the results were plotted in figure 5 were obtained.

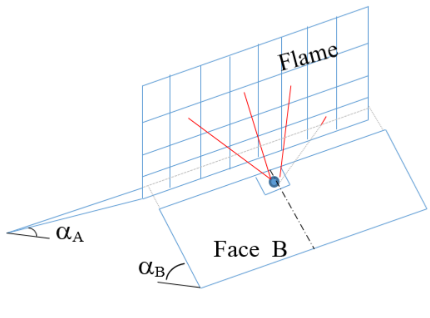

Figure 5. Skecth of the radiation flux from the vertical flame in the side A for the target in face B.

The properties of the flame and the slope of face B were established according to the average values obtained in the tests for the points plotted in figure 4, a table with the values is presented below.

Table 2. Set of data for the computation of the radiant flux.

α_{Bavg}	g/L_1	$q(kW/m^2)$
-40	0,00	94,47
-15	0,09	83,30
-20	0,21	65,12
-15	0,33	52,00
-10	0,44	40,17

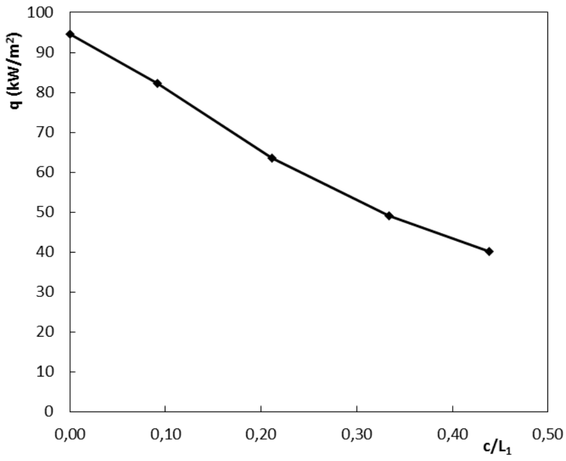

Figure 6. Computation of the net rate at which an infinitesimal element face B gains radiation due to the interaction of the flame in the side a for several values of c/L₁.

By the analysis of the data is possible understand as was expected that the rate of radiation that arrives to the face B is greatly affected by the distance between the two surfaces. It is possible to see that the trend shown in figure 4 for the variation of the average probability of fire crossing as a function of c/L_1 is very similar to the decrease of the radiation flux on the surface element that is shown in figure 5 putting in evidence the role of flame radiation in this process.

4.2. NDROS (R') and Induced Flows

In figures 6 to 8 results from NDROS (R') on face ***A*** and of flow velocity are shown as a function of time. In these tests the fire did not cross the fuel break. The coloured lines indicate the times of the end of spreading of fire for each test. The flow velocity U_1 measured at P1 is shown in figure 7 and the flow velocity U_2 measured at P2 is shown in figure 8.

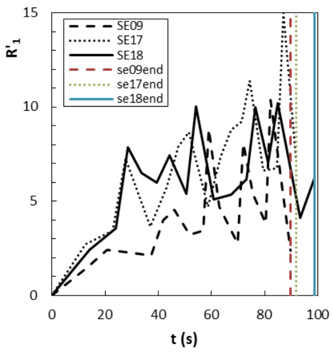

Figure 6 –ROS values as a function of time for tests: SE 09, SE 17and SE 18

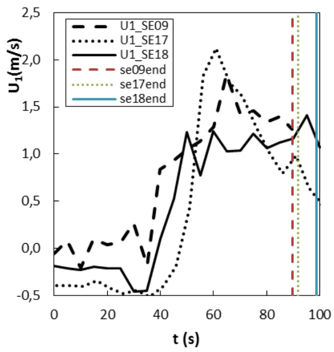

Figure 7. Flow velocity at positions P_1 as a function of time for tests: SE 09, SE 17 and SE 18

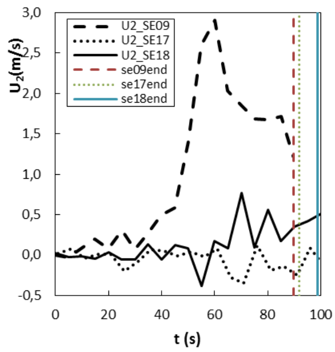

Figure 8. Flow velocity at positions P_2 function of time for tests: SE 09, SE 17 and SE 18

In the case of SE 09, dashed line, with configuration α_B=0º, the increment of the NDROS with a maximum of 10 is visible in figure 5 plotted with dashed line, coincident with this increment is the increment of the flow in both pitot tubes. The presence of a positive flow meaning that the flow is in same direction of the rate of spread was observed. The maximum flow was registered at P_2 (face B), figure 7, with the value of 3m/s. It was noticed at least in U_1 flow (figure 6) some negative periods that could correspond to the indraft of air towards the fire front as the slope of side B is not a barrier to the income of air this type of flow is allowed.

In the case of SE 17 α_B=20º, dotted line, an increment of the NDROS with the course of time until the end of side A, with a peak of 11m/s and then appears the maximum of 15m/s, was also observed.
In figure 6 it is detected that the flow measured at P_1 starts with a decreasing to negative values of -0.5m/s and then have a sharp increase until a maximum of 2.1 m/s. The value of the flow registered at P_2 was mainly negative or close of zero the reason of this behaviour could lie on the fact of the second slope works as a barrier to the feeding air for the fire front and only when the fire front is very close of P_2 it was observed some positive flow.
In the last experiment, plotted with a bold black line, that is the test SE18 with α_B=30º, was registered an increasing of NDROS very sharp and with several fluctuations the maximum value recorded was of 10 the difference in relation with the others is that in all the experiment several times was recorded high values of the NDROS.
The flow velocity U_1 also was high and constant, only at the beginning a negative flow of -0,5 m/s was recorded and then the flow shifted to positive and more or less stable at the values of 8-9 m/s. As in previous case the presence of the second slope of the face B could cause some interference on the free progress of the flow and for that the P_2 in the major part of the test present a negative flow that is against the fire spread direction and only in the very end an increase of the flow velocity to values of less than one 0.5 m/s but favourable to fire spread was registered.

5. Conclusion

Our results show that with a ridge shape like the one tested by us in the absence of wind the flow induced by the fire does not cause an inclination of the flame front towards the unburned fuel (figure 2b)) and consequently the fire does not spread across the fire break.
The probability of the fire crossing the fuel break decreases with the increase of the parameter c/L_1 and therefore it indicates that radiation is the dominant heat transfer mechanism in this process. The explanation of this lies on the fact that even for small values of the gap between the fire front and the unburned fuel bed on face B the radiation flux is relatively small and consequently the fire does not spread across the fire break.

6. Acknowledgements

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7. Symbols

Symbol	Units	Description
α_A	-	Inclination angle of face *A*
α_B	-	Inclination angle of face *B*
O	-	Origin of reference Cartesian system
c	*m*	Fuel break dimension
R’	-	Non-dimensional rate of spread (NDROS)
U_1	$m.s^{-1}$	Flow velocity measured by Pitot 1

U_2	$m.s^{-1}$	Flow velocity measured by Pitot 2
P1	-	Pitot station 1
P2	-	Pitot station 2
q	*(kW/m²)*	Net rate of radiation

8. References

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