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Construction measurements of fire protection

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ABSTRACT
Fire presents very often occurrence in today`s life. Fire is almost always characterized with uncontrolled burning and unpredictable consequences. Special examples present residential and other buildings as high objects with lot of humans inside. In these objects, potentials for fire extinguishing are limited and these objects must satisfy certain construction demands and standards, in the purpose of fire safety. It means that these objects must be built from special materials with special characteristics, in construction and fire proof sense. This paper was written to show construction measurements, materials with their fire proof and fire proof appropriacy and construction solutions for increasing of fire resistance of the objects, related to Serbian standard and simulation examples.

Key words: fire, protection, materials, standard, simulation.

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I. INTRODUCTION

Fire presents occurrence that makes many problems in every day’s life. As fire presents uncontrolled burning, the behaviour of fire and its spreading could be very unpredictable in the sense of fire strength, direction and consequences.This is especially important end open problem for fires in objects with lot of humans inside, such as residential buildings, commercial buildings and other objects with lots of humans and huge dimensions (big height of the object). Because of this problem, there were lot of measurements related to object`s purpose, position, material and others that must be realised. Of course, almost all of these objects were made by concrete so it is very important to know all characteristics of concrete in order to build object with optimal constructional and fire proof characteristics.

Related to the appropriate and valid standardisation, buildings could be classified into different groups: residential buildings, business buildings, public buildings (objects), industrial buildings, storages and high objects.

Residential building are objects that have more than 80 % of surfaces for living and accompanying subjects, such as hallways, stairs, parking garages, elevators etc. These noted objects could be classified into separated residential buildings and buildings in rows with height up to 10 meters; separated residential buildings and buildings in rows with height from 10 meters to 16 meters and separated residential buildings and buildings in rows with height from 16 meters to 22 meters. Of course, modern types of these objects should have modern systems for fire detection and fire extinguishing.

Business buildings present buildings with more than 80 % of useful space intended for business (sale, purchase and other services). The rest of rooms in these objects could be residential or with public purposes. These noted objects could be classified into separated business buildings and buildings in rows with height up to 9 meters; separated business buildings and buildings in rows with height from 9 meters to 15,5 meters and separated business buildings and buildings in rows with height from 15,5 meters to 22 meters.

Public buildings present buildings with more than 80 % of useful space intended for people gathering. The gathering reasons could be different (sports, cultural, educational, religious etc.). These objects could be classified into separated public buildings and buildings in rows with height up to 8 meters; separated public buildings and buildings in rows with height from 8 meters to 15 meters and separated public buildings and buildings in rows with height from 15,5 meters to 22 meters.

Industrial objects present objects with purpose for manufacturing and storage of industrial stuff. These objects could be classified, related to noted, into production plants and storages. These objects also have many differences, such as business object, types of materials, the way of products storage, structural characteristics (surface, the number of inside objects etc.), location and similar.

Storages present objects for different types of stuff storing. Related to the surface that they occupy, they can be classified into small storages, middle storages and big storages. Small storages have surface up to 1000 m^2; middle storages have surface from

1001 m^2 to 3000 m^2 and big storages have surface bigger than 3000 m^2.

High objects present objects with rooms for accommodation of people. These objects characterise their height-the highest floor must be located 30 m above the ground point where access of fire fighters and fire interventions are possible.

In the case that building that is more than 4 meters away from other buildings or objects presents separated building. In the case that this distance is less than 4 meters, this building presents building in array. It is also important to note that buildings could be classified related to dimension of fireproof sectors and number of people that stay there. Of course, all of noted presents general classification, where complete classification of the object related to purpose, structure, function and other characteristics could be realized by special rule books [1-3].

II. FIRE LOAD OF THE OBJECT

Fire load of the object very often presents the constructional measurement of fire hazard. Generally, this dimension presents the heat value of the complete combustion material per surface unit-heat value related in kilo Joules per one square meter (KJ/m^2). For calculation of the fire load for some specific surface, it is necessary to take into account complete combustible material that this surface was built so as complete mobile combustible material on that surface. As an example, combustible material that specific surface was built from could be concrete, wood, aluminium, windows, doors etc. Type of materials directly determinate the quantity of released heat. Related to SRPS standard UJ1.030, the complete fire load presents calculated dimension of the heat energy of one object that can be released in fire. It was noted with letter Z and it can be calculated as it is presented on equation 1:

$$Z = P_i S_i. \quad [1]$$

In this equation, letter Z presents the complete fire load in [KJ]; letter P_i presents specific fire load in [KJ/m^2]; letter S_i presents the surface of the base that the value P_i relate on in [m^2]. The type of the object`s fire protection and its degree are determined by complete calculated fire load. Specific fire load presents the heat that can be developed in some base unit (such as workshop, room, storeroom etc.), related on 1 m^2 of the surface of that room. This value can be calculated as it is presented on equation 2:

$$P_i = \Sigma q_i V_i H_i / S. \quad [2]$$

In this equation, letter P_i presents specific fire load in [KJ/m^2]; letter q_i presents specious density of the material in [kg/m^3]; letter V_i presents the volume of the material in [m^3]; letter H_i presents caloric power in [KJ/kg] and letter S presents the surface of the base in [m^2]. Index i presents index of the elementary unit. Of course, all materials that object was built from, all materials that object was built for and all of installation and equipment must be taken into account. Related to the SRPS U. J1. 030 standard, there were three different groups of specific fire load defined: low fire load (up to 1 GJ/m^2), middle fire load (from 1 GJ/m^2 to 2 GJ/m^2) and high fire load (over 2 GJ/m^2). So, it is very important for object`s design to calculate fire load, determine minimal fire resistance of the construction of the object and, after that, realize the selection of the materials and construction. Of course, it is important to note that fire load can be huge for some objects (different types of industries, for example). Also, it is almost impossible that all combustible materials should be equally distributed on the surface of the object. In the case that huge difference of fire load between some parts of the objectsexists, some of these parts are separated into specific parts by fire barriers (walls, between floors constructions etc.) and similar. Fire load of some types of the buildings are presented in table 1[1], [4].

Table 1. *Fire load of some types of the buildings (table source:Blagojević, Đ. M.,Projektovanje sistema za dojavu požara*, pp. 19*)*

Fire load of some types of the buildings						
Type	**[MJ/m^2] the floor surface**					
	Loft		**Walls**	**Supporting construction**	**Roof construction**	**Ceiling**
	built	not built				
01	1600					
02	1000	500				
03	200	100				
04	100					
05		0	*	***	C	
06		300	*	S	W	
07		1100	*	**	**	
08		1400	&	**	**	
09		800	WO	**	**	
10		1100	WP	**	**	
11		100	***	***	**	C/C
12		1100	*	S, W	**	**
13		1100		**	**	**
14		1200		**	**	**

*- concrete/stone masonry with or without mortar
**- wood with or without protection
***- concrete/stone masonry
&- wave metal plate, asbestos, mortar and similar
WO-wood (open workshop and similar)
WP-wood or plastic
C-concrete
W-wood
S-steel with F30 fire resistance
C/C-concrete/ceiling with poriferous elements

III.CLASIFICATION OF CONSTRUCTONAL ELEMENTS RELATED TO FIRE RESISTANCE

„Object`s behaviour "in the state of fire depends from fire resistance of every material that was embed in object`s construction. Different objects have different purposes and, related to that, different elements embed in their own construction. Every of these elements have their own fire resistance. It is important to note that material characteristics related to their combustibility presents reaction on fire while characteristics of construction elements presents their fire resistance. The classification related to examination of fire resistance was realised in order to SRPS EN-13501-1 standard. Material can be classified, based to this standard, related to flammability, smoke products and burning particles. Classification of materials related to their flammability is presented in table 2.

***Table 2**. Classification of materials related to their flammability*

The class of the material	Description
A1	Non-combustible materials
A2	Non-combustible materials
B	Hard combustible materials
C	Hard combustible materials (flammability from 10 to 20 minutes)
D	normal combustible materials (flammability from 2 to 10 minutes)
E	normal combustible materials (flammability up to 2 minutes)
F	Easy combustible materials or non-classified materials

Related to the smoke release, materials can be classified into three different groups: the first group presents materials with little smoke release or without smoke under fire, marked as s1; the second group presents materials that make middle quantity of smoke under fire, marked as s2 and the third group that presents materials with huge quantity of smoke under fire, marked as s3.

The smoke production during material`s burning can be examined related to the standard SRPS EN 13823, when criteria SMOGRA and TSP_{600} are used. Account can be realized relate to standard SRPS EN 13501-1, and can be classified into three noted classes above. The SMOGRA criteria (Smoke Growth Rate) presents the highest value of the coefficient of increase in smoke generation from the sample and the time of its appearance and is expressed in [m^2/s^2]. The C (Total smoke production) presents the complete quantity of smoke from sample during the time of 600 seconds and is expressed in[m^2].
Th classification of the materials are presented in table 3, related to noted values.

***Table 3.**The classification of the materials related to the criteria SMOGRA and TSP_{600}*

The material classification	SMOGRA criteria [m^2/s^2].	TSP_{600} criteria [m^2]
s1	≤ 30	≤ 50
s2	≤ 180	≤ 200
s3	-	-

The classes of reaction on fire of constructional materials related to SRPS EN 13501-1 are presented in table 4.

***Table 4**. Classes of reaction on fire of constructional materials related to SRPS EN 13501-1 (table source: Jevtić, B. R., Material for the preparation of the professional exam in the field of fire protection, pp.146)*

Non-combustible products / materials		
A1		
A2 - s1d0	A2 - s1d1	A2 - s1d2
A2 - s2d0	A2 - s2d1	A2 - s2 d2
A2 - s3d0	A2 - s3d1	A2 - s3d2
Combustible products / materials		
B - s1d0	B - s1d1	B - s1d2
B - s2d0	B - s2d1	B - s2 d2
B - s3d0	B - s3d1	B - s3d2
C - s1d	C - s1d1	C - s1d2
C - s2d0	C - s2d1	C - s2 d2
C - s3d0	C - s3d1	C - s3d2
D - s1d0	D - s1d1	D - s1d2
D - s2d0	D – s2d1	D – s2 d2
D - s3d0	D – s3d1	D – s3d2
E		
E-d2		
F		

Burning droplets represent parts of the material that are separated from the sample during the fire test according to the SRPS EN 13823 standard (SBI test), and are evaluated according to the SRPS EN 13501-1 standard, in classes d0, d1 and d2, as it is presented in table 5.

***Table 5.** The releasing of the burning droplets or particles that are separated from the sample*

The marks of the droplets	Description
d0	No droplets in period of 10 minutes.
d1	Droplets are formatting in period of 10 minutes, don't burning and separating more than 10 seconds.
d2	Materials that can't be classified into classes d0 and d1.

Related to the SRPS EN 13501-2 standard, the resistance in fire of the different elements used in construction (doors, walls, etc.) can be defined with REI 90, EI 60 and similar marks. The number in these

marks presents minimal timewhere the material retains the characteristics indicated by the next letters. The letter R purports that material mustn't lose mechanical characteristics. The letter E purports that material doesn't allow the flame penetration. The letter I purports that material`s temperature on the side that was not exposed to the fire mustn't increase for more than 140 °C (the average value) and mustn't be higher than 180 °C at any part of the material. The fire resistances of some specific materials are presented in figure 6.

Table 6. *Fire resistance of some specific materials1 (table source: Jevtić, B. R., Material for the preparation of the professional exam in the field of fire protection, pp.147)*

Construction elements	Fire resistance (in hours)
Brick wall non-plastered, 25 cm thick	6
Brick wall non-plastered, 12 cm thick	1
Brick wall, plastered, (2 x 1.5) 12 cm	2
Hollow brick wall, 22 cm thick	2
Hollow brick wall, 10 cm thick	1
A wall of hollow concrete blocks, 22 cm thick	4
A wall of hollow concrete blocks, 12 cm thick	2
A wall of hollow concrete blocks, 6 cm thick	0,5
Reinforced concrete wall, 22.5 cm thick	6
Reinforced concrete wall, 18 cm thick	4
Wall made of rammed concrete, non-plastered, 15 cm thick	6
Wall made of rammed concrete; non-plastered 12 cm thick	4
Wall made of rammed concrete; non-plastered 10 cm thick	2
Brick pillar 25 x 25 cm	2,5
Brick pillar 25 x 38 cm	3
Brick pillar 38 x 38 cm	4,5
Brick pillar 38 x 51 cm	5,25
Brick pillar 51 x 51 cm	6,5
Reinforced concrete column 20 x 20 cm	2
Reinforced concrete column 20 x 40 cm	2,75
Reinforced concrete column 30 x 30 cm	3
Reinforced concrete column 30 x 50 cm	3,5
Reinforced concrete column 40 x 40 cm	4
A pillar of iron, unprotected	0,25
A post made of iron, protected by plaster on the grid or a concrete lining	2,5 - 5,0
Iron pillar, protected by brick	6,5 - 12,0

The designed fire resistance degree is defined related to the base fire resistance degree, but it is increased for one class in case that building has great importance (museum, bank, court etc.). The designed fire resistance degree can be decreased for one in case that building would be equipped with installation for automatic fire extinguishing, such as sprinklers.

The building or the part of the building can have degrees of the fire resistance as it is presented in table 7.

Table 7. *Fire resistance degrees for building or part of the building*

Fire resistance degree	Description
I	Without resistance
II	Small resistance
III	Middle resistance
IV	Bigger resistance
V	Big resistance

Fire resistance of the material is usually marked with letter and number (F 15, F 30, F 60, F 90 or F 120). The number besides letter purports the time in minutes for which the material will not lose its properties. Related to that, as construction material, stone, brick, wood could have mark F 15. Mark F 30 belongs to huge mass steel and steel protected with fire proof paint; monolithic wood without fire protected paint etc.Mark F 60 belongs to walls with full and perforated brick with at least 12 cm thickness; gypsum plates with 8 cm thickness, different concrete walls with thickness from 8 to 20 cm etc. Mark F 90 marks belongs to walls with full and perforated brick, single side mortared with at least 12 cm thickness, gypsum wall plateswith at least 8 cm thickness, concrete bearing pillars (10 cm thickness) and non-bearing pillars (14 cm thickness), reinforced beams with 15 cm thickness, reinforced pillars with 25 cm thickness etc. Mark F 120 belongs to walls with full and perforated brick, both side mortared, with at least 12 cm thickness, special walls with at least 20 cm thickness, gypsum wall plates with at least 8 cm thickness, concrete bearing pillars (12 cm thickness) and non-bearing pillars (16 cm thickness), reinforced beams with 20 cm thickness, reinforced pillars with 30 cm thickness etc. [1-3], [5], [8], [9], [10].

IV. DIFFERENT CONSTRUCTION SOLUTIONS FOR FIRE PREVENTION

One of the most important tasks of fire prevention is the elimination of fire spreading and its limitation inside some determined area. These limitations can be realized in all directions, horizontal

and vertical, with use of fire obstacles. For realization of fire obstacles, the potential conditions of fire spreading in rooms that would be separated must be known.

Related to the potential fire spreading, fire spreading can be linear and spatial. Linear fire spreading purports moving of flame limitation at the surface of burning material, in one direction and one plane. Spatial fire spreading purports the mechanism of production of new fires at determined distances related to the main fire.

Horizontal obstacles present constructions between floors with bigger fire resistance. Vertical obstacles present walls with bigger fire resistance. Fire resistance walls purport walls with purpose to stop the fire from one room to other. Every of fire proof walls must be constructed from non-combustible material with determined degree of resistance. These walls are built from ground and their end is about 0.4 meters above the roof surface. In the case of buildings with big fire load, the height above the roof can be increased on 0.7 meters. These walls must completely cut all combustible parts of the building or some other object in order to eliminate the spreading of fire at any other place. The examples of these walls are presented on figures 1, 2 and 3, realized by simulation of fire in different objects (school and residential house).

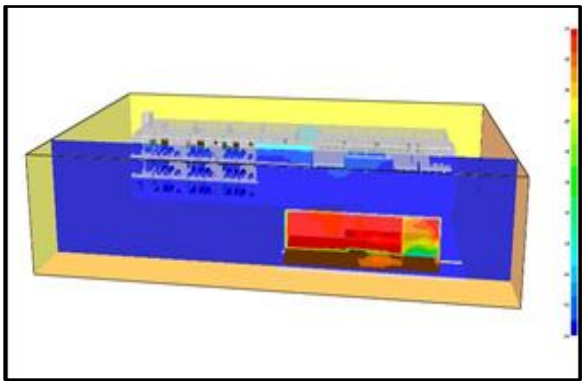

Fig. 1. *Presentation of thermal distribution on the walls of the classroom, realised by simulation of fire in Electrotechnical school Nikola Tesla in Niš (figure source: Jevtić, B. R., The fire simulation as a safety advantage in fire prediction and fire protection).*

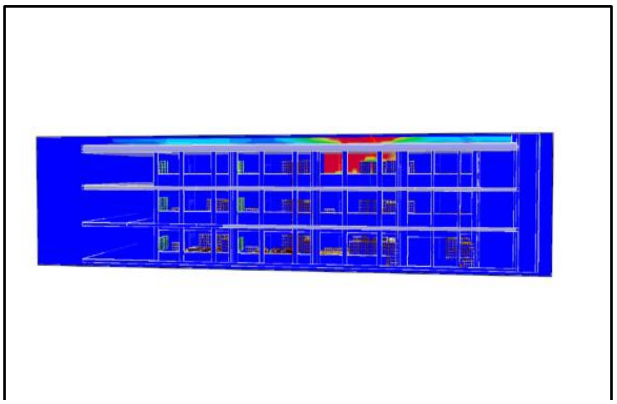

Fig 2.*Presentation of thermal distribution on the walls of the laboratory, realised by simulation of fire in the laboratory part of the Electrotechnical school Nikola Tesla in Niš*

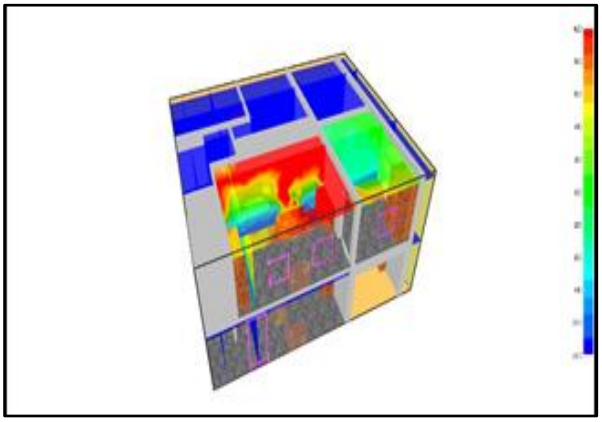

Fig. 3. Presentation of thermal distribution on the walls of the house, realised by simulation of fire in residential house (figure source: Jevtić, B. R., *Fire simulation in house conditions*).

In the case that building or object possess wood elements, such as canopies, they should be cut with vertical walls, too. In the case that vertical wall can`t be built (construction demands, technical process of manufactory etc.), so called „hanging" walls in the combination with water screen. It is important to note that these systems can be applied in large industrial workshops, but only at upper parts of these objects, at constructions that have enough fire resistance. It is very important that these walls don't have doors or any kind of other openings, what is very hard for realization, because and these kinds of walls sometimes need doors or some other openings. These doors must possess enough fire resistance and their size must be reduced to the smallest possible size. Also, the door`s material must be non-combustible. These doors are the most often made by metal in combination with some thermalization material. These materials are located between outer and inner part of

the door. The biggest space of openings in these doors mustn't be bigger than 25 % from their surface.
Fire proof walls present the most suitable obstacles for fire spreading elimination in the vertical directions. Related to vertical obstacles, horizontal obstacles present between floors constructions with bigger resistance related to fire, made by non-combustible material. It is important to note that fire resistance of horizontal obstacles is lower related to fire and their values are from 1 to 4 hours. In the cases of bigger fire threats, all materials should have the same fire resistance (fire proof obstacles and fire proof walls). It would be ideal that fire proof obstacles don't have any kind of openings, pores, compartments or similar, but it is not possible. Because of purpose and way of functioning of object or building, these fire proof obstacles have many holes, pores, canals, compartment and similar parts where electrical cables, pipes, mechanical parts are located. These locations could be very danger in the case of fire and they must be specially protected. This purports not only flame penetration protection but also gasses penetration protection whit hermetical protection. Also, all connections of fire proof walls and ceilings with other walls and ceilings must be hermetically protected.
Fire sector presents part of the object that makes one unit, in the constructional and functional sense, separated from the rest parts of objects, in fire sense. This part of the object presents the part that would be potentially destroyed in the case of fire. The intention is that fire sectors should be as small as possible, because the potential fire damage shouldn't be huge. The materials that these sectors are made from should be with big fire resistance and must be without cracks. One fire sector could present one or more rooms at the same floor. As an example, stairs and elevators shafts should be separated fire sectors. The surfaces for some fire sectors are limited, related to some standards. For example, for residential, business and public objects fire sectors surfaces are limited on 500 to 1500 m^2. For other kind of objects, such as warehouses, fire sectors could be limited to 800, 200, 300 even and 4500 m^2, in dependence of stored material and used protection systems.
Fire segment presents fire separated part of the object which makes one unit, in constructional and functional sense. Fire segment must contain at least two fire sectors. The borders of fire sectors present walls with bigger fire resistance, at least from 2 to 3 hours.

Generally, fire obstacles have a great importance in fire elimination and reducing of damage that may occur by fire. For success realisation and installation of fire obstacles, several factors need to be known: the conditions of fire spreading in areas separated by fire obstacles,fire load in these areas, maximal expecting temperatures etc[1], [6], [7].

V. CONSTRUCTION MEASUREMENTS OF FIRE PROTECTION OF CONSTRUCTIONAL ELEMENTS

There are different construction elements used for objects and buildings construction. These elements must have special characteristics, especially in construction, mechanic and fire resistance sense.
One of the most important construction materials used in construction is wood. Wood is very appropriate material because it conducts heat very week; it also heats up only at the surface where it burns, while the inside of the wood is not heated. There were many known cases where iron elements lost their bearing power much sooner than wood elements.The main reason is in the fact that iron is heating over the entire volume. Related to flammability, conifers have better flammability than deciduous trees. The fire protection of wood construction can be realised on several ways: by using of appropriate covering, such as mortar, isolation plates and other non-combustion material; by coating with different protection materials and with wood impregnation.

One of the most used material in construction is steel. Steel presents non-combustible material with great heat conductivity and low fire resistance. Usually, deformation occur on temperatures higher than 400 °C. The development of technology enables the appliance of new types of steel with much better characteristics (fire resistance, heat conductivity, fragility, resilience, impact resistance etc.). One of the most famous types of steel is so called MMFX steel. The fire protection of steel construction can be realised on several ways: by using of asbestos isolation, brick layers, by using of mortar, by using of gypsum layers, by using of concrete layers etc. An examples of fire protection of steel by asbestos isolation and perlite concrete are presented on figures 4 and 5.

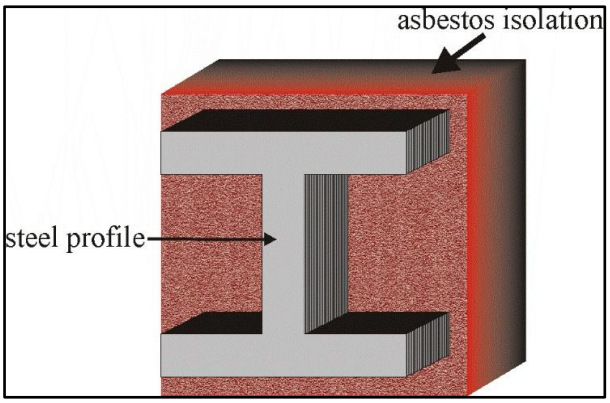

Fig. 4. Steel protection of fire with asbestos isolation

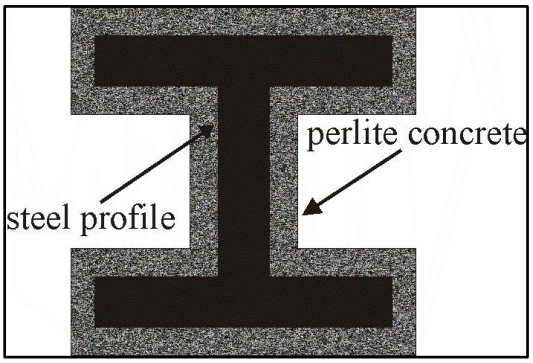

Fig. 5. Steel protection of fire with perlite concrete

Concrete also presents one of the most used materials in construction. In the dependence of what kind of concrete is used and in what purpose, the characteristics could be different (light concrete, unreinforced concrete or reinforced concrete). Today, there are many new types of concrete, realised with different technological procedures whit much better characteristics and resistance. As an example, the concrete can be treated with steel fibres what significantly improve their characteristic [1-3], [5], [8], [9], [10].
The fire characteristics of the most used materials in construction are presented in table 8.

Table 8.*The fire characteristics of the most used materials in construction(table source: Jevtić, B. R., Material for the preparation of the professional exam in the field of fire protection, pp.153)*

Material	Characteristics
brick	low heat conductivity; non-combustible material; getting soft at temperatures higher than 1100 °C.
stone	non-combustible material; more resistant as limestone than quartz
light concrete	volume weight smaller than 1800 kg/m^3 ; very appropriate for isolation purposes
unreinforced concrete	non-combustible; material, much better characteristics with addition of crushed brick
reinforced concrete	high fire resistance; shrinking and stretching at temperatures higher than 100 °C; the resistance of steel armature quickly decreases on temperatures from 200 to 300 °C; increases resistance with years of use
mortars	present connect materials; cement mortar has much better fire resistance than lime mortar; getting destroyed at temperatures higher than 530 °C
glass	getting soft at temperatures higher than 500 °C; transforming into liquid mass at temperatures from 900 to 1000 °C; with use of wire armature has much better fire resistance
gypsum	present connect materials; has high fire resistance; at high temperatures becomes brittle

VI. CONCLUSION

Every object must be built related to appropriate standards and must satisfied many different measurements. Very important measurements present construction measurements of fire protection. As fire presents phenomena that can always occur, successful fire protection presents always complex and open task. This is especially important for objects with lot of humans inside. Construction measurements of fire protection have changed and improved as technology has advanced.Appropriate standards related to this topic are constantly changing and improving in the sense of using of new materials with better characteristics, better protection of construction elements, new strategies etc. It is very important to note that construction measurements for fire protection purports not only noted measurement in this paper but also other measurements, such as urbanistic planning and strategy, installation of hydrant net, installation of appropriate traffic approaches and many others what were not possible to present because of technical limits of this paper, but what on the best way reflect how this problematic important and complex could be and how is important to be constantly improved. The contents of this paper could help in creation of new ideas where and how this improvements could be realised (for example, the use of appropriate simulation software).

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