Fire Stairs in Residential Towers: Architectural and Structural Concept Evaluation regarding Fire Safety

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Abstract

High-rise residential buildings represent a significant part of urban inheritance dating from the second half of 20 century. At the time they were built, fire safety legislations were less or more demanding, so the features are to be assessed regarding contemporary fire safety standards. Evacuation possibility is one of the basic conditions regarding tenants' safety in case of fire, which depends on accurate architectural and structural fire escape concept.

This paper represents the results of research work done on residential towers in Novi Sad city area, in past two years. Data base includes all high-rise residential towers in Novi Sad: 61 buildings, and only 14 consists emergency stairs. Evaluation criteria, both for buildings and for existing fire stairs, are formulated in accordance to current regulations. Based on applied concept evaluation and characteristic buildings' structures, the interventions are proposed for two different case – studies: in order to improve the existing fire stair and in order to find a proper way to extend one, if there is no other solutions for safe evacuation in case of fire.

The fire safety preventive action-list for high-rise residential buildings, based on research-study, valid legislations, contemporary European standards and previous experience is proposed in conclusion part of the study.

Keywords: high-rise residential building, fire safety, evacuation, fire stair

1. Introduction

High level population migration to towns in the second half of the XX century, and the influence of actual city zoning theory, lead to formation of "residential settlements" at suburbs and poorly settled city regions. The basic character of modern residence in urban areas originates from the separation of built residential forms into specific area and functional entities; *residential quarters, dwelling units, dwelling blocks...* They are formed on the basis of special, actual, principles of spatial planning and city designing (workplace – dwellings – traffic – recreation), hierarchic city structure (dwelling group – dwelling block – dwelling zone – group of dwelling zones – city), strictly and standardly defined size and place of city centers, opening of dwelling block, standing for high-rise freestanding residential forms. Those characteristic urban forms are to be found in every main city in Europe, our region (Hungary, Romania, and Serbia) and Novi Sad (Laban, 2005), as well.

Figure 1. Residential towers in Novi Sad: Bulevar oslobođenja, Beogradski kej, Liman I

The modernism in architecture promoted the high-rise residential tower as the optimal residential form for the modern city. "Skyscraper is, for sure, the most obvious symbol of modern movement. Without him, and without technological innovations which enabled it, most new approaches in urban designs developed in the first decades of the previous century would fail. " (Blake, 1998). However, although the tradition of building of residential low and medium floored forms was partially continued – freestanding high-rise buildings – towers and large dwelling blocks represent the residential symbol in the city of today. For that reason, residential towers are the significant part of the urban inheritance and dwelling fond, and are chosen to be the topic of this paper.

Modern engineering design (Fire Safety Engineering) is based on the application of scientific research and engineering principles, using calculations, measurements, empiricism and judgment. Formerly it was not so and a simplified and often uniform solution was proposed resulting in the univocal rules, focused on the simplest solutions that were then extrapolated to larger models. This is called *prescriptive* or *required rules*, which had double negative effect: we do not know whether these extrapolations are still acceptable for the newest technical evolutions of buildings, materials and users domains and a large part of the actual research is not applied to new concepts, where they could possible bring about savings without harming the required comfort and security level. Fire Safety Engineering (Milanko, 2006) intends the application of design principles, regulation and an expert evaluation, based on a scientific concept of the fire phenomenon thus resulting in : the saving of lives, the protection of goods and the protection of the environment and patrimony ; the determination of

risk and dangers of fire and the consequences; the analytic evaluation of the optimal protection and prevention measurements necessary to limit the consequences of a fire within certain determined limits.

2. Fire safety criteria analysis

Creating *Buildings characteristics data base* is the first step to significantly improvement fire safety possibilities, especially for high-rise residential buildings as high-risk features regarding fire issues. To provide such a base, setting a list of fire safety criteria is necessary (Laban, Milanko, 2007).

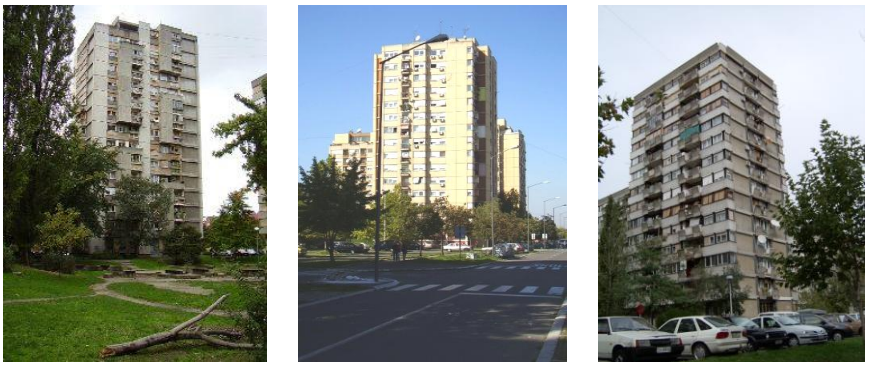

Figure 2. Residential towers built in industrial way

The concept of residential towers, observed in case-study, is defined, first of all, in the context of *Regulations on technical normative for fire prevention of high-rise buildings,* where the high-rise object means *'building with rooms where people stay, and where the floor of the highest floor is at least 22 m above the lowest approachable level and where the intervention using auto mechanical scaffolds is possible."* In fact, it mostly includes buildings with 9 or more floors. Having in mind that most residential towers were built in the period of intensive residential building, with no detailed regulations on fire protection, fire safety evaluation of built structures is necessary. Aiming to achieve a satisfactory level of fire protection, e.g. safety of people and material goods, especially in high-risk objects like high-rise residential objects – towers, it is necessary to review the conditions and perform comparative analyses of obtained results and actual demands of safety engineering in the field of fire protection. Fire safety Low and other national legislations and European standards are describing many demands to be applied in urban, architectural and structural design, and some of them are crucial in life saving issue, so they form a ***list of building's fire safety criteria***:

1. Industrial and residential zones are to be situated at proper distance, as well as residential buildings themselves (at least ½ higher structure);
2. Access roads are to be planned in a way and wide enough to provide movement of fire engines (only forward);
3. Access road has to lead to the plateau for fire-fighting intervention, which provides access to building's entrances/openings (windows);
4. Load-bearing building's structure has to stay stabile in fire for 2 hours;
5. Building should be divided into fire compartments 500-1500m^2 plan area, with separating membranes -walls - fire proof 90, each compartment has it's own fire escape, with escape

route no longer than 30m, doors in fire compartment's walls also has to be 1,5 hours fire proofed;

6. It is not allowed to connect the cellar to upper floors of building;
7. The building exit door should be opening to outside and at least 2,30m height, width depends upon number of residents;
8. Machine rooms (boiler room, transformer station, booster pump) should be separated fire compartments (90 minutes fire resistance);
9. At least one fire safe staircase, separated from hall, with pre-entry space, fume ventilated, accessible from each floor, with fire-proof doors;
10. Fire escape / fire stair – secondary staircase, made of metal or concrete;
11. Dimensions and shape of façade elements in a way to avoid the fire spread;
12. Route of evacuation should be with proper signalization and emergency light (60 minutes operating, with its own power supply);
13. Elevator shafts should be separated from staircase because they can contribute to the spread of smoke and fire, and automatically shut down in emergencies.
14. Wet standpipes should have hose cabinets on each floor (house fire hydrants). These hose cabinets contain 1" fire hose with a nozzle. In case of a fire, tenants can open the hose cabinet, pull out the hose and then open the valve allowing water to flow through the hose. With this having been said, this type of system requires that water be provided and pressurized up to each hose cabinet at all times. Buildings can either use county water pressure, or have some type of pressure booster, such as a pump;
15. Fire alarm system, as active fire protection system, that detects fire or the effects of fire, (heat detectors, smoke detectors, manual pull stations/manual call points) should be installed and functional, and as a result provides one or more of the following: notifies the occupants, notifies persons in the surrounding area, summons the fire service, and controls all the fire alarm components in a building. Fire alarm systems can include alarm initiating devices, alarm notification appliances, control units, fire safety control devices, annunciators, power supplies, and wiring.

Named demands, for their significant importance related to life saving issue, are *main criteria in fire safety building analysis.* Besides them, there are more technical standards regarding heating, ventilation, water and electrical supplying system. Most of them are difficult to investigate during field observation. Due to luck of maintaining, all buildings are in poor condition.

3. The data-base of high-rise residential towers in Novi Sad

Identification of high-rise residential towers was done based on actual city plan and field research activities. During the investigation, building plans and technical documentation were also used, in order to get some further information about building structure and characteristics. Every structure has its own characteristic details (form, layout, floor plans, materialization, construction type, position, staircases, entrances, infrastructure, etc), which can significantly affect the fire safety performance of the building. Therefore, the data-base containing a list of objects and their typology, as well as valid technical documentation should be the starting point of fire safety improvement.

In the observed city area - Novi Sad, most residential towers are built in industrial way – "IMS" building system (use of precast prestressed elements – skeleton construction – Fig. 2). Those buildings' structures, because of its construction type, could be even more vulnerable in case of fire and performing preventive measures is particularly important safety issue. However, classical way of building was also used and the principles of improved building technology were applied as well (Fig.1). 61 high-rise residential towers were identified, and 26 of them represent characteristic groups of built structures – building types. One representative sample of each group was further examined in detail, for common characteristics related to building type: load bearing structure type, floor plans, building materials, façade shaping, staircases and elevators, smoke evacuation, fire compartments and fire escapes. All buildings were inspected for actual state of fire alarm systems and house fire hydrants, access roads and evacuation routes. Case-study will provide better insight into the study. State of the fire safety, based on data base statistics, indicates main topics for actions.

3.1 Case - study

The group of residential towers, observed in case-study, includes three buildings with ground floor +14 stories. Similar groups of two or three 9 to 14 floored same residential towers were settled at four locations (*Fig. 3*) in Liman city area: 22.000 m^2 of flats were made based on only one project design. These towers were built in the period from 1968 to 1976, applying IMS building technology – which in some research works has shown low fire resistant characteristics. The project designing solution (*Fig.12*) includes neither fire stairs, nor other predicted measures for safe evacuation of inhabitants, or intervention of expert firemen squads. There are no any measures for fire prevention or limitation. There are neither fire compartments nor other fire resistant walls to separate any part of building from the other, or from escape rout. Elevator shaft is integrated in staircase, only glass wall separates them.

Figure 3. Residential towers S-3 (P+9), S-4 and S-6 (P+14) Liman III-1 block;

Emergency light and signalization is badly damaged, as well as house fire hydrants. Fire alarm system – manual pull stations were installed once, but some of them are gone and the rest of them were never checked. Although the fire load estimations usually indicate high level loading range in case of multi-residential buildings, no preventive measures have been additionally applied so far. It must be reconsidered, especially in experts' domain and experts' responsibility domain (Karabasil, Milanko, 2004.). Smoke extraction in fire events is a very important life-saving item, and there are no appropriate openings for smoke evacuations in these buildings, with the exception of 1 m^2 big roof exit. So, intervention of firefighter teams and life saving operations are very difficult. Additionally

difficulty circumstances are inappropriate building positions regarding approaching possibility for fire squad interventions: parked cars or other barriers at access routes, or impossibility of access, at all, to some sides of buildings (*Fig.13*). Besides measures, as the building of fire stairs, formation of fire compartments in accordance with current legislations, formation of fire safe zones and supplying of stationary sprinkling systems and systems of automatic fire alarm, as well as the appropriate approach for intervention teams in case of accident, the maintaining of structures is also very important.

Figure 4. Damaged surface layer of prefabricated elements: corrosion of concrete and steel bars

During previous investigations (Laban, Milanko, 2006.), significant damages of façades were established (*Fig.4*). These structures were built in industrial way more than 30 years ago, applying prefabricated reinforced concrete elements. Subsequent passive protective measures, both on outside and inside surfaces of constructive elements – materials, should include complete reconstruction of protection layer, e.g. coating of additional layer of protective material, with high thermo isolative properties. Care should be taken that construction stability must not be disturbed.

Base constructive elements, which can enable fire spreading from one fire sector to another, or from one floor level to another, and evacuation staircase, should be made of inflammable materials resistant to fire at least for 90 minutes. Same resistant is requested for supporting and façades outstanding walls. Coating with fire-resistant mortar or compact resin, sprinkling with mineral fibers could be some of efficient solutions for the recovery of protective layer. These materials bond to base concrete (ceiling and wall surface). Even thin layers provide for good thermal protection, so, for example, 80 mm concrete ceiling coated with 12 mm thick layer of compact resin is fire – resistant for 3 hours. Use of mineral or gypsum board, or at least coating with 2 cm thick "perlit" mortar layer, prolongs the fire-resistance for one more hour.

4. Fire safety assessment of residential towers

Research work and field investigations provided several data series regarding observed building performance and characteristics. Integrated data according to main criteria in fire safety building analysis are presented in Table 1.

As the outcome shows, the findings of a survey are defeated. Not one building is situated at safe distance from another one, and there are no fire compartments in any of buildings or fume excavation. Fire and fume spreading is easy possible, and tenants' lives are in serious jeopardy, in all buildings.

Table 1: Integrated data according to main fire safety criteria

Criteria:	*Satisfactory outcomes / All outcomes*
1. Proper –safe distance between the buildings	*0 / 61*
2. Access roads	*27 / 61*
3. Plateau for fire-fighting intervention	*27 / 61*
4. Load – bearing building's structure stability in fire	*61 / 61*
5. Fire compartments	*0 / 61*
6. Connection between cellar and upper floors	*0 / 61*
7. The building exit door	*61 / 61*
8. Machine rooms	*14 / 61*
9. Staircase/fume ventilation	*0 / 61*
10. Fire stair	*14 / 61*
11. Façade elements	*41 / 61*
12. Route of evacuation (signalization, light)	*0 / 61*
13. Elevator shaft	*0 / 61*
14. House fire hydrant	*6 /61*
15. Fire alarm system	*17 / 61*

Fire prevention system in high-rise buildings represent special problem and its organization level as well as efficiency is far behind real society' needs. Aiming to achieve a satisfactory level of fire protection, e.g. safety of people and material goods, especially in high-risk objects like high-rise residential objects – towers, it is necessary to review the conditions and perform comparative analyses of obtained results and actual demands of safety engineering in the field of fire protection.

5. Architectural and structural concept of fire stair

Fire stair is, basically, the second or alternative staircase in high-rise buildings, made to be used for evacuation in case in fire. Fire stair can be built as outer or interior staircase.

Internal staircases are defined as separate fire compartment, made of inflammable materials, with 90 minutes fire resistance. According to previous, staircase can be built of reinforced concrete - at least 14 cm thickness of shaft walls, with smoke prevention doors, same fire resistance as shaft walls and door closer. If the building is higher than 40 meters, interior fire stair has to be separated from communication corridor by ventilated fire safety zone at least 5sq.m area and 125cm width. Stairways and steps have to be made of materials witch are 90 minutes fire resistant (concrete or protected steel or wood construction). Cantilevered and spiral stair construction for fire stairs is not allowed. Minimal stairway width is 125cm (up to 200 people for evacuation). Regarding to number of people to be evacuated, width is increasing: 60cm for every 100 more people, up to 220cm, when the second fire stair is necessesary to provide.

Outer fire stairs are also defined as separated fire compartment. Serbian regulation demands it's accessibility from hall, or, at least from two rooms at each floor. A solid wall or 150cm distance from façade openings is also required. Façade walls must be 90 minutes fire resistant, but fire resistance for windows or balcony doors is not specified. Outer fire stairs must be made of inflammable materials, and its quality, dimension and shaping has to provide safety usage in any weather conditions. Spiral stairs or ladders are not allowed. Minimal stairway width is 80cm, with angle of inclination up to 45^0. The required height of safety fence is 120cm.

5.1 Fire safety evaluation of existing fire stairs

Except for checking the fulfillment of requirements in the safety assessment of existing fire stairs, successful and safe evacuation of people from building in flames also depends on other factors, which are characteristics of actual situation, the specifics of building or real number of tenants who evacuated. Event development depends, also, on the place of initial fire, fire load, weather conditions and others. Reliable information on fire safety in hole or in any segment is based on detailed research, fire scenario formulation and simulation of typical situations. Rescuing people from high floors of buildings in flame is only possible via the fire stairs, so it is considered that the assessment of fire safety staircases security certainly is one of the key starting points for creating fire scenario.

Figure 5-7: A turntable ladder truck fire engine in rescue action, intern fire escape and larder ventilation openings to staircase

During the field inspection and evaluation of fire safety criteria, it was determined that none of them can be considered as fire escape stairs. Either architectural-constructive concept was incorrect or tenants occupied the staircase space and use it as storage. The recommended measures vary from case to case, so each problem must be considered individually in order to find functional and efficient, as well as economically acceptable solutions. Fire Brigade performs regular exercise in Novi Sad, on high rise or otherwise hazardous buildings. Structure of analyses and evaluation findings provide better insight into the complex character of the results formulation process.

Observed residential tower is higher than 40m, and fire stair is one of the better maintained in the city. According to actual legislations, fire stair should be separated from the hall by ventilated underpressered room, with fireproof and smoke control doors, which was not applied. The integrity of stair case fire compartment is seriously compromised with ventilation openings of commons. In the case of fire, in any apartment, the smoke would rapidly spread through staircase shaft due to chimney effect, so the only safe way for evacuation will became the deadly trap. There is no adequate stair width and it is partly constructed as spiral stair. Ventilation opening on top of the stairs is locked,

while the associated attic rooms are full of combustible materials and improvised antenna and power system.

Figure 8-11: Locked staircase ventilation opening, apartment door in hall end, behind escape door, dangerous wiring and flammable materials in fire escape staircase

Recommended preventive measures are formulated in order to prevent fire in staircase shaft (to clear attic rooms, to remove cables, and close commons' ventilation openings). It is necessesary to form ventilated underpressured room as entrance part to stairs, but existing floor plan doesn't provide simple solutions.

5.2 Upgrading external fire stairs analysis

Post installation of external fire stairs on the existing high residential buildings has been analyzed, repeated in a group of 6 buildings built during the '70 in the last century according to system IMS, which practically had the same size of bases but different number of floors (from 11 till 14 floors). The main raster of the base is IMS ceiling 4.20x4.20m, combined with raster 3x5, with the addition of cantilevered IMS ceilings with parapets in rooms and sloping AB attics on terraces.

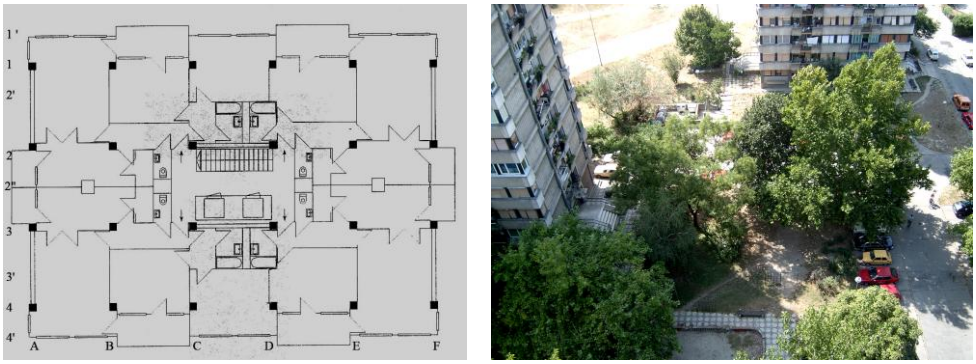

Figure 12, 13: Typical floor layout and internal yard between towers

During the analysis, Regulation for high buildings has been applied. Existing internal stairs (fig. 12) are isosceles, located in the central core, with a few lifts, and vertical communication through the main exit in the basement is achieved (axis A/2-3). Each floor has four apartments and approach to the facades is possible only through them. On the transverse facade there is a possibility for installation of staircase with two final facade walls AB (axis F/1-2 and F/3-4), however, due to the volume of intervention and terms for exiting on the staircase at each floor from two rooms, installation of staircase in the central field on the centerline of the building at the shorter façade

(figure 10. axis F/2") has been envisaged. At this place, exit from smaller terraces of two apartments through kitchens is possible. For this solution, the existing facility needs only an intervention on the fences of the terraces.

Due to height of the building, during the calculation of the impact on horizontal effects, influence of wind and seismic forces must be taken into account. Two conflicting criteria can be found here: the impact of wind loads is reduced if the structure is not closed, but unclosed structure is protected from impact from atmosphere (freezing, snowing, thus an occurrence of slippage). In addition, closed structure is protected from turning of the smoke during the fire caused by wind. Since the staircase must provide safe evacuation of people during the fire danger in winter, this concept of solutions recommends that holes of the staircase should be closed by sandwich sheet and reinforced glass. In addition, it is recommended to install continuous AB apron, as vertical fire barrier on the outside, with minimum height of 30cm; at least with the existing AB-attic terrace aprons (axis F/2-3 and A/2-3), for disabling transmission of fire on the façade, and also the replacement of windows and doors uninflammable materials or materials with higher fireproof.

Next to the front door, which are bright and 70cm wide, it is necessary to build pedestal width 1.50m (although, in this case it could be even less, considering the distance between holes). There is a plan for constructions of doors, which do not lock from the outside of the building, and have an automatic lock for closure. On each floor, from the inner space of external staircases, it is possible to unlock the door of fire stairs to the direction of the residential facility, if the special lock on each floor is installed. Since the probability that in case of fire someone stays at least in one of two apartments who have exit to the fire staircase is larger, it gives another reason more to accept this concept of installation external PP staircase with two accesses.

The buildings are not divided in sectors of fire and smoke so, the whole building is a fire sector. Since two external fire staircases are advisable, the second staircase installs as the first one, on the axis of A/2, and in this case, it is necessary to make an intervention at the entrance of the main staircase as well. Usually, at the ground floor (which is about 1.5m above the ground surface) there is only one entrance of the staircase in the building, rarely two. This concept of security staircase, which presents a construction of large heights, represents the idea of TOWER program, analyzed as a model of bifurcated IMS staircase in raster 3.60x4.20, with pillars 34x34cm and ceiling console as pedestal to the existing facility.

According to actual low slope of PP stairs is less than 45 °, and ratio of stairs min b/ max h = 26/19cm (-36 °) and min b/ max h = 33/20cm (-31 °). For the floor height 2.90m, a possible solution can be bifurcated stairs with tread dimension 29/18.lem. External AB staircase can be made as bifurcated or with one branch from concrete, steel or in IMS system. Analysis of bifurcated concrete staircase provides period of oscillation for the first ton around 2.5-3 seconds. Due to added mass, even if the concrete plane is used, there is no significant reduction of the oscillation period, which leads to utilization of steel construction at external staircase, or between new and old construction connections. Exclusion of the earthquake impact from the analysis of PP staircases is not logical, because an earthquake is often fallowed by fire in buildings and facilities.

In this short analysis, using only one concrete example, it has been shown that location selection and materialization of the external security staircase is a serious problem, and depending on the case, it requires the application of multi-criteria decision making models, including the sociological aspects of the problem and the unavoidable legislation.

6. The fire safety preventive action-list for high rise Residential buildings

As can be seen from the findings of this research paper, the fire safety in residential high rise towers in Novi Sad is at extremely low level. A cay challenge facing us is public consciousness of fire safety issue. Any recommended measures and actions should be applied gradually, step by step, and after every action we should be looking for response from the residents. This approach seams to be the only way to improve fire safety, because actual legal demands failed, and everything depends on citizens' awareness and their financial power. Proposed action list is divided into two parts: short-time action list and long-term action list. The first one doesn't imply lot of financial efforts and could upgrade actions or facilitates which already exists. The other one implies society consensus and determined support about fire safety issue.

Short-term action list:

- Education and informing (could be performed during fire drills);
- Provide one fire extinguisher in each apartment;
- Repair and improvement on installed facilities (house fire hydrants, manual pull stations), periodical checking and regular maintaining;
- Installation of sprinkler units at high risk points – kitchens: there is possibility of their connection on existing water-supply system.

Long – term action list:

- Provide prior conditions for constitution a financial support system to able residents for investments and maintains (insurance low);
- Planning and construction of fire escapes for every building to be accessible from each apartment;
- Installation of automatic fire alarm system in buildings;
- Make revisions to the actual legislation in order to define and standardize procedures inspections and maintaining fire safety building performance and facilities.

Research work on fire safety of residential towers started three years ago. During that time we had many contacts with residents and fire department, as well. So far, fire drills were performed every month in deferent residential tower, but tenants haven't paid much attention, although we notified them in advance and prepared information leaflets. According to these findings, and the findings of this report, it's necessary to put more efforts to aware both public and legislative power about the state of fire safety of high rise residential buildings.

The next step in our investigation and research work is the development of fire scenario analysis based on assembled high rise residential towers data - base.

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