Seismic Vulnerability of Existing Buildings in the Taroudant Urban Area, Morocco, using Different Approaches

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Abstract: Due to its location at the extreme north-west of Africa, a zone of collision between the African and Eurasian plates, Morocco is a country exposed to seismic risk. In the context of the Morocco National Integrated Risk Management Strategy, with the objective of strengthening the resilience to hazards of the national territory, this article presents a study in which we evaluate the seismic vulnerability of buildings in the Taroudant urban area. This city falls within the seismic zone 2 with a peak ground acceleration of 14%g, which is the second important seismic zone in Morocco. Taroudant building are clustered according to the European Macro-seismic scale. We then analyze one category building using two seismic vulnerability assessment methods; a deterministic and overall approach. The results are quite similar for damage probabilities obtained by the deterministic approach and those evaluated by the overall approach for a seismic intensity scenario between VIII and IX. Using these results along with a Geographic Information System, maps of the spatial distribution of seismic building categories and vulnerabilities are produced. These maps provide a scientific and technical support to the authorities for the assessment of potential risk points within Taroudant city.

1 INTRODUCTION

Morocco has experienced several destructive earthquakes, particularly in many of its larger cities. During the 20th century, the recorded seismicity was relatively moderate (Iben brahim et al., 2003) . The 1960 Agadir earthquake, with a magnitude of 5.7 on the Richter scale, was the most violent and deadly event, with more than 12,000 victims and more than two thirds of the city's buildings and infrastructures disappeared. More recently, the 6.3 magnitude Al Hoceima earthquake of 2004, resulted in a death toll of 629 people (Mouraouah et al., 2004; Talhaoui et al., 2005). The Al Hoceima earthquake of 24 February 2004 has further shown deficiencies related to the socio-economic and environmental vulnerability of basic infrastructures. It also showed institutional, technical and organizational gaps in managing natural disasters of this scale.

The issue is then to suggest simple models to help address the problem of studying seismic vulnerability, and to present a tool to help decision-making in planning and seismic risk management. Thus, for the Taroudant urban area, this paper focuses mainly on assessing the seismic vulnerability of its buildings.

There are several methods for the assessment of seismic vulnerability. The selected method is made according to the quality and quantity of available data and the desired accuracy, i.e. whether we seek the estimation of the seismic vulnerability of a single building or a group of buildings. We can thus, cite the ATC methods (Rojahn et al., 1988) then taken up by FEMA ((US), 2017) in the United States, the GNDT method (Petrini, 1993) in Italy and the European project RISK-EU (Milutinovic & Trendafiloski, 2003). In this work, the vulnerabilities are assessed based on the direct methodology described by the RISK-EU project, namely the overall approach level 1 based on the vulnerability index, where a system of building classifications are proposed to group them under a similar vulnerability index VI. In addition, we also use a level 2 approach based on the Pushover analysis, which is the basis of the deterministic

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method for the elaboration of fragility curves. (Combescure et al., 2005; E, 2020; Hammoumi et al., 2009; M. A. El Azreq, Moudrik, A. El Hammoumi, A. Iben Brahim, K. Gueraoui, A. El Mouraouah, A. Lbadaoui, M. Kerroum, M. Kasmi, 2012).

This article is structured as follows; the following section provides an overview of the urban area of Taroudant by introducing a description of its building typology and construction methods. The spatial distribution of these typologies is further mapped using GIS (Geographic Information System) and is discussed. Then, a type C building is analyzed using the two above-mentioned methods of seismic vulnerability. Finally, this paper presents probable damage scenarios for our study area with a comparison between the two assessment methods adopted in this work.

2 DESCRIPTION OF THE STUDY AREA, DATA AND RESOURCES

2.1 Study Area

Taroudant is a city located in the south-west Morocco, this study concerns the overall urban area of Taroudant, which covers an area of 13.3 Km². In terms of seismicity, Taroudant occurs in seismic zone two with a peak velocity PVA = 0.10 m/s and a peak ground acceleration PGA=0.14g according to the Moroccan Seismic Code (RPS2000, 2011). This zone is the second most important seismic zone in Morocco.

2.2 Building Typology and Construction Procedures

For seismic vulnerability assessment, buildings in the Taroudant urban area are grouped into five standard typologies. These are selected such that each building-type reflects a distinct vulnerability class with respect to seismic hazard. The selection of the classes is based on the EMS 98 scale (Grünthal, 1998) and is completed by taking into account the state of dilapidation, the materials and quality of construction, the irregularity shape of the building, the seismic design level etc. These criteria are also used to assign to each class a basic vulnerability index.

2.2.1 Types and Age of Housing

Data from the General Census of Population and Housing of Morocco (*RGPH 2014*, 2014), shows that the most common type of housing is the Moroccan house 80.5%, apartments account for only 13.4%, the proportion of villas is 2.3% while the parts of rural and basic type housing only exceed 1.6% and 0.9% respectively. Similarly, an analysis of data on the age of housing shows that about half of urban houses were less than 50 years old, compared with 22.8% of houses between 10 and 19 years of age, 15.8% less than 10 years old, and 13.8% are 50 years-old and over.

In fact, the performances of the buildings appear opposite. On one hand, older buildings perform poorly, due to the lack of a building code and its application, as well as the degradation of materials and the need to repair them. On the other hand, younger buildings are constructed or rehabilitated with an acceptable level of seismic design, which means that they are rather earthquake-resistant buildings.

2.2.2 Definition of Typologies and the Associated Vulnerability Class

The data we collected and analyzed from various government sources does not contain detailed information on building methods in the Taroudant urban area. Thus, in order to collect information on the different local construction methods and to rank the housing stock in our study area, we conducted an on-site data collection in February 2020. During this visit, more than a hundred photos were taken and georeferenced using GPS positions and the GIS geographic information system. The results of the survey helped identify five categories of buildings based on different building materials and types of structures “Table 1”.

This data set made it possible to define different vulnerability classes based on the European macro-seismic scale (EMS 98) and to map them. The following pictures show examples of buildings that can be considered as representative of the building stock in our study area “Table 1” (Grünthal, 1998; Ningthoujam & Nanda, 2018; *RGPH 2014*, 2014).

A GIS database of geographical maps defining the different types of building structures and vulnerability classes in our study area has been elaborated “Figure 1” (Grünthal, 1998; Ningthoujam & Nanda, 2018; *RGPH 2014*, 2014).

Table 1: Illustration of the selected building classification.

Vulnerability class	Description	
A (Type_1): Unreinforced constructions	- Constructed using a basic construction method with walls consisting of small elements of adobe or mud bricks, arranged irregularly. - Floors are generally made of mixed materials (wood, earth, zinc...).	
A (Type_2): Unreinforced masonry constructions as a whole	- made of masonry in rough rubble, dressed stone or mud bricks and arranged regularly. - Traditional floors generally built in wood on top of thick walls and sometimes built out of an improved concrete slab. - Non-homogeneous and condensed spatial aspect.	
B (Type_3): Reinforced masonry constructions as a whole	- Constructed mostly out of brick masonry walls and reinforced concrete floors, - Constructed without taking into account seismic rules of the Morocco seismic code (RPS 2000), - Are of one, two, three or four storeys types and generally regular in plane and elevation. These buildings are in direct contact against each other. - Geometrically rectangular or square spatial appearance.	
C (Type_4): Buildings with columns / beams and unreinforced hollow brick infill walls	- Constructed mostly out of brick masonry walls and reinforced concrete floors. - Constructed with an acceptable level of seismic design according to the RPS 2000 code, even though the rules of construction in seismic zones are not perfectly respected, - Are of type three or four storeys and generally regular in plane and elevation. - Homogeneous Spatial aspect.	
D (Type_5): Reinforced concrete buildings: concrete gantries and walls	- Constructed mostly with brick masonry walls and reinforced concrete floors, - Constructed with a medium level of seismic design according to the RPS 2000 code, - Spatial aspect geometrically rectangular or square and easy to identify.	

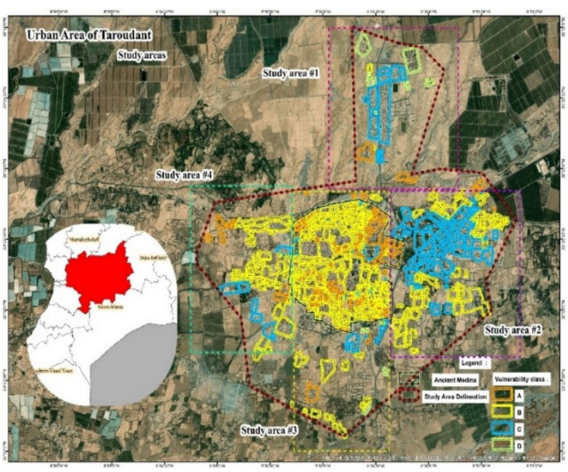

Figure 1: Geographical distribution of building-classes in the Taroudant urban area.

3 METHODOLOGY SEISMIC VULNERABILITY ASSESSMENT AND DAMAGE ESTIMATION

The procedures used to assess vulnerability or construct vulnerability curves depend on the nature, quantity of data collected, and the anticipated purpose, i.e. whether we are concerned with an estimate of seismic vulnerability for a single structure or a group of buildings. In the following, a distinction should be made between deterministic methods based on numerical simulations for a structure defined by a specific model, and probabilistic or statistical methods developed based on statistical data that group several typologies of structures with similar structural properties, which may undergo similar damages under a given seismic loading. For this purpose, this work uses these two approaches as techniques for estimating the vulnerability of a type C structure as well as on a large scale (Combescure et al., 2005; Dang, 2014; Hammoumi et al., 2009).

3.1 Seismic Vulnerability by a Deterministic Approach

This approach, defined as the set of methods used to accurately estimate damages caused by a seismic event, is based on two models. A seismic demand/capacity model obtained by dynamic modelling of structures subjected to seismic loading, and a model for calculating the probability of damages using fragility curves in the form of a probability distribution function of the log-normal distribution (Bendada et al., 2017; Nchiti, El Hammoumi, Gueraoui, Ibenbrahim, et al., 2020).
In the following, we will discuss in more detail a procedure proposed by the European project RISK-EU; namely the LM2 Method (Benjabrou et al., 2017; E, 2020; El Azreq et al., 2010, 2011).

3.1.1 Case Study

We thus, apply the LM2 method for the analysis of a type C building, which represents the Moroccan house and apartments which are more common in the Taroudant area. In addition, the mode of construction of these types of buildings is currently the most adopted one in our study area. The building we consider is a four floors frame structure with columns, beams and infill walls made out of unreinforced hollow bricks as shown in “Figure 2”.

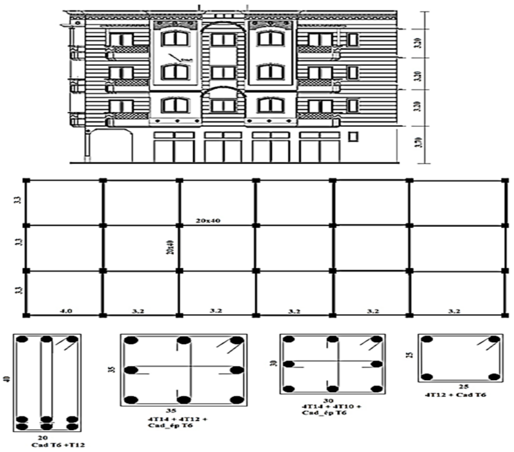

Figure 2: Plan, elevation views and details of the selected Type C building.

The dimensions of the structural design are 9.90×20 m^2 and this structure is modelled using the MIDASGEN finite element design software, while the seismic lateral loading was appraised based on the RPS2000 “Table 2”.

Table 2: Seismic parameters of the selected building according to the seismic code RPS2000 version 2011.

Seismic parameters	Style name:
Structural systems	Frames
Structure classification	III
Fundamental period of vibration	$T=0.075xH^{3/4}$ =0.52s
Amplification spectrum	Za/Zv > 1
Ductility class	ND1
Behavior factor	2
Seismic zoning	PVA = 0.10m/s PGA=0.14g
Site Influence	S1

3.1.2 Pushover Analysis

Pushover analysis is a non-linear static analysis of a structural element or structure under monotonous loading to describe the relationship between shear force and roof displacement (Ghobadi & Yavari, 2020; Mosleh et al., 2016). The method investigated in part of this work is the spectrum response-capacity method of Chopra & Goel (1999) (Chopra & Goel, 1999). According to Freeman's studies this method consists of the following steps (S A Freeman, 1975; Sigmund A Freeman, 1978) :
Step 1: Synthesis of a curve of shear force vs. displacement at the root, under monotonic lateral loading, is obtained by means of a finite element modeling of the structure, called the Push-over curve (V-ΔR) “Figure 3”.

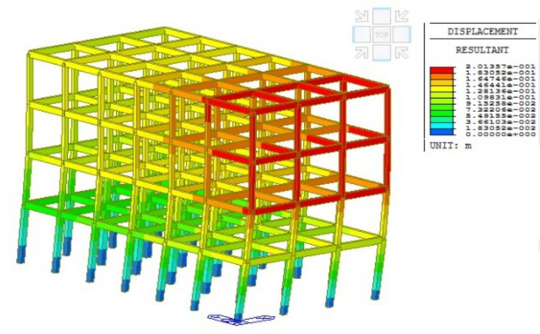

Figure 3: Numerical simulation and the resulting displacement of the selected building computed using the pushover analysis.

Step 2: Converting the capacity curve (V-ΔR) into a capacity spectrum (A-D), based on the following formulations:

$$A = V / W.\alpha_1 \quad (1)$$

$$\alpha_1 = \frac{\left(\sum_{i=1}^{N} m_i \phi_{i,1}\right)^2}{\sum_{i=1}^{N} m_i \left(\sum_{i=1}^{N} m_i \phi_{i,1}^2\right)} \quad (2)$$

$$D = \Delta_R / PF_1 \phi_{1,R} \quad (3)$$

$$PF_1 = \frac{\sum_{i=1}^{N} m_i \phi_{i,1}}{\sum_{i=1}^{N} m_i \phi_{i,1}^2} \quad (4)$$

A / D: Acceleration / spectral displacement;
W: Total mass of the structure;
m_i: The per-story mass concentrated at the ith floor level;
$\phi_{i,1}$: Amplitudes of the first eigen-mode on the ith floor;
α_1 : Coefficient of the modal mass of the first Eigen-mode ;
$\phi_{R,1}$: Amplitude of the first Eigen-mode at the roof level (Nth floor);
PF1: Modal participation factor corresponding to the first vibration mode;
Step 3: Transformation of the normalized elastic response spectrum (A-T) to pseudo-acceleration (A-D).
The Moroccan seismic regulation RPS2000, proposes an elastic spectrum that represents an idealization of the envelope for various normalized response spectra. It defines the dynamic amplification factor (D) of the response in function of the fundamental period of the structure (T). Then the definition of the elastic spectrum (A-T) is made via the dynamic amplification factor D (T) by:

$$A(T) = (A_{max} / g) / D(T)A \quad (5)$$

Where A_{max} is the peak ground acceleration and g is the acceleration of gravity.
The inelastic response spectrum is obtained by the introduction of the reduction factor K. The spectral displacement is $D = (T/2\pi^2)$ A (Belmouden, 2004; Fajfar, 2000).
Step 4: Combining the capacity and response spectrum and determining the performance point, "Figure 4" shows the combination of the capacity spectrum with the response spectrum in order to obtain the performance point.

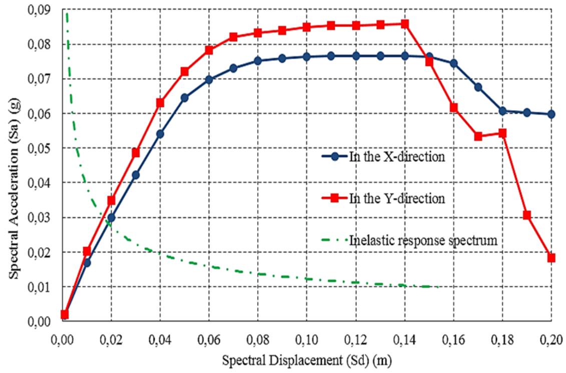

Figure 4: Combination of Capacity and Response Spectra.

3.1.3 Fragility Curves

For the development of fragility curves, all previous work uses a log-normal cumulative distribution model as a statistical distribution model to represent the fragility curves of a structure. (Kumar & Samanta, 2020; Maio et al., 2020; Milutinovic & Trendafiloski, 2003):

$$P\left[ds / S_d\right] = \phi\left(1/\beta_{ds} \ln\left(S_d / \bar{S}_{d,ds} \right)\right) \quad (6)$$

Where:
Sd is the parameter related to seismic hazard;
$\bar{S}_{d,ds}$ is the median and β_{ds} is the standard deviation of the spectral displacement for the building attaining a certain degree of damage ds:

$$\overline{Sd_1} = 0.7D_y \quad (7)$$

$$\overline{Sd_2} = D_y \quad (8)$$

$$\overline{Sd_3} = D_y + 0.25(D_u - D_y) \quad (9)$$

$$\overline{Sd_4} = D_u \quad (10)$$

$$\beta_{Sd1} = 0.25 + 0.07\ln(D_u / D_y) \quad (11)$$

$$\beta_{Sd2} = 0.2 + 0.18\ln(D_u / D_y) \quad (12)$$

$$\beta_{Sd3} = 0.1 + 0.4\ln(D_u / D_y) \quad (13)$$

$$\beta_{Sd4} = 0.15 + 0.5\ln(D_u / D_y) \quad (14)$$

Φ is the probability distribution function of the normal distribution;
Du is the ultimate point of spectral displacement;
Dy is the elastic yield point of spectral displacement;
"Table 3" presents the definitions of these states as a function of spectral displacements derived from capacitance spectra.

Table 3: Definition of limit states as a function of spectral displacements (cm).

Sd,ds				βds			
$S_{d,1}$	1.4	$S_{d,3}$	4.25	$\beta_{Sd,1}$	0.369	$\beta_{Sd,3}$	0.782
$S_{d,2}$	2.0	$S_{d,4}$	11.0	$\beta_{Sd,2}$	0.507	$\beta_{Sd,4}$	1.002

"Figure 5" shows the fragility curves obtained from the lognormal distribution hypothesis of the C-type structure presented in "Figure 2".

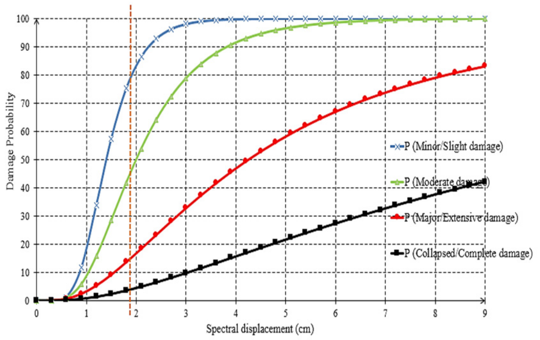

Figure 5: Derived fragility curves for our Type C building.

In addition, it is possible to identify the levels of damage on the analyzed structure by means of fragility curves and the value of the maximum spectral displacement that can be obtained from the point of performance, which is determined by the intersection of the capacity curve with the inelastic response spectrum. As shown in "Figure 4", by intersection with the fragility curves, the spectral displacement occurs at 1.9 cm in "Figure 5". The statistical distribution of the obtained damage is given in the histogram of "Figure 6".

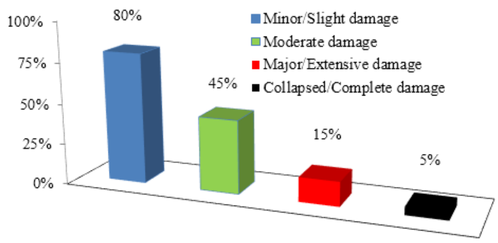

Figure 6: Summary of the fragility probabilities for the selected building.

3.2 Seismic Vulnerability by the Overall Approach

The overall approach is used for large-scale vulnerability analyses using a collection of geographical data to define a differentiation of structures into vulnerability classes according to the European macro-seismic scale (EMS 98) (Grünthal, 1998) as shown in "Table 1".

3.2.1 Vulnerability Index Method

The RISK-EU project suggests a semi-empirical method (LM1 Method) by which semi-empirical mean vulnerability functions are defined that relate the mean degree of damage μ_D to the macroseismic intensity I and vulnerability index V_I. This method proposes a system of building classifications to group them into similar vulnerability index V_I values ranging from 0 (less vulnerable building) to 1 (more vulnerable building) (Nchiti, El Hammoumi, Gueraoui, & Iben Brahim, 2020). For each type of building, RISK-EU gives the most probable V_I^* value, [V_I^-; V_I^+] the possible range and [V_I^{min}; V_I^{max}] maximum and minimum limits of the vulnerability index value V_I. For each seismic class, these values are evaluated according to the percentage of different types of buildings identified in the chosen class "Table 4". The basic vulnerability index V_I^* associated with the typology will then be amplified in accordance with the constructive parameters specific to each structure (Rezaei Ranjbar & Naderpour, 2020).

3.2.2 Fragility Curves

In order to obtain the damage probability of our seismic class C building , it is necessary to define, first of all, the mean degree of damage for different intensities as follows (Nchiti, El Hammoumi, Gueraoui, & Iben Brahim, 2020; Rezaei Ranjbar & Naderpour, 2020) :

Table 4: Vulnerability index for different classes of buildings in our study area.

Vulnerability class V_c	V_I representative values					ΔV_m	ΔV_f	Vulnerability index V_I
	V_I^{min}	V_I^-	V_I^*	V_I^+	V_I^{max}			
A	0.50	0.659	0.767	0.895	0.980	0.02	0.04	0.827
B	0.3	0.49	0.627	0.817	0.883	0.02	0.04	0.688
C	-0.02	0.007	0.402	0.76	0.98	0.1	0.04	0.542
D	-0.02	0.047	0.386	0.67	0.86	0.05	0.04	0.476

$$\mu_D = 2.5\left[1 + \tanh\left(\frac{I + 6.25V_I - 13.1}{2.3}\right)\right] \quad (15)$$

Subsequently, it is possible to calculate the damage distribution for each seismic class, using probability density and cumulative distribution equations:

$$p_\beta(x) = \frac{\Gamma(t)}{\Gamma(q)\Gamma(t-q)} \frac{(x-a)^{q-t}(b-x)^{t-q-1}}{(b-a)^{t-1}} \quad (16)$$

$$P_\beta = \int_a^b p_\beta(z)dz \quad (17)$$

Where a=0, b=6, t and $q = t(0.007\mu_D^3 - 0.052\mu_D^2 + 0.2875\mu_D)$ are the distribution factors, and x is the continuous variable in the interval [a,b]. The discrete beta density probability function is calculated from the probabilities associated with damage states k and k+1 (k = 0, 1, 2, 3, 4, 5), as follows:

$$p_k = P_\beta(k+1) - P_\beta(k) \quad (18)$$

$$P(D \geq D_k) = 1 - P_\beta(k) \quad (19)$$

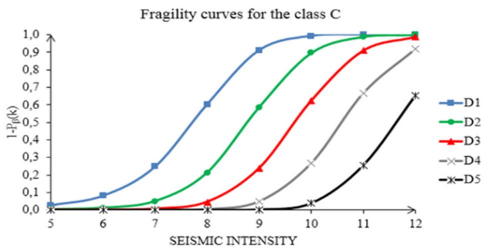

Figure 1: Summary of the fragility probabilities for the selected building.

Based on the fragility curves shown in “Figure 7”, it is possible to deduce the state of damage for a given seismic intensity. For a scenario of seismic intensity between VIII and IX, class C buildings will suffer 78% of negligible to slight damage, 40% of moderate damage, 12% of significant to important damage, 2% of very important damage. These results show a good agreement with those evaluated by the deterministic approach “Figure 6” for a type C building within the urban area of Taroudant under a seismic intensity VIII.

4 CONCLUSIONS

In this paper, two models for assessing the seismic vulnerability of buildings are developed for typical structures in the urban area of Taroudant, in particular for type C buildings which are more abundant in this city. The first model is based on a seismic vulnerability index system for buildings. Then, a reference model is developed according to a more precise method, the non-linear static analysis, for comparison of the damage assessed by the two methods. Maps of the spatial distribution of seismic building categories are developed.

For type C buildings and for a seismic intensity scenario between VIII to IX, the results turn-out to be quite similar between the damage probabilities obtained by the deterministic approach and those evaluated by the overall approach.

Based on these results and the maps of the spatial distribution of seismic building categories, this study provides a valuable technical support to the authorities for the identification and assessment of potential risk sites.

Future research on the development of seismic vulnerability assessment models for buildings can take this work as a standard and unified procedure for studying vulnerable areas on a national scale.

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