Comparative Analysis on Response of a School Building against Gravity, Earthquake and Tsunami forces

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Abstract –: *A series of seismic waves in water is known as Tsunami. These waves are caused due to the displacement of water in oceans, large lakes,, volcanic eruptions, earthquakes and underwater explosions and other interruptions above or below the water will generate Tsunami. When reaching towards the coastal depths height of the wave increases. The main objective is to analyse a school building against gravity, earthquake and Tsunami forces. To analyse the building forces due to gravity, earth quake and Tsunami are calculated for different inundation depths and considering the obtained forces response of building will be known in case of moments. By considering each critical moment of each force design of structural element is carried out and compared.*

***Key Words*: Earthquake, Tsunami forces, gravity forces, Inundation depths, coastal depths.**

1. INTRODUCTION

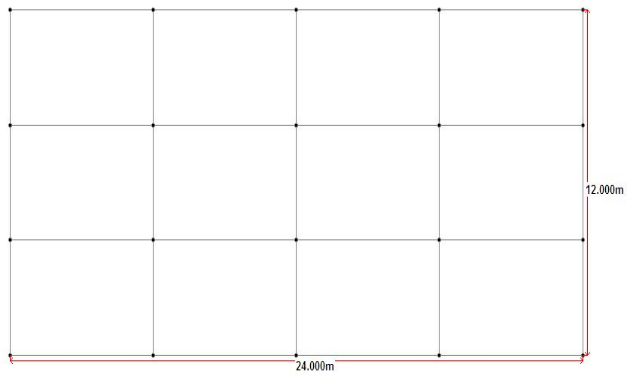
Earthquake is an endogenous natural disaster, which occurs suddenly without any warning. Depending upon the magnitude and intensity, bulk of devastation takes place with a short duration of time. The vast destruction of engineering systems and facilities during the past earthquakes has exposed serious deficiencies in the common design and construction practices. These disasters have created a new responsiveness about the disaster awareness and easing plans. Tsunami resistant analyses are complex in nature as the motion is transient and the force functions are time dependent. Though there are no well established design procedures, FEMA CCM and draft code of Bureau of Indian Standards provide some guidelines to calculate tsunami loads act on coastal structures. A review report by Harry Yeh etal (2005) suggested that tsunami loads exerted on structures can be obtained in terms of hydrodynamic, surge and impact forces for given depth of inundation and the velocity of approaching tsunami. Nearly 90% of all the earthquakes due to tectonic events, primarily movement on faults and secondly volcanism. Elastic rebound theory gives the physics behind earthquake activities.

1.1. Physics of earthquake and tsunami's

Tsunamis are series of sea waves of extremely long wave length and long period generated when seafloor suddenly lifts up almost the entire water column vertically upwards. As the tsunami crosses deep ocean ,its wave length from crest to crest may be a few hundred kilometres but its height will only a few centimetres .In deep oceans ,these waves will reach speeds exceeding 970km/hour. When tsunami enters the coastal lines, the velocity of its waves reduces and the wave height increases, sometimes to a height of 30m, and strike the coast with disturbing force. The other features of tsunami which influence the size of tsunami are the shoreline, bathymetric formation, the velocity of sea floor deformation and the water depth near the source of earthquake. Tsunamis are characterized as shallow water waves and are different from wind generated waves .A tsunami can have a period in the range of ten minutes to two hours and a wave length in excess of 500km. The speed of shallow water wave is equal to the square root of the product of acceleration due to gravity and the depth of water. The rate at which a wave loses its energy is increased proportional to its wave length. Hence tsunamis travel in deep waters with high speeds and travel great transoceanic distances with limited energy loss. Near the coast, as the depth of water decreases the speed of tsunami diminishes. However as the change in total energy remains constant, the speed of tsunami decreases as it enters shallower water and the height of the wave grows. Because of "shoaling effect", a tsunami that was unnoticeable in deep water may grow to be several meters in height. When a tsunami finally reaches the shore, it appears as rapidly rising and falling tide, a series of breaking waves. An earthquake occurs when the pressure along a fault becomes stronger than the pressure holding the rocks mutually. Then the rocks on either side of the fault suddenly split apart, sometimes at supersonic speeds. The two sides of the fault slide past one another, releasing the pent-up pressure. Energy from this taking apart radiates outward in all directions, including towards the surface, where it is felt as an earthquake.

1.2. Mathematical model:

In this paper, school building is chosen for the analysis and the tsunami forces, earthquake forces and gravity forces imparted on these structures are worked out of different heights located at Zone-III region.



2. Analysis of forces

2.1. Tsunami forces

When turbulent flow hitting on the structure hydrodynamic and impact forces are considered

Hydrodynamic forces:

$$F_D = \frac{1}{2}\rho C_D b h_{max} u^2$$

$$\frac{h_{max} u^2}{g R^2} = 0.125 - 0.235\frac{Z}{R} + 0.11\left[\frac{Z}{R}\right]^2$$

Impact forces:

$$F_i = C_m U_{max}\sqrt{km}$$

$$U_{max} = \sqrt{2gR\left(1 - \frac{Z}{R}\right)}$$

The total force that is considered to act on the structure is obtained by summing up of the hydrodynamic and impact forces at different levels of each structure and presented in tables with slope 1:50.

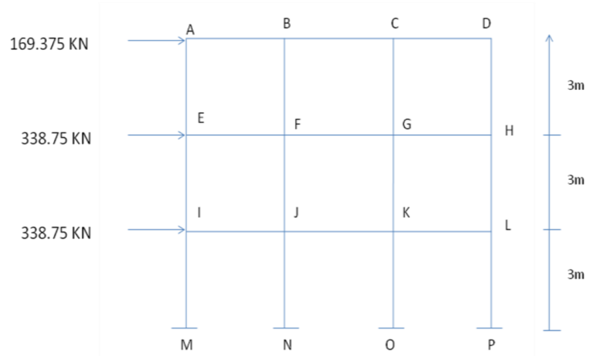
Table 1: forces on the structure

R(M)	Hydrodynamic force(KN)	Impact force(KN)	Total(KN)
5	292.74	686.9	979.64
8	1129.14	1073.3	2202.44
11	2508.7	1556.30	4065

Load on the selected frame

Table 2: load on the frame

Height of structure from ground (meters)	Total (KN)
3	244.91
6	550.61
9	1016.25



2.1.1. Moments due to Tsunami loads

Beam moments

Table 3: Tsunami beam moments

MEMBER	MOMENT (KN)	MEMBER	MOMENT (KN)
AB	42.34	IJ	338.74
BA	42.34	JI	338.74
BC	42.33	JK	338.75
CB	42.33	KJ	338.75
CD	42.34	KL	338.74
DC	42.34	LK	338.74
EF	169.375		
FE	169.375		
FG	169.36		
GF	169.36		
GH	169.37		
HG	169.37		

Column moments

Table 4: Tsunami column moments

MEMBER	MOMENT (KN m)	MEMBER	MOMENT (KN m)
AE	42.345	GK	254.06
EA	42.345	KG	254.06
BF	84.675	HL	127.03
FB	84.675	LH	127.03
CG	84.675	IM	211.71
GC	84.675	MI	211.71
DH	42.375	JN	423.43
HD	42.375	NJ	423.43
EI	127.03	KO	423.43
IE	127.03	OK	423.43
FJ	254.06	LP	211.71
JF	254.06	PL	211.71

2.2.Earthquake forces

Lateral Forces and Base Shears

The total design lateral force or design seismic base shear (VB) along any
Principal direction shall be determined by the following expression:

$$V_b = A_h X W$$

Where,
Ah = Design horizontal acceleration spectrum
W = Seismic Weight of the building

Ah = 0.06,

W= (2X3576+2745.2) =10000

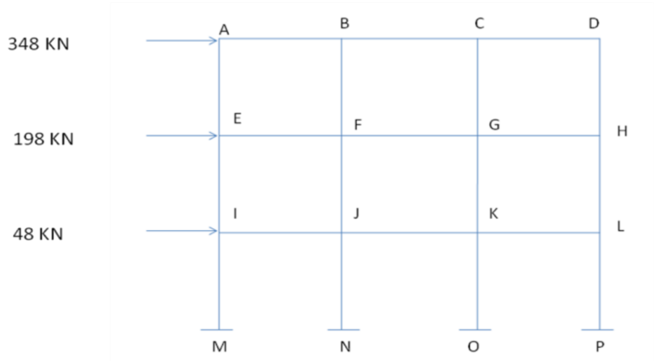
Vb= 0.06X1000=600 KN
The design base shear computed shall be distributed along the height of the building

$$Q_i = V_b * (w_i h_i^2 / \Sigma w_j h_j^2)$$

Calculation of Base Shear

Table 5: Base shear

Storey	W_i	h_i	$W_i h_i^2$	$w_i h_i^2 / \Sigma w_j h_j^2$	Q_i
2	2745.2	9	222361.2	0.58	348
1	3576	6	128736	0.33	198
G	3576	3	32184	0.08	48



2.2.1. Moments due to Earthquake forces

Beam moments

Table 6: beam moments due to EQ forces

MEMBER	MOMENT (KN m)	MEMBER	MOMENT (KN m)
AB	78.84	IJ	258.525
BA	78.84	JI	258.525
BC	78.84	JK	258.525
CB	78.84	KJ	258.525
CD	78.84	KL	258.525
DC	78.84	LK	258.525
EF	202.575		
FE	202.575		
FG	202.575		
GF	202.575		
GH	202.575		
HG	202.575		

Column moments

Table 7: Column moments

MEMBER	MOMENT (KN m)	MEMBER	MOMENT (KN m)
AE	78.84	GK	247.32
EA	78.84	KG	247.32
BF	157.68	HL	123.66
FB	157.68	LH	123.66
CG	157.68	IM	134.865
GC	157.68	MI	134.865
DH	78.84	JN	269.73
HD	78.84	NJ	269.73
EI	123.66	KO	269.73
IE	123.66	OK	269.73
FJ	247.32	LP	134.865
JF	247.32	PL	134.865

2.3. Gravity forces

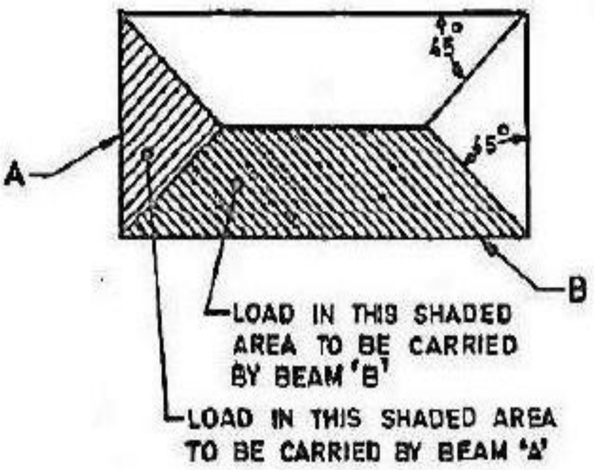
Loads onto beam are considered as

• Trapezoidal section of slab / triangular section of slab or both from one side or two sides.
• From Wall, if any
• Self-weight of rib of Beam

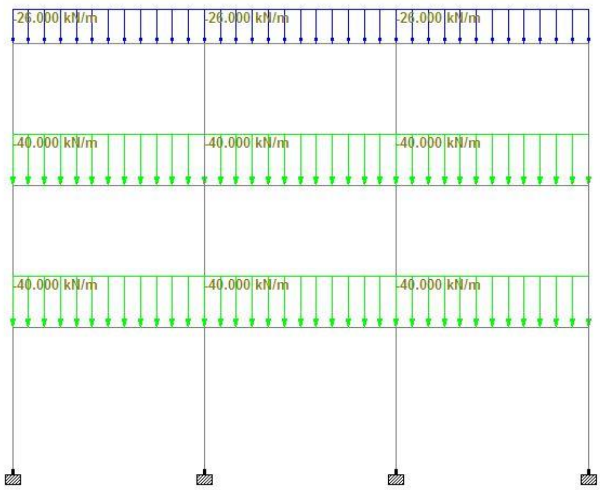
Load distribution from the slab is in accordance with the Yield line theory.
Elastic analysis deals with the study of strength and behavior of the members and structure at working loads. Frames can be analyzed by various methods.

Assumptions

Relation between force and displacement is linear. (i.e. Hook's law is applicable).
Displacements are extremely small compared to the geometry of the structure in the sense that they do not affect the analysis.



LOAD CARRIED BY SUPPORTING BEAMS



2.3.1. Moments due to Gravity Forces

Beam moments

Table 8: Beam moments

MEMBER	MOMENT (KN m)	MEMBER	MOMENT (KN m)
AB	-21.29	IJ	-38.94
BA	39.8	JI	59.91
BC	-36.39	JK	-55.11
CB	36.33	KJ	55.02
CD	-39.76	KL	-60.01
DC	21.43	LK	38.83
EF	-41.62		
FE	59.29		
FG	-54.625		
GF	54.55		
GH	-59.37		
HG	41.535		

Column moments

Table 9: Column moments

MEMBER	MOMENT (KN m)	MEMBER	MOMENT (KN m)
AE	21.42	GK	2.24
EA	20.46	KG	1.715
BF	-3.31	HL	-21.11
FB	-2.54	LH	-22.7
CG	3.305	IM	16.16
GC	2.53	MI	8.09
DH	-21.41	JN	-2.14
HD	-20.47	NJ	-1.06
EI	21.09	KO	2.12
IE	22.67	OK	1.07
FJ	-2.24	LP	-16.2
JF	-2.72	PL	-8.09

Observations

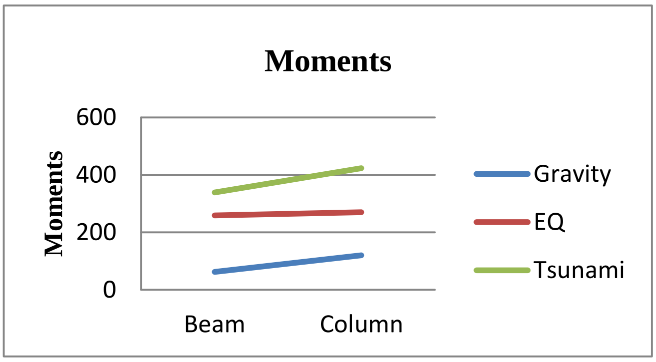
Moment

From the observed moments considering critical sections of beam and columns for different type of loadings are compared

Table10: Moments

Force	Beam (KNM)	Column (KNM)
Gravity	62.62	120
Earthquake	258.525	269.73
Tsunami	338.75	423.435

Representation of moments through graphs

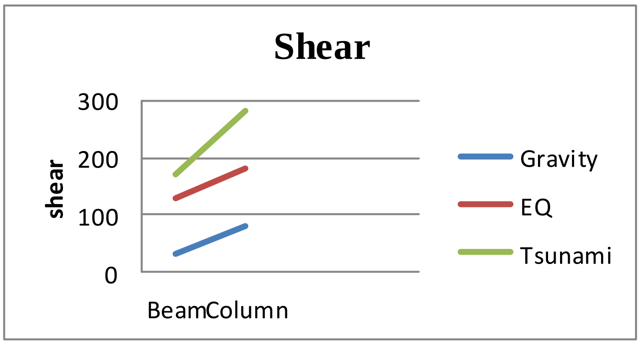


Shear

Table 11: Shear

Force	Beam (KN)	Column (KN)
Gravity	31.31	80
Earthquake	129.26	179.82
Tsunami	169.375	282.29

Representation of beam and column shear



3. Design of beam and column

3.1. Tsunami

Column

Table 12: Column

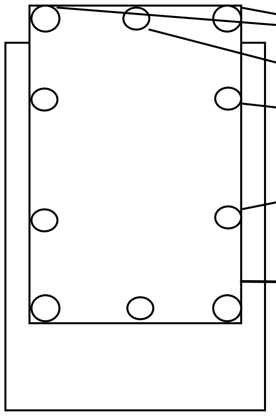
Size	0.3*0.6
Cover	50 mm
Axial load	600 KN
Moment	423.435 KNM
f_{ck}	25
f_y	415
D	0.6
$\frac{P_U}{f_{ck}bd}$	0.13
$\frac{M_U}{f_{ck}bd^2}$	0.15
$\frac{d'}{D}$	0.10

From sp16 chart 45

$$\frac{p}{f_{ck}} = 0.10$$

$$A_{st} = \frac{p*b*d}{100} = 4500\ mm^2$$

Provide 4 bars of 25 mm dia at corners of column, and 6 bars of 22 mm dia



Beam

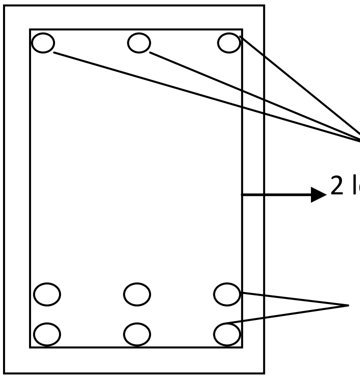
Table 13: Beam

Size	0.3*0.65
Cover	50 mm
Shear	169.375 KN
Moment	338.75 KNM
f_{ck}	25
f_y	415
D	0.6

$M_U = 0.87 * f_y * A_{st} * d * (1 - \frac{A_{st} f_y}{b * d * f_{ck}})$

$A_{st} = 1894\ mm^2$

Provide 6 bars of 22 mm dia



3.2. EARTHQUAKE

Beam

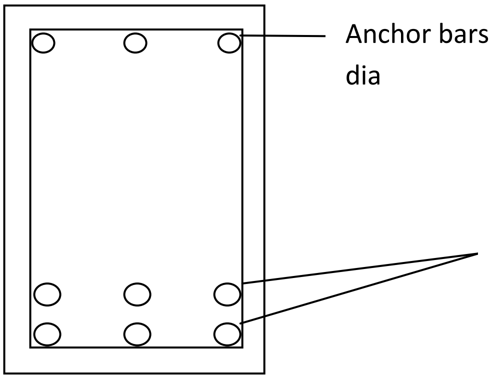
Table 14: Beam

Size	0.3*0.55
Cover	50 mm
Shear	129.26 KN
Moment	258.525 KNM
f_{ck}	25
f_y	415
D	0.50

$M_U = 0.87 * f_y * A_{st} * d * (1 - \frac{A_{st} f_y}{b * d * f_{ck}})$

$A_{st} = 1785\ mm^2$

Provide 6 bars of 20 mm dia and 2 legged 10mm dia stirrups



Column:

Table 15: Column

Size	0.3*0.5
Cover	50 mm

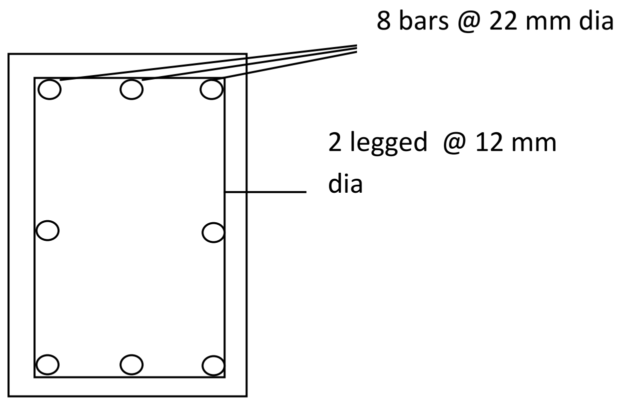
Axial load	600 KN
Moment	269.73 KNM
f_{ck}	25
f_y	415
D	0.5
$\frac{P_U}{f_{ck}bd}$	0.16
$\frac{M_U}{f_{ck}bd^2}$	0.14
$\frac{d'}{D}$	0.1

From sp16 chart 45

$\frac{p}{f_{ck}} = 0.08$

$A_{st} = \frac{p*b*d}{100}$=3000 mm^2

Provide 8 bars of 22 mm dia



3.3. Gravity

Beam

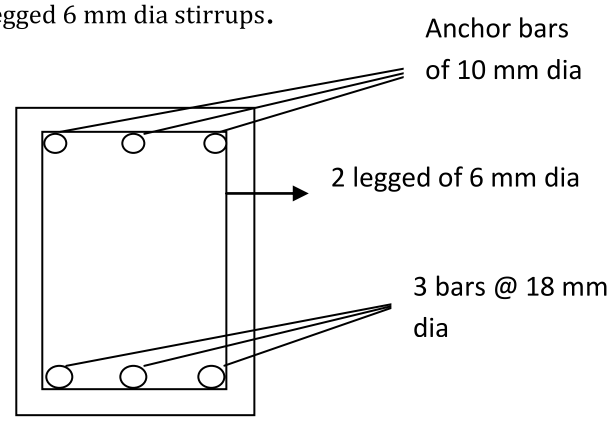
Table 16: Beam

Size	0.23*0.35
Cover	50 mm
Shear	31 KN
Moment	62.62 KNM
f_{ck}	25
f_y	415
D	0.3

$M_U = 0.87*f_y * A_{st} * d * (1 - \frac{A_{st}f_y}{b*d*f_{ck}})$

$A_{st} = 700\ mm^2$

Provide 3 bars @ 18 mm diameter in tension face and two legged 6 mm dia stirrups.



COLUMN DESIGN

Gravity loaded column design

Table 17: Column

Size	0.23*0.45
Cover	50 mm
Axial load	600 KN

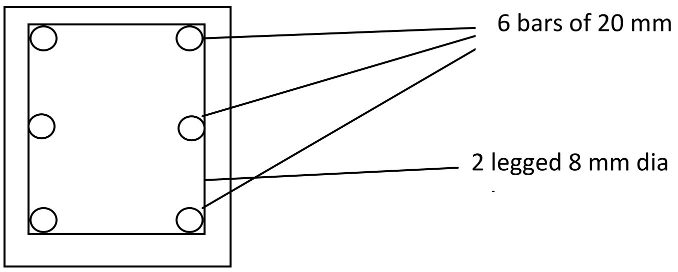
Moment	120 KNM
f_{ck}	25
f_y	415
D	0.45
$\frac{P_U}{f_{ck}bd}$	0.19
$\frac{M_U}{f_{ck}bd^2}$	0.10
$\frac{d'}{D}$	0.1

From sp16 chart 45

$$\frac{p}{f_{ck}} = 0.06$$

$$A_{st} = \frac{p*b*d}{100} = 1552.5\ mm^2$$

Provide 6 bars of 20 mm dia



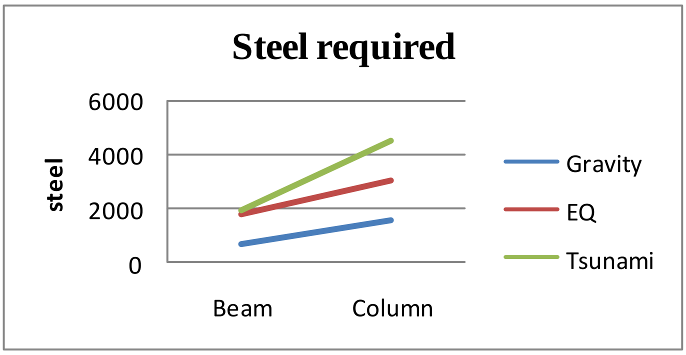
Results

Table 18: Result

Force	Beam dimension (mm)	Column dimension (mm)	Area of steel for beam(sq mm)	Area of steel for column (sq mm)
Gravity	0.23*0.35	0.23*0.45	700	1552.5
E.Q	0.3*0.5	0.3*0.5	1785	3000
Tsunami	0.3*0.6	0.3*0.6	1894	4500

Representation of results through graphs

Area of steel vs. Type of load for beams and column



4. Conclusions

- Steel required for tsunami resistant column is 50% higher than the steel required for earth quake resistant column
- When Earthquake is compared with Gravity it is 93.23% higher
- Steel required for tsunami resistant beam is 6.1% higher than the steel required for earth quake resistant column
- When Earthquake resistant beam is compared with Gravity it is higher
- A building configuration can be so arranged that the tsunami waves pass through the openings and by the breaking the facade or non structural walls, mostly at lower floor levels, while the structural elements like column, beam, shear wall and foundation are designed to withstand the waves.
- Awareness about tsunamis and their impact on coastal structures has to be created among the public, field engineers, scientists and administrators. Early warning systems are necessary to establish at various locations along the coast.

5. NOTATIONS

- FEMA: Federal Emergency Management Association
- L-Distance of location of structure from shoreline
- R-Maximum run-up height of tsunami above shoreline
- Z-Height of location point of the structure above shore line
- h max- Maximum inundation depth above base of the structure
- U-Tsunami wave velocity approaching the structure
- ρ- Mass density of seawater (1025kg/m3)
- b- Breadth of exposed column/wall
- Q_i=Design lateral force at floor i

- w_i = seismic weight of floor i
- h_i= height of floor i measured from the base
- n = number of storey's in the building

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