Experimental Study on Tuned Liquid Damper and Column Tuned Liquid Damper on a Framed Structural Model

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Abstract - The goal of this study is to examine the Tuned Liquid Damper (TLD) and Column Tuned Liquid Damper (CTLD), which are based on the movement of liquid in a rigid tank to change a structure's dynamic properties and lessen vibration energy during seismic excitation. A three-storey structure was created for this purpose and put through vibration tests. TLD and CTLD is install at top floor separately for different frequencies. A TLD and CTLD, is a device that employs water restrained in a container that is usually placed on top of a building to limit the displacement of the system when it is subjected to excitation. On a scaled model of the structure with TLD and CTLD, several experimental observations are made to assess their operation when subjected to seismic excitation. Using controlled uniaxial shake table testing, a rectangular-shaped TLD and CTLD with varying mass ratios are evaluated over various frequencies. Based on the structure's response reduction, TLD and CTLD effectiveness are assessed. The experiment's sensor, an accelerometer, measures the structure's acceleration in the presence and absence of a TLD and a CTLD while it is subjected to vibrations.

Key words: Seismic excitation, tuned liquid damper, Tuned liquid column damper, Energy dissipation, Mass Ratio.

1. INTRODUCTION

The demand for taller, lighter, more flexible constructions with relatively low damping values has increased in recent years. All tall and narrow structures, including chimneys, skyscrapers, high-rise buildings, cable structures, telecommunication towers, etc., are characterized by having a relatively low natural frequency as well as a low structural damping. This will increase the likelihood of failure and, in addition, cause issues with serviceability. As a result, dynamic stresses such as wind loads and seismic loads. The dynamical response of a Framed structure is a characteristic of structural damping and the magnitude and frequency of the implemented load. Thus, to reduce the dynamic response of the Framed structure, one must either to adjust the loading or increase the damping.[1]

Today there are several techniques available for minimizing structural vibrations, a recent one being the concept of using Tuned Liquid Damper (TLD). This study was conducted to investigate the effectiveness of using TLDs and CTLDs to control the vibration of structures. It seems to be the most accepted means of increasing damping in high-rise buildings, chimneys, cables, telecom towers, skyscrapers, etc, by installing Tuned Mass Dampers (TMD). However, over the last 10-20 years, Tuned Liquid Dampers (TLDs) have grown in popularity and are now widely available. Its popularity is easy to understand given the simplicity of a TLD, which is essentially nothing more than a partially filled water tank.Obviously, such a device requires very little maintenance compared to TMD. The popularity of TLDs seems to be limited by the fact that their description is much more complex than a simple spring-mass system like a TMD, making them difficult to design and just as important, unpredictable from a design point of view.[9]

A TLD (Tuned Liquid Damper) is a passive control device, usually placed on a structure, that dissipates applied excitation energy through liquid boundary layer friction, waves, and free surface contamination.[6] If the TLCD is perfectly tuned, by controlling the opening ratio, one could easily obtain a satisfactory performance from the TLCD.[2] To design an efficient TLD, it is crucial to use an appropriate model to illustrate the fluid behavior and to know the optimal TLD parameters.

2. LITERATURE REVIEW

Fahim Sadek and et al. (1997) The objective of this study was to work out the design parameters for tuned liquid column dampers (TLCDs) for seismic applications. [3]

S.D.Xue. and et al. (1999) A precise experimental study has been performed to analyze the effectiveness and overall performance of Tuned liquid column damper in suppressing pitching vibration of structures.[4]

Y. K. Ju and et al. (2004) The characteristics of a TLD with wire screens and little blocks connected to the wall are evaluated in this study, and an equation is proposed for the equivalent damping ratio of the TLD.[5]

Emili and et al. (2013) This present study targeted at implementation of a TLD for mitigation of structural response.[6]

Jitaditya Mondal and et al. (2014) They had done the experimental setup models a building using polymer beams and trusses and makes use of moveable base, powered by a motor, to simulate an earthquake.[7]

Namrata Yannawar and G.R.Patil (2014) In this study, a water tank was constructed to act as a tuned liquid damper.[8]

3. PROBLEM STATEMENT

A model of a G + 3 storey frame structure attached with the TLD and CTLD has been considered and is to be analysed to determine optimal parameters of TLD and CTLD in the structure for reducing the maximum displacements of the structure under harmonic sinusoidal ground motion. The optimal parameters of TLD and CTLD were found out by considering different combinations of the parameters which were verified by carrying out shake table analysis of an actual model attached with TLD and CTLD.

4. METHODOLOGY

Determine the natural frequency of the framed model with TLD and CTLD attached on top floor center, then do its FFT (Fast Fourier Transform) to get the Natural Frequencies of the framed structural model, got the natural frequency as 1.2 Hz, 4 Hz and 6 Hz. Damper is attached to the top floor center and then change the water level according to mass ratio(%). Mass ratio(%) for TLD is taken as 5%, 10%, 15%, 20%, 25%, 30%, 40%, 50%, 60%, 70%, 75% and 80%. Mass ratio(%) for CTLD is taken as 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, and 55%. Then the Base of the structure i.e. shake table is set up as: Amplitude = 5 mm, frequency = 1.2 Hz and no. of cycles = 15. And harmonic sinusoidal motion is applied. For each Mass ratio, structure's maximum displacement is recorded. Then same procedure is repeated for Damper for Amplitude = 5 mm, frequency = 4 Hz, and no. of cycles = 40.

5. FRAMED MODAL AND DAMPERS DESCRIPTION

Table-1: Framed Model and Damper Description

FRAMED G+3 MODEL DESCRIPTION	
Type of the Structure	Multi-storey rigid jointed plane frame
Number of Storeys	Three, (G + 3)
Material	Plywood and Aluminium
Slab Descriptions	Plywood (Dimensions: Length= 360 mm, Width = 260mm, Thickness = 12mm, Density = 8.458 KN/m^3)
Column Descriptions	Aluminum (Dimensions: Width = 19 mm, Thickness = 2 mm, Floor to Floor Height = 400 mm)
Weight	3500 gm
TUNED LIQUID DAMPER(TLD) DESCRIPTION	
Material	Acrylic
Damper Descriptions	(Interior Dimensions: Length = 200 mm, Width = 140 mm, Height = 180 mm, Thickness of acrylic sheet = 3mm)
Weight	846 gm
COLUMN TUNED LIQUID DAMPER(CTLD) DESCRIPTION	
Material	Acrylic
Damper Descriptions	(Interior Dimensions: Length = 200 mm, Width = 14 mm, Height of Bottom Channel = 40 mm, total Height = 18 mm, Width of Vertical Column = 40 mm Each, Thickness of acrylic sheet = 3 mm)
Weight	775 gm

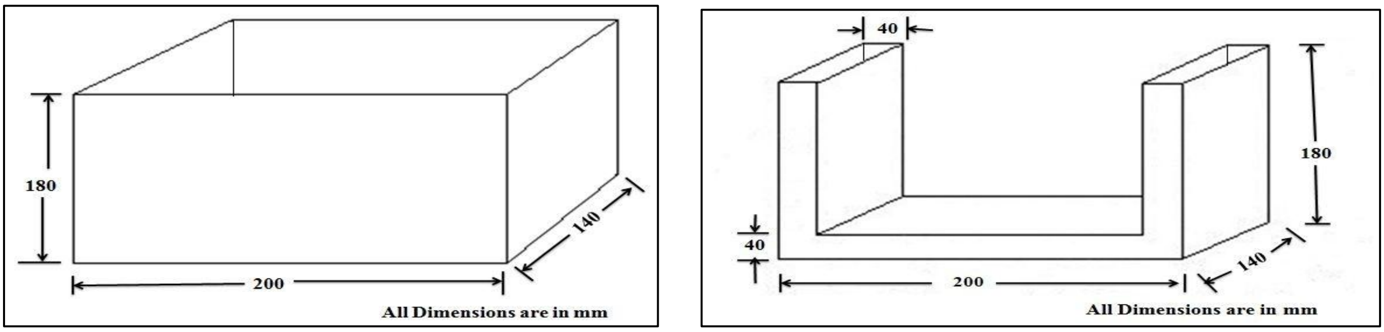

Fig -1: Dimensions of TLD

Fig -2: Dimensions of CTLD

7. EXPERIMENTAL ANALYSIS USING SHAKE TABLE

7.1 Free Vibration Analysis of the Framed Model with TLD and CTLD

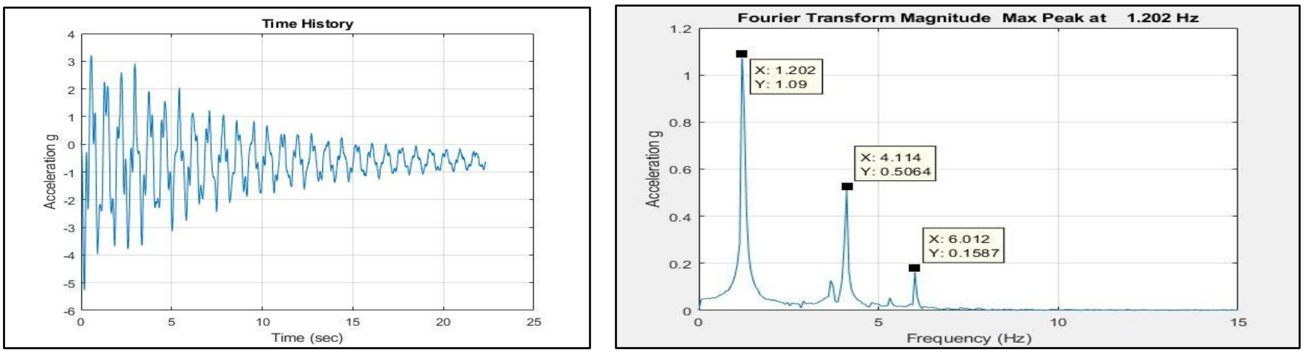

Fig -3: Time Response and Natural Frequency of TLD for Free Vibration

8. RESULTS AND DISCUSSION

When 1.2 Hz frequency is considered, Accelerometer is attached at the top i.e top displacement is measured.

When 4 Hz frequency is considered, Accelerometer is attached at the 2^{nd} floor when TLD/CTLD is attached on Top floor.

η = Efficiency, Mr = Mass Ratio, $\eta = \frac{\text{Displacement for No Damping} - \text{Displacement for nth Mass Ratio}}{\text{Displacement for No Damping}} \times 100$, $Mr = \frac{\text{Mass of Water}}{\text{Mass of Structure}} \times 100$

8.1 Maximum Displacement when TLD at 1.2 Hz Frequency

Table-2: Maximum Displacement for Varying Mass Ratio when TLD at 1.2 Hz Frequency

Sr. No.	Mr (%)	Hs (mm)	When TLD is at TOP Floor	
			Ymax (mm)	η (%)
1	0	0	43.32	0
2	5	8	28.69	33.77
3	10	16	16.38	62.19
4	15	24	14.34	66.9
5	20	32	14.33	66.92
6	25	40	14.24	67.13
7	30	48	13.49	68.86

8	40	64	11.97	72.37
9	50	80	12.17	71.91
10	60	96	11.18	74.19
11	70	112	9.704	77.6
12	75	120	8.637	80.06
13	80	128	9.867	77.22

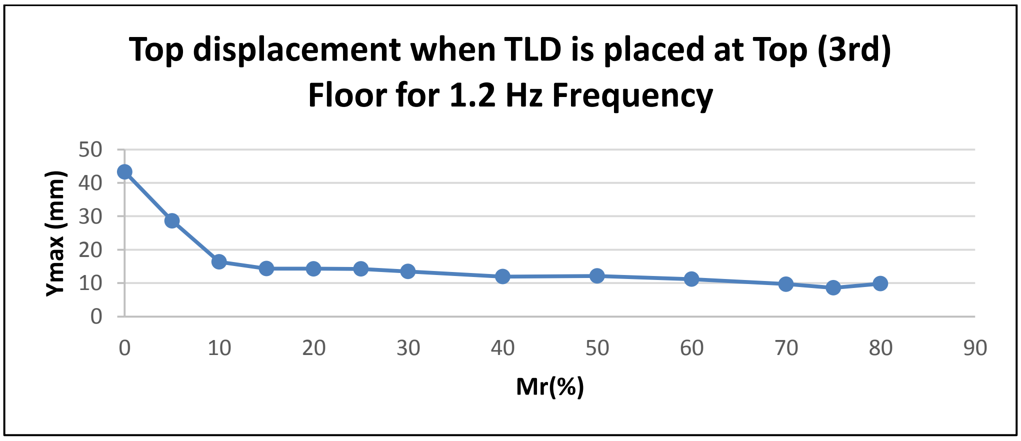

Chart -1: Maximum Displacement for Varying Mass Ratio when TLD at 1.2 Hz Frequency

8.2 Maximum Displacement when TLD at 4 Hz Frequency

Table-3: Maximum Displacement for Varying Mass Ratio when TLD at 4 Hz Frequency

Sr. No.	Mr (%)	Hs (mm)	When TLD is at TOP Floor	
			Ymax (mm)	η (%)
1	0	0	15.15	0
2	5	8	14.19	6.34
3	10	16	14.5	4.29
4	15	24	12.98	14.32
5	20	32	12.51	17.43
6	25	40	11.93	21.25
7	30	48	11.65	23.1
8	40	64	11.43	24.55
9	50	80	11.92	21.32
10	60	96	12.47	17.69
11	70	112	12.59	16.9
12	75	120	12.73	15.97
13	80	128	12.31	18.74

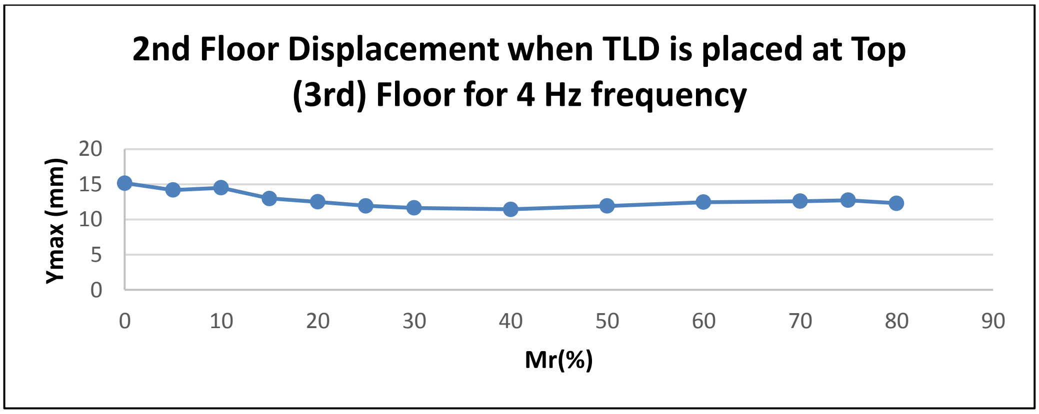

Chart -2: Maximum Displacement for Varying Mass Ratio when TLD at 4 Hz Frequency

8.3 Maximum Displacement when CTLD at 1.2 Hz Frequency

Table-4: Maximum Displacement for Varying Mass Ratio when CTLD at 1.2 Hz Frequency

Sr. No.	Mr (%)	Hs (mm)	When CTLD is at TOP Floor	
			Ymax (mm)	η (%)
1	0	0	35.14	0
2	5	7.5	27.51	21.71
3	10	15	18.32	47.87
4	15	22.5	15.11	57.0
5	20	30	12.82	63.52
6	25	37.5	13.63	61.21
7	30	52.5	13.25	62.29
8	35	71.25	12.26	65.11
9	40	90	12.35	64.85
10	45	108.75	10.52	70.06
11	50	127.5	10.62	69.78
12	55	146.25	11.09	68.44

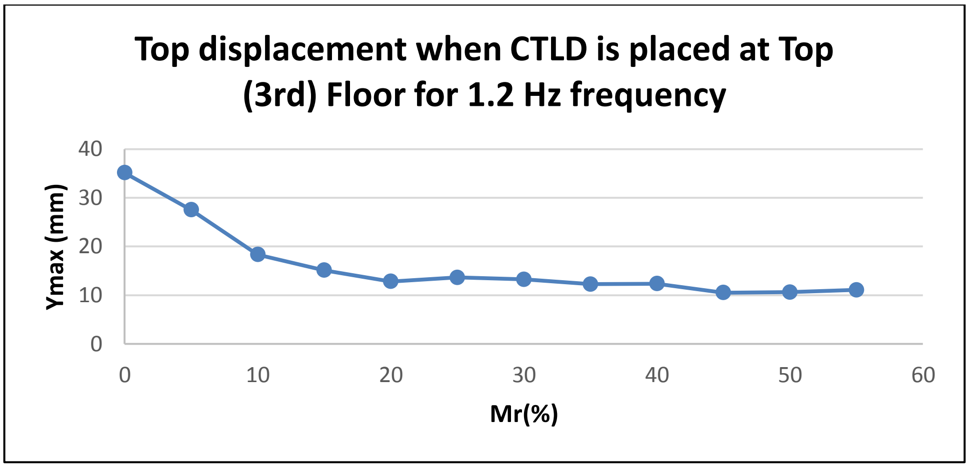

Chart -3: Maximum Displacement for Varying Mass Ratio when CTLD at 1.2 Hz Frequency

8.4 Maximum Displacement when CTLD at 4 Hz Frequency

Table-5: Maximum Displacement for Varying Mass Ratio when CTLD at 4 Hz Frequency

Sr. No.	Mr (%)	Hs (mm)	When CTLD is at TOP Floor	
			Ymax (mm)	η (%)
1	0	0	15.18	0
2	5	7.5	14.47	4.68
3	10	15	13.84	8.83
4	15	22.5	12.9	15.02
5	20	30	12.48	17.79
6	25	37.5	12.39	18.38
7	30	52.5	11.54	23.98
8	35	71.25	12.38	18.45
9	40	90	12.83	15.48
10	45	108.75	12.93	14.82
11	50	127.5	13.55	10.74
12	55	146.25	13.53	10.87

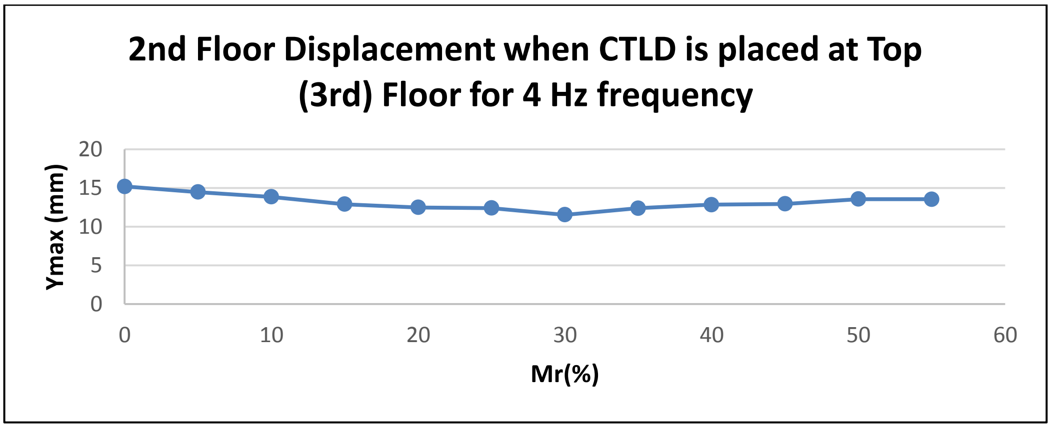

Chart -4: Maximum Displacement for Varying Mass Ratio when CTLD at 4 Hz Frequency

8.9 Comparison Between TLD and CTLD on Top Floor for 1.2 Hz Frequency

Table-6: Comparison Between TLD and CTLD on Top Floor for 1.2 Hz Frequency

Sr. No.	Mr (%)	Displacement when TLD is at Top Floor (mm)	Displacement when CTLD is at Top Floor (mm)
1	0	43.32	35.14
2	5	28.69	27.51
3	10	16.38	18.32
4	15	14.34	15.11
5	20	14.33	12.82
6	25	14.24	13.63

7	30	13.49	13.25
8	40	11.97	12.35
9	50	12.17	10.62

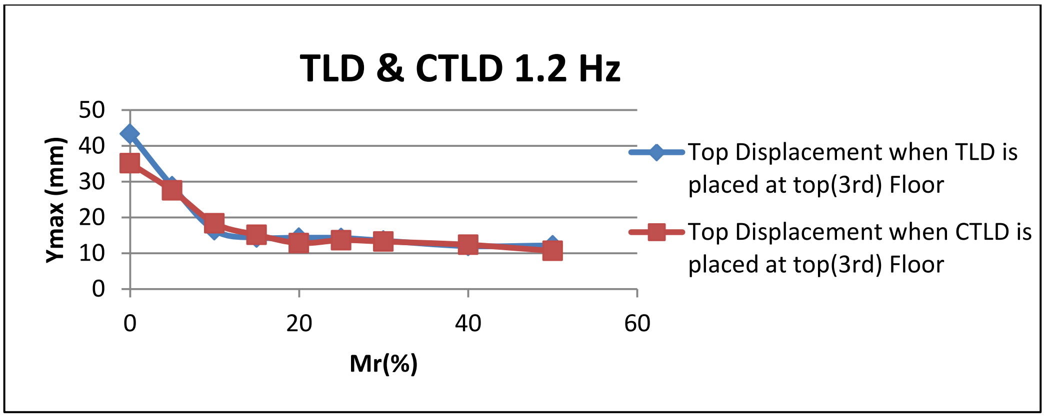

Chart -5: Comparison Between TLD and CTLD on Top Floor for 1.2 Hz Frequency

8.10 Comparison Between TLD and CTLD on Top Floor for 4 Hz Frequency

Table-7: Comparison Between TLD and CTLD on Top Floor for 4 Hz Frequency

Sr. No.	Mr (%)	Displacement when TLD is at Top Floor (mm)	Displacement when CTLD is at Top Floor (mm)
1	0	15.15	15.18
2	5	14.19	14.47
3	10	14.5	13.84
4	15	12.98	12.9
5	20	12.51	12.48
6	25	11.93	12.39
7	30	11.65	11.54
8	40	11.43	12.83
9	50	11.92	13.55

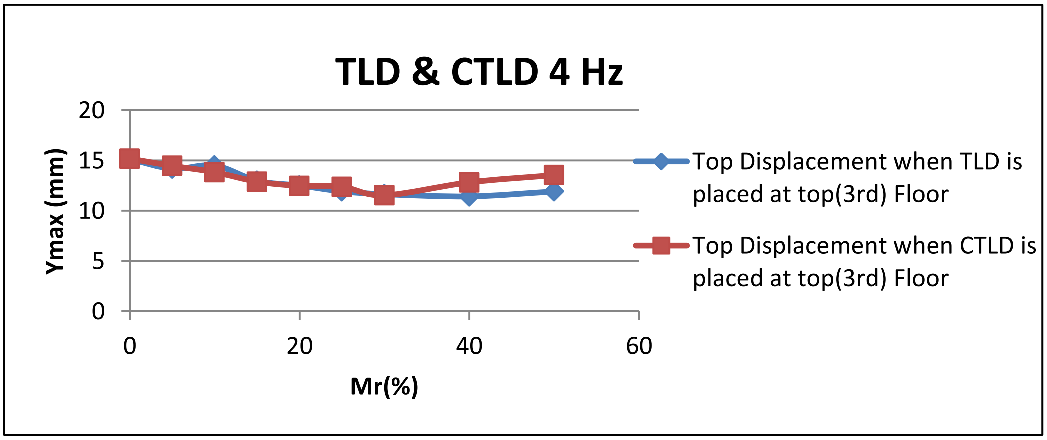

Chart -6: Comparison Between TLD and CTLD on Top Floor for 4 Hz Frequency

9. CONCLUSION

1) Experimental analysis showed that TLDs and CTLDs can effectively reduce a structure's response to earthquakes.

2) It has been found that for 1.2 Hz frequency the effect of TLD increases with an increase in mass ratio. The mass ratio for the TLD design has been found to be optimal when it is around 15% after that the decrease in displacement is very less. The efficiency of TLD is found to be around 67% for 15% Mass Ratio.

3) For 4 Hz frequency the displacement is already very less so there is not much considerable difference of TLD when mass ratio is increased.

4) It has been found that for 1.2 Hz frequency the effect of CTLD increases with an increase in mass ratio. The mass ratio for the CTLD design has been found to be optimal when it is around 15% after that the decrease in displacement is very less. The efficiency of CTLD is found to be around 57% for 15% Mass Ratio.

5) On comparing the displacement values of TLD and CTLD for optimal position i.e top center it has been found CTLD is acting slightly better in reducing the vibration excitation than TLD.

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