

Static Strength Analysis of a Tubular K- Joint of an Offshore Jacket Structure

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Abstract: Offshore construction is the installation of structures in marine environment for the production and transmission of electricity, oil, gas etc. These structures provide a safe working environment for the people and equipments operating on it. Jacket structure is a type of offshore structure. The substructure of a jacket structure is called a jacket, a three dimensional frame made up of tubular members. In tubular frame the intersection between two members is called tubular connection. So the analysis of various types of tubular joints is relevant for offshore structures. This paper investigates the static strength analysis of tubular K type joint using ANSYS software. Finite element model is created and analysis is done by applying different loading cases. For each loading case, deflection and stresses corresponding to different load values are tabulated. From the maximum stress value, the load at which the joint yielded is obtained. For axial tensile and compressive loading joint yielded at a load of 7KN, for in plane bending and out plane bending, the joint yielded at a moment of 0.38KNm and 0.17KNm respectively. Parametric study is done by changing the chord thickness, analysis is done and maximum stress and deformations are obtained. It is concluded that the, as the thickness increases, the stress values and deformation decreases.

Keywords: tubular joint, jacket structure, braces, chord, static strength

1. Introduction

To optimize the cost and risks of installing large offshore platforms, different construction strategies have been developed. One strategy is to fully construct the offshore facility onshore and tow the installation to site floating on its own buoyancy. The size of offshore drills can be reduced by making the construction modular, with each module being constructed onshore and lifted using a crane vessel into place onto the platform. Offshore structures are located in depths from very shallow water to deep oceans. Offshore jacket structures are composed of Circular Hollow Sections (CHS) called tubulars. Tubular or CHS are used for jacket structures due to the capability in resisting various forces. Also, they have good buoyancy to weight ratio, good resistance against hydrostatic pressure, Uniform property across the cross section etc. It is recommended in API that the material used for tubular construction is steel with yield stress is typically ranging from 250MPa to 400MPa. The intersection of one or more branch members to the main member form the tubular joints.

There are different types of offshore structures, jacket structure is one among them. The substructure of a jacket structure is called jacket, which is a three dimensional space frame made up of tubular members. For the construction of jacket structures, it is necessary to join the tubular members at some points. These joints are called tubular joints. The main member of the tubular joint is called chord, and the secondary member is called brace. The tubular joints are of different configurations, based on the shape of joints. They are represented by different alphabetical letters such as T joint, K-joint, Y joint, X joint, YT joint, KT joint, DT joint (Double T joint), DY joint (Double Y joint), DK joint (Double K joint), XDT joint, DYDT joint (Double Y Double T joint), DKDT

(Double K double T joint). In the present study an attempt is made to investigate the static strength of tubular K- joint by applying various loads. ANSYS 15 is used for the modeling and analysis of the tubular K- joint as shown in Figure 1.

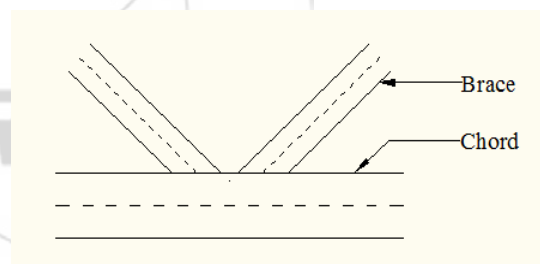


Figure 1: Tubular K joint

2. Modeling of Tubular Joint

2.1 Geometric Model

For the modeling of Tubular K joint in ANSYS WORKBENCH 15 the engineering data is assigned as shown in Table 1. The geometric model is shown in Figure.2. The detailed dimension of the geometric model is shown in Table 2

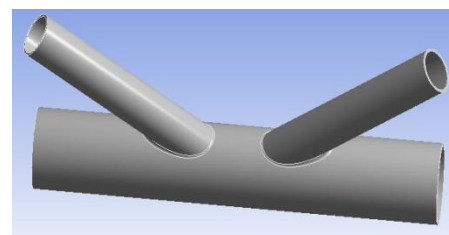


Figure 2: Geometric model before meshing

After creating the geometric model, meshing is done using the meshing tool.

Table 1: Engineering data

Engineering data	Specifications
Materials used	Mild steel
Modulus of elasticity	$2 \times 10^5 \text{ N/mm}^2$
Poisson's ratio	0.3
Yield stress	250 N/mm^2

Table 2: Geometric dimensions

Geometric Parameter	Chord	Brace
Diameter	76.2 mm	42.5mm
Length	440 mm	200mm
Thickness	2mm	2mm

Chord and brace thickness of actual model is 2mm. Chord thickness is varied to 4mm, 5mm, 6mm, 7mm and 8mm for parametric analysis.

2.2 Boundary Conditions

The two ends of the chords are held fixed.

2.3 Load assigning

Four different loading cases are assigned. Tension, compression, In-plane moment and Out-plane moment. For each loading case, different load values are given.

2.3.1 Axial Tensile loading:

In axial tensile loading shown in Figure 3, load is given in the upward direction on the two free ends of the braces. Force is given as remote force, so that it can uniformly distributed along the brace, it is applied gradually and corresponding stress values and deflections can be obtained. The safe load was obtained from the yield point. In this loading case failure occurs at chord near the joint.

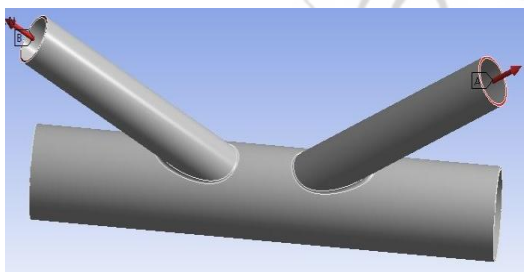


Figure 3: Axial Tensile force

2.3.2 Axial compression loading:

In axial compression loading as shown in Figure 4, load is given in the downward direction on the two free ends of the braces. Force is given as remote force, so that it can uniformly distributed along the brace, it is applied gradually and corresponding stress values and deflections can be obtained. The safe load was obtained from the yield point. In this loading case, failure occurs at chord near the joint.

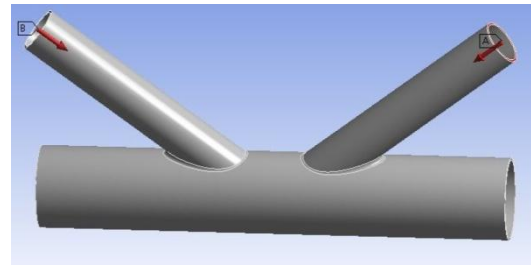


Figure 4: Axial Compressive force

2.3.3 In-plane bending

In this case also, two ends of the chord are fixed and the ends of the braces are free. The two ends of each braces are considered for load application as shown in Figure 5, the loads applied in the opposite direction on the two ends of the braces forming a couple, the distance between the forces will be equal to the diameter of the braces. In this case, while applying force couple formed and deflection will be parallel to the chord. Maximum stresses and deformations are obtained.

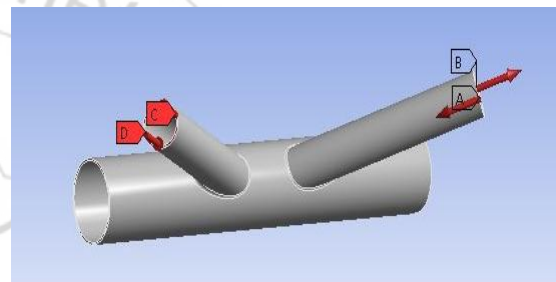


Figure 5: In plane bending

2.3.4 Out-plane bending

In this case also, the same procedure as that of the in-plane bending is adopted, but the points where the direction of load applications are different as shown in Figure 6. The loads are applied in the opposite direction on the two ends of the braces forming a couple, the distance between the forces will be equal to the diameter of the braces. In this case, while applying force couple formed and deflection will be perpendicular to the chord. Maximum stresses and deformations are obtained.

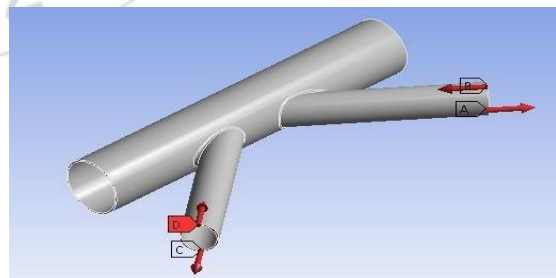


Figure 6: Out plane bending

3. Analysis Using ANSYS

3.1 Maximum stresses and deformation

Various loading cases are applied, and the stresses and deformations corresponding to various loads are obtained.

3.1.1 Axial tensile force

Various load values are given, and the yield occurs at a load of 7KN. The corresponding stress values and deflections are shown in Figure 7 and Figure 8.

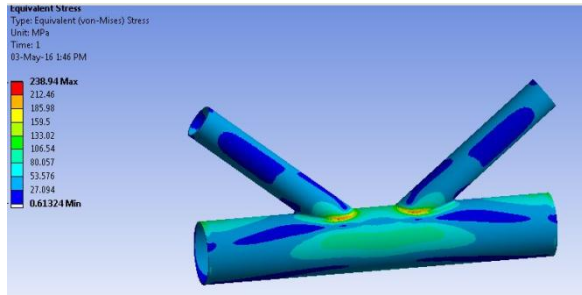


Figure 7: Equivalent Stress

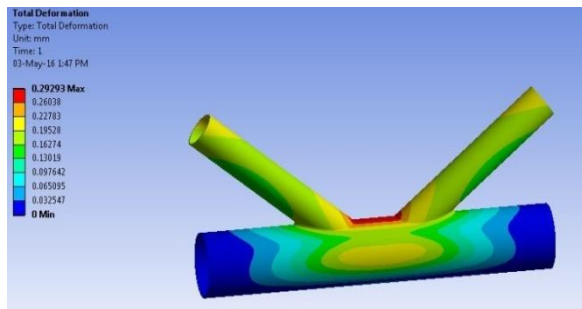


Figure 8: Maximum deformation

3.1.2 Axial compressive force:

Various load values are given, and the yield occurs at a load of 7KN.

3.1.3 In plane Bending force

Various load values are given, and the yield occurs at a load of 7.5KN, that is 0.3187KNm.

3.1.4 Out plane bending

Various load values are given, and the yield occurs at a load of 4KN, that is 0.17KNm.

3.2 Parametric Study

Parametric study is done for tubular K joints by varying the thickness of the chord. Geometry is varied by changing the thickness as 4mm, 5mm, 6mm, 7mm and 8mm, and corresponding stresses and deformations are obtained for tensile, compressive loading, in-plane bending, out plane bending.

4. Results and Discussion

From the output of ANSYS, various results are obtained. And these results are evaluated by preparing various tabular columns and graphs. It is to find the maximum load at which the joint can withstand, also to find the increase in capacity of joint when the chord thickness increases.

4.1 Load cases and yielding point

Various loading cases were applied separately in a Tubular K joint, and for each loading cases analysis is done by assigning different load values to obtain the load at which the joint is yielded. The joint is subjected to an axial tension, axial compression, in plane bending and out plane bending individually. And for each loading cases, load value is increased gradually and obtained that joint yielded at a tensile and compressive load of 7KN, and in plane bending moment and out plane bending moment of 0.318KNm and 0.170KNm respectively. The different loading cases and the load at which the joint is yielded is shown in Table 3.

Table 3: Load cases and yielding point

Loading case	Yielding point
Tension (KN)	7.0
Compression (KN)	7.0
In plane bending (KNm)	0.318
Out plane bending (KNm)	0.170

4.2 Maximum stresses values with increase in chord thickness

4.2.1 For Axial Tension and Axial compression

For axial tension and axial compression, as the chord thickness increases, the stresses values decreases. That is, the joint can withstand higher load, while the thickness goes on increasing. The maximum load which can withstand by the joint with the increase in thickness and the maximum stresses corresponding to each load values are given in Table 4.

Table 4: Maximum stress values and loads for varying chord thickness

Load (KN)	Maximum Stress in Mpa				
	4mm	5mm	6mm	7mm	8mm
13.0	250.18	206.61	175.46	149.52	145.4
15.0	288.67	238.4	202.46	172.52	168.03
16.0	307.92	254.09	215.96	184.02	179.23
18.0	346.41	286.08	242.95	207.03	201.64
19.0	365.65	301.97	256.45	218.53	212.84
20.0	384.90	317.86	269.94	230.03	223.69
21.0	404.14	333.76	283.44	241.53	235.24
22.0	423.39	349.65	296.94	253.03	246.94
23.0	442.63	365.54	310.44	264.53	251.24

From the above table, it is seen that the tubular K joint with 4mm thickness chord start yielding at a tensile load of 13KN, 5mm thickness chord start yielding at a tensile loading of 16KN, 6mm thickness chord start yielding at a tensile loading of 19KN, 7mm thickness chord start yielding at a tensile loading of 22KN and 8mm thickness starts yielding at a tensile loading of 23KN.

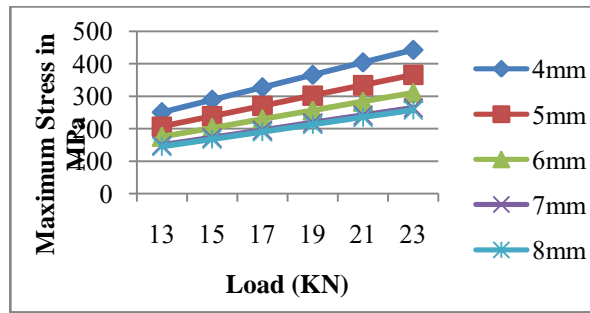


Figure 9: Maximum stress and load values for various thicknesses

From the graph, it is seen that there is a sharp decrease in stress values as the thickness increases from 4mm to 5mm. But increase in thickness from 7mm to 8mm causes a slight decrease in stress values.

4.2.2 For In Plane Bending

For in plane bending, as the chord thickness increases, the stresses values decreases. with the increase in thickness. The maximum stresses corresponding to each load values are given in table 5.

Table 5: Maximum stress values and loads for varying Chord thickness

Load (KN)	Maximum stresses in MPa				
	4mm	5mm	6mm	7mm	8mm
8	210.9	206.1	214.2	196.3	194.0
10	263.7	257.6	267.7	246.4	242.5
12	316.4	309.1	321.3	294.5	291.0
14	369.2	360.6	374.8	343.6	339.5
16	421.9	412.2	428.4	392.7	388.0
18	474.7	463.7	481.9	441.8	436.5

From the above table, it is seen that the joint with 3mm chord thickness starts yielding at an in-plane bending force of 9KN, 4mm thickness, 5mm thickness and 6mm thickness starts yielding at an in-plane bending force of 10KN, 7mm thickness and starts yielding at an in-plane bending force of 11KN. Also, it is seen that for all load values, as the thickness increases, stress values decreases and it suddenly increases for a thickness of 6mm and then decreases.

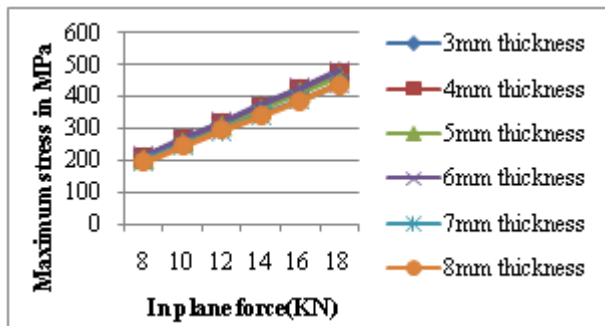


Figure 10: Maximum stress and deformation values for various thickness

From graph, it is seen that as the thickness increases, stress values decreases. But for thickness of 6mm, there is a sharp increase in stress values than 5mm thickness

4.2.3 For out plane bending

For out plane bending, as the chord thickness increases, the stresses values decreases. The maximum load which can withstand by the joint with the increase in thickness and the maximum stresses corresponding to each load values are given in Table 6.

Table 6: Maximum stress values and loads for varying chord thickness

Load (KN)	Maximum stress in MPa				
	4mm	5mm	6mm	7mm	8mm
6	182.2	146.5	117.9	97.9	84.85
8	242.9	195.4	157.2	130.6	113.1
10	303.7	244.2	196.5	163.3	141.4
12	364.4	293.1	235.8	196	169.7
14	425.1	341.9	275.1	228.6	198
16	485.9	390.7	314.4	261.3	226.2

From the above table, it is seen that the joint with 3mm chord thickness starts yielding at an out-plane bending force of 6KN, 4mm thickness starts yielding at an out-plane bending force of 9KN, 5mm thickness and starts yielding at an in-plane bending force of 11KN, 6mm thickness and starts yielding at an in-plane bending force of 13KN, 7mm thickness and starts yielding at an in-plane bending force of 15KN.

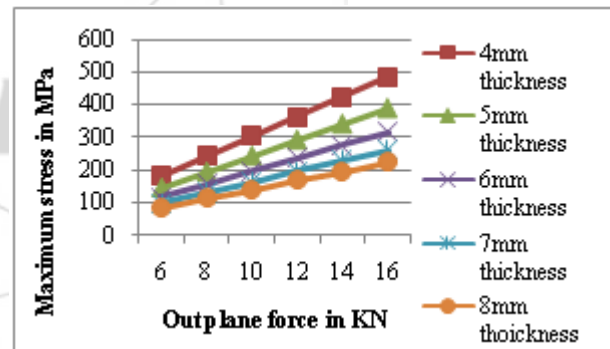


Figure 11: Maximum stress and deformation values for various thickness

From the graph it is seen that, there is a sharp decrease in stress values as the thickness increases from 3mm to 4mm, and the decrease in stress values are considerably less, when thickness increases from 7mm to 8mm

4.3 Maximum deformation with increase in chord thickness

4.3.1 Axial Tension and axial compression

For axial tension and axial compression, as the chord thickness increases, the deformation values decrease. The maximum load which can withstand by the joint with the increase in thickness and the maximum stresses corresponding to each load values are given in table 7.

Table 7: Maximum stress values and loads for varying chord thickness

Load (KN)	Maximum Deformation in mm				
	4mm	5mm	6mm	7mm	8mm
13.0	0.192	0.1552	0.1364	0.125	0.118
15.0	0.221	0.1791	0.1547	0.144	0.136
16.0	0.236	0.1911	0.1679	0.154	0.145
18.0	0.266	0.2149	0.1888	0.173	0.163
19.0	0.281	0.2269	0.1994	0.183	0.173
20.0	0.295	0.2388	0.2098	0.192	0.182
21.0	0.310	0.2508	0.2204	0.202	0.191
22.0	0.325	0.2627	0.2308	0.2119	0.200
23.0	0.339	0.2746	0.2413	0.221	0.209

From the above table it is seen that deformation values decreases, as the thickness increases.

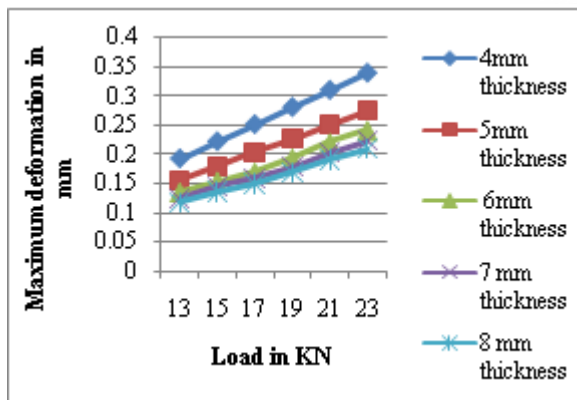


Figure 12: Maximum deformation and load values for various thickness

From the graph, it is seen that there is a sharp decrease in deformation values, as the thickness increases from 4mm to 5mm thickness, and the decrease in deformation values are considerably less, when increase in thickness from 7mm to 8mm.

4.3.2 In Plane Bending

For in plane bending also, as the chord thickness increases, the deformation values decrease. As the thickness increases it can withstand higher loads. The maximum load which can withstand by the joint with the increase in thickness and the maximum deformations corresponding to each load values are given in table 8.

Table 8: Maximum stress values and loads for varying chord thickness

In plane Force in KN	Maximum deformation in mm				
	4mm	5mm	6mm	7mm	8mm
8	0.540	0.489	0.457	0.436	0.421
10	0.675	0.611	0.512	0.545	0.526
12	0.810	0.734	0.686	0.654	0.632
14	0.945	0.856	0.801	0.703	0.737
16	1.080	0.978	0.915	0.872	0.842
18	1.215	1.101	1.103	0.981	0.948

From the above table it is seen that deformation values decreases, as the thickness increases. Also for in plane bending, when the thickness increases the stresses increases a thickness of 6mm (table 8), but the deformation reduces.

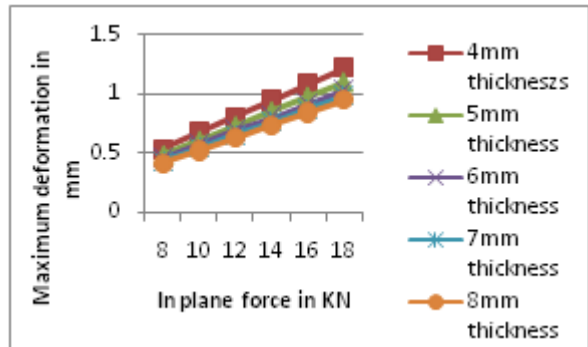


Figure 13: Maximum deformation and load values for various thickness

From the graph, it is seen that there is a sharp decrease in deformation values, as the thickness increases from 4mm to 5mm thickness, and the decrease in deformation values are considerably less, when increase in thickness from 7mm to 8mm.

4.3.3 Out Plane Bending

For out plane bending, as the chord thickness increases, the deformation values decrease. The maximum load which can withstand by the joint with the increase in thickness and the maximum deformations corresponding to each load values are given in table 9.

Table 9: Maximum stress values and loads for varying chord thickness

Out - plane Force in KN	Maximum deformation in mm				
	4mm	5mm	6mm	7mm	8mm
6	0.716	0.576	0.494	0.442	0.408
8	0.955	0.767	0.659	0.589	0.543
10	1.193	0.959	0.823	0.737	0.679
12	1.432	1.152	0.988	0.884	0.815
14	1.671	1.343	1.163	1.032	0.951
16	1.912	1.534	1.318	1.180	1.087

From the above table it is seen that deformation values decreases, as the thickness increases.

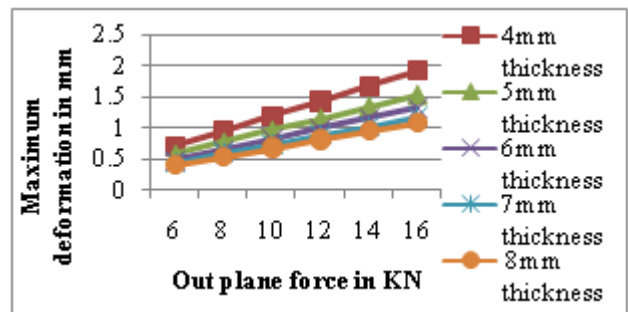


Figure 14: Maximum deformation and load values for various thickness

From the graph, it is seen that there is a sharp decrease in deformation values, as the thickness increases from 4mm to 5mm thickness.

5. Conclusions

The main conclusions obtained from the analysis of tubular K-joint are summarized below:

- 1) In all the four cases of loading, the stress is maximum at same part of joint parallel to chord length
- 2) For tension and compression cases of loading, the deformation is maximum at the gap between two braces
- 3) The yielding point for tensile loading is same as that of compressive loading
- 4) The in plane bending moment at which the joint is yielded is almost double as that of out plane bending moment
- 5) From the parametric study, it is obtained that, by increasing the chord thickness, there is tremendous decrease in stress values and deformation values
 - For tensile loading and compression loading- stress values decreases by 17%, 15%, 14.7% and 2%, from 4 to 5, 5 to 6, 6 to 7, 7 to 8mm.
 - For tensile and compressive loading- deformation values decreases by 19%, 12%, 8% and 5% with increase in thicknesses from 4 to 5, 5 to 6, 6 to 7, 7 to 8mm.
 - For out plane bending- stresses decreases by 28%, 19%, 16%, 13% and 10%, with increase in thicknesses from 3 to 4mm, 4 to 5, 5 to 6, 6 to 7, 7 to 8mm.
 - For in plane bending- stress values increases by 3.99%, with increase in thicknesses from 5mm to 6mm- then decreases
 - For in plane bending, deformation values decreases by 14%, 9.46%, 6.5%, 4.5%, 3.4%, with increase in thicknesses 3mm to 4mm, 4mm to 5mm, 5mm to 6mm, 6mm to 7mm and 7mm to 8mm.
- 6) Tubular K-joint is more effective in carrying the load with increase in chord thickness.
- 7) For the Out plane bending force condition, the joint starts yielding at a load of 4KN. So more consideration is to be given for this condition

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