BEHAVIOR ABOUT ANALYSIS OF STEEL WIND POWER TOWER

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Abstract- Recently, the rotor and blade is becoming enlarged with the effort for the increased efficiency. Wind power tower is becoming moreover enlarged by rotor and blade.But wind power tower is vulnerable to buckling. So need to make up for the weak point in steel wind power tower. On the study, it was using on MIDAS CIVIL 2009 for analysis of characteristic on steel wind power tower. For detailed analysis to suitable thickness, conducted research on this study strength a safety ratio 2. Also, determined whether to resonate through the 1 natural frequency analysis. And checked the stability of buckling about axial load.

Keywords- Steel Wind Power Tower, Strength A Safety Factor 2, Frequency of Vibration of Normal Mode, Stability of Buckling

I. INTRODUCTION

All countries of the world try to reduction of greenhouse gas from the climate change. so they have high interest to the renewable energy. And that is increasing expansion and investment. SouthKorea is not greenhouse gas reduction duty target country now. But which take possession rank 9 of the co2 emission 1.8% in the world. which is possible to greenhouse gas reduction duty target country most likely to get greenhouse gas reduction duty target in one of the country in the poster Tokyo protocol it is discussed to the reduction measures after 2013 years.

The wind power energy of among the renewable energy, it is unit cost is cheaper than other renewable energy. It is core energy possible to using to the efficient on the unit area. so it is displaying the high level growth every year.

Rotor and blade is becoming bigger size for the increased to power generation. And the tower is also becoming bigger size.Rotor and blades are becoming bigger size in efforts to increase the power generation amount. And the tower is also becoming bigger size.
The steel monopile is a high price in comparison with other type. but it don't damage an appearance. it is possible to moving to through the tower nacelle safely. so it is doing many uses. Steel is becoming the principal material. Because it is easy to fabrication, movement and establishment.

The method in which the wind power tower occupies the part which is abundant by 26.1% among the total wind power construction cost and promotes the electric power production instead of the new wind power construction by the change of the upper part turbine is preferred.Therefore, the stable height and diameter has to be determined for the life cycle so that the large-scale generator to cost of the tower of the calculation of the largest energy is able to make possible. Currently, the wind of the good quality is obtained due to the wind of speed which it increases as it becomes far on characteristic ground in the atmosphere. The tower more than 100m is used.

As to the wind power technology, because the foreign technology dependability is high such as Europe and several advanced country major company occupies 95% of the market share, the generalization of the technology can say as the necessary part.

Especially, in the case of the steel wind power tower, the local buckling is most likely to occur as it becomes bigger. Therefore, there is the defect that the profitability is decreased that the steel material cost increased continuously since the thickness of the steel pipe becomes thick by more than necessity in order to prevent this.

Therefore, on this study, the research for the economical section design analysis of the steel wind power tower is researched through the interpretation in order to supplement the defect of the existing the steel material tower.

II. WIND POWER TOWER

Wind power tower, supported to main component included to blade, hub and nacelle to upper side. Type of steel monopile tower is commercialized currently.

And it is fabricated to welding and bolting. Function of the tower is against to wind load, dead load and vibration from rotation of blade.

Role that tower to support the load received by the wind, and role of the passage for the power connections. the wind power tower is occupying to big portion among the total wind power construction cost.

Wind power tower itself have a high unit cost. So it is important to development to safety and economical tower.

2.1 The tower design method

2.1.1 Natural frequency analysis
Most of important thing is to avoid blade and resonance on that point, when it has Natural frequency design and analysis. For this reason, it needs to satisfyto Regulation being offered by GL formula (2.1) and formula (2.2).

when it have normal operating range state, in the formula(2.1), rotor rpm have to below the 95% on the Natural frequency of the tower. Formula (2.2), all of natural frequency in the tower means that it has to under the 5% on the blade frequency, when it consider to all of blade number.

$$\frac{f_R}{f_1} \leq 0.95 \quad (2.1)$$

$$\frac{f_{R,m}}{f_n} \leq 0.95 \text{ or } 1.05 \leq \frac{f_{R,m}}{f_n} \quad (2.2)$$

여기서, f_R = maximum frequency of rotor on operating
f_1= First natural frequency on the tower
$f_{R,m}$= pass frequency of blade from rotor m
f_n= n degree natural frequency on the tower

2.1.2 Analysis of design load
Design load to the tower come through to aero-elastic analysis. The procedure used to aero-elastic analysis where it finds the design load can refer to a GL procedure and IEC 61400-1.

Wind power take depend on design load cases, generator condition, malfunction of generator, starting condition, normal stop

2.1.3 Strength analysis
For the analysis of strength, in order to have enough safety rate, have to design on the composed to of all part about each ultimate strength.

The result through to strength analysis, have to satisfy with formula (2.3), formula (2.4) and formula (2.5).

The partial safety factor about the materialwhich presented in a GL regulation, <Table 2.1>.

$$F_d = \gamma_f F_k \quad (2.3)$$

$$f_d = \frac{f_k}{\gamma_m} \quad (2.4)$$

$$\gamma_f F_k \leq \frac{1}{\gamma_m} f_d \quad (2.5)$$

여기서, F_d= The design load value
γ_f= The design value about material about Load
F_k= The load value of a characteristic
f_d= The design value about material
γ_m= The partial safety factor about material
f_k = The characteristic about material property

TABLE 2.1 Partial safety factor for material

Material	Partial safety factors
Steel	1.1

2.1.4Analysis of the buckling stability
The column with wind power tower, need to checking about stability of buckling to axial load. Buckling stress limit, the shape of each section forming the tower, the thickness of the shell varies depending on the material, such as the tower diameter.

2.2.The selection of steel wind power tower
On this study the first model UNISON KBP-2000M U88 is designed during develop.

Wind power class is defined to wind velocity and turbulence parameter. Part of the wind class is applied to the most of wind condition ranges. And wind velocity and turbulence parameter is represented to characteristic value of many of area.

IEC-TC2A is designed wind power to experiment wind conditions Vref(=42.5m/s) and turbulence intensity (I_{ref}=0.18).in the wind class, Recurrence Period of 50 years in the hub location is under the wind of average 10 minute withstand environmental condition designed wind power.

<Table 2.3> is fundamental parameter to define to wind power class.
S355 of DIN standard is the material when it using the tower shells. And likely to <table 2.4> elastic modulus 210000Mpa, unit weight 7850kg/m^3, Poisson's ratio 0.3. <table 2.5> like to this material property.

In here, the yield strength of S355 is the value applied to the partial safety coefficient (γ_m=1.1) about steel material.

First steel wind power tower thickness is separated to 4 section according to S355 material of DIN standard.Assuming the same as the <table 2.6>, The side shape is the same as the <picture 3.1>

TABLE 2.2the initial model data value

Class Type	IEC-TC2A
Rated roter speed	15RPM
Roter diameter	88m

Hub height	80m
Top diameter	3m
Bottom diameter	4.2m
Tower shell mass	169,200kg
Top head mass	103,600kg

TABLE 2.3fundamental parameter of wind power class

Wind turbine Class	I	II	III	S
V_{ref}(m/s)	50	42.5	37.5	Values specified by the designer
V_{ave}(m/s)	10	8.5	7.5	
A	0.18			
B	0.16			

TABLE 2.4Steel materials

elastic modulus	210000Mpa
unit weight	7850kg/m^3
Poisson's ratio	0.3

TABLE 2.5 Material properties for S355

Material	Limit of yielding Strength(Mpa) (γ_m=1.1)		
Thickness	t≤16mm	16 < t≤40mm	40 < t≤63mm
S355	322.7	313.6	304.5

TABLE 2.6Selected to steel tower thickness

Height(m)	Tower thickness(m)
48~77	0.022
26~48	0.030
10~26	0.038
0~10	0.046

III. MODELING OF TOWER

3.1 Natural frequency analysis

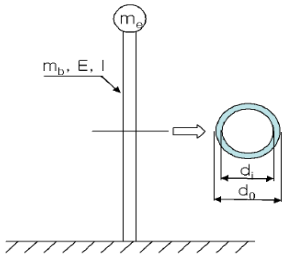
Actual wind power is lower than only tower's Natural frequency in the tower. it is made by the mass imposition effect in the rotor and blade.

It got to the theory about this with the Rayleigh's energy method.In this case, simple model is composed to concentrate weight in the upper side and shell. According to same as the <picture 3.1>

It gets the equivalent spring constant about transverse strain in the cantilever. Natural frequency can decided as follows, if it got to the transverse direction kinetic energy with the valid mass.

Fromthe formula, Natural frequency of tower can be proportional to a diameter and the unique frequency can know to be inversely proportional to the square of the height. Also, Natural frequency is also decreased by concentrate force in upper side. If used to theory model. And it can be structure change to consider the sensitivity of the design element.

Formula (3.3) the reliability was already proved about the steps verified of the differently various boundary condition about beam structural. Therefore, it decided this adequacy compared with the analysis value of the common software (MIDAS Civil 2009), and using to analysis of Natural frequency.



Picture 3.1 Simple modeling for the theoretical interpretation.

$$f_1 = \frac{1}{2\pi}\sqrt{3EI/l^3\,(0.2357m_b + m_e} \qquad (3.1)$$

The mass of tower is the same as the next.

$$m_b = \pi dhl\rho_m \qquad (3.2)$$

$m_b = \pi dhl\rho_m$Next, the first natural frequency of the tower is determined with the next

$$f_1 = \frac{0.097d_{av}}{l^2}\sqrt{\frac{E}{\rho_m\,(0.2357 + \rho)}} \qquad (3.3)$$

3.2 finite element analyses

The input value for the characteristic first natural frequency analysis of the tower from the Rayleigh's energy method and common software (MIDAS civil 2009) is the same as the <table 3.1>.

Gave the unique first natural frequency of the tower the change of the thickness and calculated. a result is the same as the <table 3.2>. Resulted to the difference of the results of the comparison 0.1~0.3% of the theoretical value and FEM analysis value.

Therefore, it was determined to be nearly no difference. Optimum was determined as to the use of common software (MIDAS Civil 2009) according to

first natural frequency analysis.

TABLE 3.1theoretical value / FEM analysisinputvalue

h(average thickness)	0.034m
d(average diameter)	3.6m
L(length of tower)	77m
D(density)	7850kg/m
E(young's modulus)	2.1E+11N/m
m_{ε}(Top mass)	103,600kg

TABLE 3.2first natural frequencies

Thickness	first natural frequency	
	theory	FEM/MIDAS
0.5h	0.287	0.285
1h	0.369	0.367
1.5h	0.417	0.416
2h	0.446	0.449
2.5h	0.473	0.473

IV. RESULT OF ANALYSIS

4.1 natural frequency analyses

Modeling of first steel tower is used to 1540 node of shell element in the common software (MIDAS Civil 2009). Fixed the lowest bottom part, and the thickness is applied to according to the height as shown in it assume in the before. and performed to 214.4 ton of total weight.

The natural frequency analysis result of modeling tower. resulted to the same as <table 4.1>.

This frequency, result it distinguish the resonance or not with the maximum rotor frequency of operating and start up m=3. satisfies the condition according to the GL regulation.

The mode shape is the same as the <Fig.1>~< Fig.3>

TABLE 4.1first natural frequency of steel tower

First degree	0.456
Second degree	3.159
Third degree	8.910

TABLE 4.2the resonance distinction of first steel tower

Maximum frequency of the rotor during operation	15.3RPM(=0.255Hz)
Rotor blade passing frequency	6.0RPM(=0.1Hz)
Number of blades	3
First natural frequency	0.456
Second natural frequency	3.159
$f_{R,3}/ f_1$	0.589<0.95 (ok)
$f_{R,}/ f_1$	0.657<0.95 (ok)

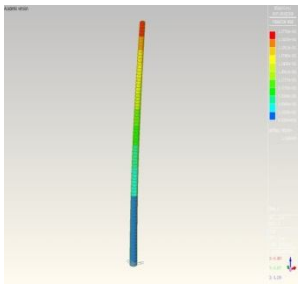


Fig. 1 First natural frequency of steel tower

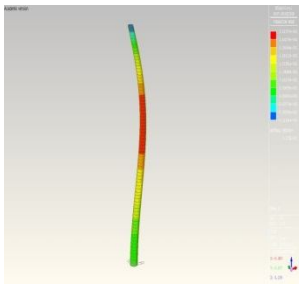


Fig. 2 Second natural frequency of steel tower

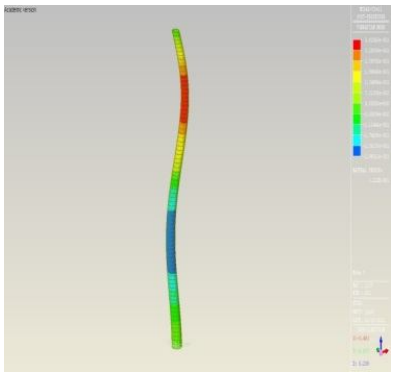


Fig. 3 Third natural frequency of steel tower

4.2Design load analysis

Applied to the load from on study which is the first model UNISON KBP-2000M U88 is designed during develops. the same as the <table 4.3>.

The load value in the each height, presented GL regulation on the ultimate limit state analysis, are the value applied a partial safety coefficient (γ_m=1.35). Andtheresultant force result is among the extreme load according to the load case result about the biggest case.

TABLE 4.3ultimate loads from the tower

Height [m]	Partial Safety factor	Load Case	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
10	1.35	DLC6.1	146.2	-1191	-3478	74520	-3991	1731
26	1.35	DLC6.1	36.46	-1142	-2912	56710	-7399	1756

48	1.35	DLC6.1	-111.3	-1082	-2308	32310	-6560	1813
77	1.35	DLC1.3	484.3	-91.39	-2008	335.1	-8521	1413

4.3Strength analysis

In order to analysis to the strength safety rate of the steel tower assumed as the optimal thickness in this study applies the yield theory of Von-mises.

Applied to ultimate state load according to the height in the each section.in order to see the safety ratio of the strength about this, analyzed the Von-mises of the value which is big among the top & bottom side of the shell element in the analysis of FEM.

The maximum stress in each section is the same as the <table 4.4>

In the section 1, 158.9Mpa maximum stress from the element No.52 in the load application of 10 m height.In the section 2, 179.7Mpa maximum stress from the element No.281 in the load application of 26 m height. And In the section 3, 194.4Mpa maximum stress from the element No.631 in the load application of 48 m height.the section 4, 136.0Mpa maximum stress from the element No.1512 in the load application of 77 m height.

Thus, analyzed with the safety ratio with yield strength according to the S355 thickness applied to the maximum stress in each section the partial safety factor (γ_m=1.1) about material. The same as the <table 4.5>.

if the strength safety ratio, the safety ratio about the strength safety ratio of the tower is analyzed with the minimum safety ratio 1.92, maximum safety rating 2.31. And analyzed to safety of tower about ultimate load.

Apply with the ultimate load according to each height; the stress distribution in each section is the same as the <fig. 4> ~ <fig. 7>.Apply with the 77m load, stress distribution of tower is the same as the <fig. 8>. And stress concentration is occurred in the location of which the thickness of the tower is changed.

TABLE 4.4initial steel tower maximum stress

Section	Tower thickness	Height [m]	Load Case	σ_{max} [Mpa]
1	0.046	0~10		158.9
2	0.038	10~26	DLC6.1	179.7
3	0.030	26~48		194.4
4	0.022	48~77	DLC1.3	136.0

TABLE 4.5 initial steel tower strength ratio

section	σ_{max} [Mpa]	σ_y [Mpa]	Strength safety ratio
1	158.9	304.5	1.92
2	179.7	313.6	1.75
3	194.4	313.6	1.61
4	136.0	313.6	2.31

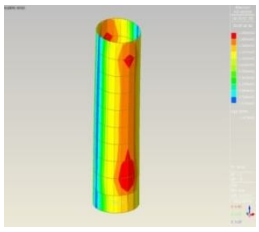


Fig.4 Stress distribution in the section 1

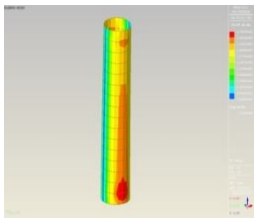


Fig.5 Stress distribution in the section 2

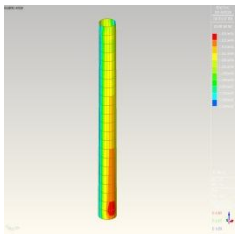


Fig.6 Stress distribution in the section 3

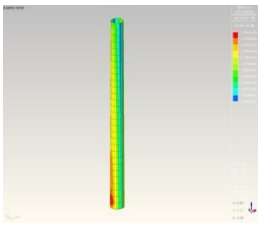


Fig.7 Stress distribution in the section 4

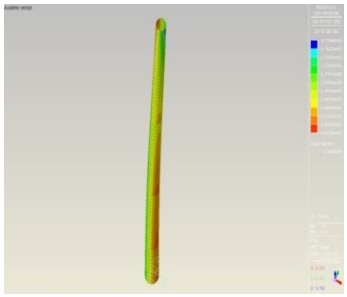


Fig.8Stress distribution in the tower

4.4 Buckling stability analysis

On this study, studied to elastic buckling analysis of modeling tower applied to common software MIDAS Civil 2009.

So checked the buckling critical load of the tower which it becomes the modeling. checked to whether which safety according to the relationship with the axial load. For this purpose, the tower was assumed as the column without the deformity and the bottom was fixed and the upper portion was assumed as the pin condition. Load condition is apply to axial load unit weight for the acquired to natural critical load value according to mode.

At this result,acquired to natural critical load value the same as the <table 4.6>, and checked the safety about buckling.

<fig. 9> ~ <fig. 11> show each mode buckling shape.

TABLE 4.6 Buckling critical load of first steel tower

n	Pcr(kN)	P(Kn)
1	59858	
2	382196	2008
3	998272	

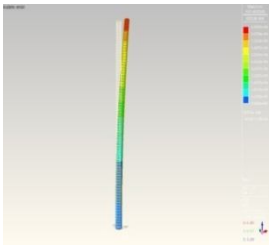


Fig. 9First buckling mode of steel tower.

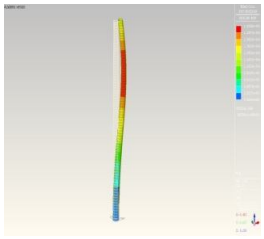


Fig. 10 Second buckling mode of steel tower.

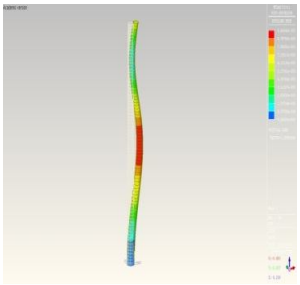


Fig. 11third buckling mode of steel tower.

V. THE STEEL TOWER THICKNESS RE-COMPUTATION

for the comparison that is case of the steel tower, the strength safety ratio of each section with 2. performed with a Trial & error method to be suitable as 0.5% error rate 2.Re-computation thickness, the same as the <table 5.1>.

TABLE 5.1recomputed thickness of steel tower

section	Tower thickness [m]	σ_{max} [Mpa]	σ_y [Mpa]	ratio
1	0.049	149.8	304.5	2
2	0.044	156.1	313.6	2
3	0.038	155.4	313.6	2
4	0.019	156.8	313.6	2

TABLE 5.2thickness variation of steel tower

section	Height [m]	First model [m]	remodel	Thickness variation [m]
1	0~10	0.046	0.049	+0.003
2	10~26	0.038	0.044	+0.006
3	26~48	0.030	0.038	+0.008
4	48~77	0.022	0.019	-0.003

5.1 Natural frequency

Analyzed to Natural frequency for distinguish the resonance or not, using to thickness which steel tower of recomputed. all weight is analyzed with 21 ton, increasing than first model by 235.4 ton.Re-computation steel tower is suitable to a GL standard.It compared the Natural frequency of the tower which it becomes the initial model and re-computation in <table 5.3>.

Comparison result, the first and third Natural frequency increased. And the second Natural frequency decreased.

The reason why the first Natural frequency increases in the total weight and Natural frequency was due to increase doing recomputed to thickness. Andthe reason why the second Natural frequency decreases, total weight of tower is increased but upper side thickness is decreased. So it is determined as one decreasing due to the impact on the thickness.And when resonance a possibility, in the first model, the possibility for resonance of the maximum 69%by the Natural frequency.But in the recomputed tower, analyzed to the possibility for resonance of the maximum 65%by first Natural frequency.

TABLE 5.3comparison of Natural frequency in the steel tower

n	First model	remodel
1	0.0456Hz	0.487Hz
2	3.159Hz	3.028Hz
3	8.911Hz	8.916Hz

5.2 buckling stability

By using the steel tower thickness which becomes a re-computation, it accomplished the analysis of buckling stability according to the axial load. Compared the buckling critical load of the tower which the buckling critical load of the first model and recomputed is analyzed. Same as the <table 5.4>. comparison result, buckling critical load is increased all of degree. in this reason. increased to buckling critical load thereby total weight is increased as the recomputed to thickness. In addition, steel tower of re-computation, checked to decline of the buckling efficiency in the first mode.

TABLE 5.4comparison of Natural frequency in the steel tower

n	초기모델	리모델	P(Kn)
1	59858	65543	
2	382196	390202	2008
3	998272	1011615	

5.3 Material cost according to quantity

Steel plate for material cost analysis of tower of re-computation has been steel, 1 tons 1,134,800 yen per apply the (price of information 2011), as a result, the material cost of the tower of the re-calculation has been steel about 200 million of 70 million won cost me was calculated.

TABLE 5.5Material cost of the tower of the recalculation

Steel tower	weight[ton]	Material cost(원)
Remodel	235.4	267,131,920

The value obtained by substituting in equation (3.1) that is presented in GL provisions for the natural frequency of the tower of the re-calculation has been steel was shown in <Table 5.6>.The value of the porting has to be 0.95 or less. Means that possibility of the resonance is enlarged in 0.95 as it is fine.

Result of analysis. The largest value among the possibilities in the second and third-order resonance, because not only about 10.4%, the analysis of the primary natural frequency of eigenvalue analysis is thought to be important.

While re-calculate the thickness of the tower of steel thickness of the natural frequency of the increase or decrease in accordance with the increase or decrease was shown in <Table 5.7>.

The steel material tower was re-calculated and the total weight was increased. However, it could look at to increase the first natural frequency depending on the thickness increase and decrease of the bottom part of the tower. It could look at that second natural frequency increases depending on the thickness increase and decrease of the upper part of the tower.

The thickness of the upper part of the tower is considered to exert an influence on the second natural frequency.

TABLE 5.6Possibility of resonance of the steel tower

n	Steel tower	
	f_R / f_1	$f_{R,3} / f_1$
1 degree	0.523(55%)	0.616(65%)
2 degree	0.084(8.8%)	0.099(10.4%)
3 degree	0.028(2.9%)	0.033(3.5%)

TABLE 5.7Natural frequency of the increase depending on the thickness of the increase

Steel tower		
Total weight		increase
Tower thickness	4(48~77m)	decrease
	3(26~48m)	increase
	2(10~26m)	increase
	1(0~10m)	increase
First natural frequency		increase
First natural frequency		decrease
First natural frequency		increase

VI. RESULT

In this study, after interpreting the steel material tower in order to analyze the behavior peculiarity of the steel material tower, the research was performed. in the detail,So as to satisfy the strength safety ratio 2 for the steel tower, using a common software (MIDAS Civil 2009), were calculated the proper thickness.Furthermore, through the respective modeling to determine whether resonates through the natural frequency analysis, analyzed the buckling stability against axial load.

Finally tried to check the cost according to the amount of material about the tower.results in this study it was analyzed as follows.

Fist, first natural frequency of the tower of the recomputed has been steel, has been analyzed in 0.487Hz. it is possible to 65% of resonance Second, the analysis of the natural frequency of the increase or decrease in response to increasing or decreasing the thickness of the first natural frequency was analyzed that the thickness of the bottom of the tower is the greatest effect.

Then, the second natural frequency was analyzed that the thickness of the upper end of the tower is the greatest effect. Therefore, the tower design, to solve first natural frequency of the problem, to be considered the thickness of the bottom of the tower in top priority is determined to be advantageous.Third, Buckling strength critical load value by axial load of the tower of the re-calculation has been steel, has been calculated to 655543kN in the no.1 mode. Forth, Material costs in accordance with the amount of tower of re-computation has been steel was calculated at about 24,000 dollar. However, in this study, as a basic research of the tower of economic evaluation the wind power tower that made the surface of behavior characteristics and material costs of the tower of steel, it is a additional, such as impact assessment of the impact and detail load of fatigue of the tower of steel it is determined to be necessary research.

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(MEST)

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