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NATIONAL HIGHWAY DESIGN-A CASE STUDY OF KADAPA TO KURNOOL NATIONAL HIGHWAY

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ABSTRACT

Indian Road Congress has specified the design procedures for flexible pavements based on C.B.R values. The pavement design has accompanied by the code IRC: 37-2000 and Ministry of State Transportation (MOST) specifications. In this project report, the pavement layers, its prescribed limits by Ministry of State Transportation (MOST) and sources of raw materials required for the laying of pavement associated with laying of 4 lanes on National Highway (NH)-18 between Kadapa and Kurnool. The project road starts from Kadapa (km 167.750 to km 356.502) to Kurnool, which has the design length of project road of 188.752 km. This length is considered as one package for construction purpose on Build Operate and Transfer (BOT) basis as per the directions of National Highway Authority of India (NHAI).The alignment of highway passes through plain terrain for 177 km length and balance length of 15.2 km is in rolling and mountainous terrain with reserve forest land on both sides of the alignment. Generally, the existing road is on 0.5-2.5 m high embankment except at approaches to major bridges, where it is up to 5 m. The existing carriage width is 7.0 m with 1.5 m paved shoulder at locations of settlements. There are 437 no. of Cross Drainage (CD) structures present in 192.2 km stretch of the project road. These include 5 major bridges, 69 minor bridges and 363 culverts.

Key words: Highway Design, Plain Terrain, Embankment, Quality Control

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1. INTRODUCTION

1.1. GENERAL

As per the Indian Road Congress (IRC)-37-2000 and Ministry of State Transportation (MOST) these guide lines will apply to Flexible Pavements for Express Way, National Highway (NH), State Highway (SH), Major District Roads (MDR), Other District Roads (ODR) and Village Roads (VR) Flexible pavements are considered to include the pavements which have Bituminous surfacing, Dense Bituminous Macadam (DBM), Wet Mix Macadam (WMM), Granular Sub-Base (GSB) and Sub-Grade courses conforming to Indian Road Congress and Ministry of State Transportation (IRC and MOST) standards.

The prime factor influencing the structural design of a pavement is the required load carrying capacity. The thickness of pavement necessary to provide the desired load carrying of the following variables:

- Vehicle wheel load or axle load;
- Configuration of vehicles wheels or tracks;
- Volume of traffic during the design life of pavement;
- Soil strength (Sub-grade); and
- Modulus of rupture (Flexural Strength) for concrete pavements.

The procedure for design of flexible pavements is generally referred to as the California Bearing Ratio (CBR) design procedure. This procedure requires that each layer be thick enough to distribute the stresses induced by traffic so that when they reach the underlying layer, they will not overstress and produce excessive shear deformation in the underlying layer. Each layer must also be compacted adequately so that traffic does not produce an intolerable amount of added compaction.

1.2. SCOPE OF STUDY

The Experimental investigation is planned as under:

- To obtain the quality control of NH by standard methods; and
- To get the knowledge of NH.

Advantages of NH 18:

The efficiency of the vehicles will be increased;

The cost of laying of NH is high;

The fuel efficiency of the vehicles will be increased; and

We can control the traffic, accidents and time.

Disadvantages of NH 18:

- The materials used for NH is high;
- Lots of skilled labours are required;
- High level equipments are used in NH; and
- Acquiring of agricultural lands creates lot of economical problems.

1.3. OBJECTIVES OF STUDY

The objectives of the present investigation are:

- To collect the data required for a NH design;
- To design a four lane NH; and
- To compare the above design with NH 1

2. METHODOLOGY

2.1. TESTS ON SOILS

All the tests on soils where carried out as IS 2720

2.1.1. Liquid Limit

The liquid limit is the water content at which the shear strength is so low that the soil flows to close a standard groove when jarred in a Specific manner. It is the minimum water content at which the soil tends to flow as liquid. Casagrandes appraratus used for liquid limit test is shown in Fig: 2.1.1. 2.1.2 Plastic Limit denotes the boundary between plastic and semi-solid Status of a soil, at which its capacity to retain shape is minimum. Especially this is defined as the water content at which the soil tends to crumble when rolled into threads of 3 mm diameter.

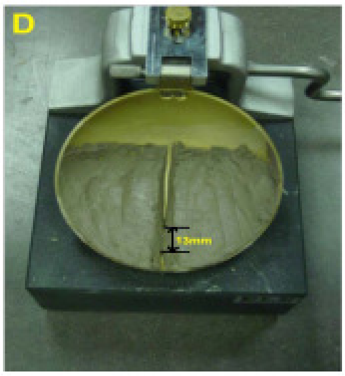

Figure 2.1.1 Liquid limit apparatus

2.1.2. Standard Proctor Compaction Test

The aim of this test is to find the moisture content at which a Maximum dry density attained when the soil is compacted as per standard proctor or AASHTO method. The test is conducted on material passing through sieve no. IS 4.75 mm.Standard proctor test apparatus is shown in Fig.2.1.2

Figure 2.1.2 Standard compaction test apparatus

2.1.3. California Bearing Ratio Test

The C.B.R test was developed by California division of highways as a method of Classifying and evaluating soil sub-grade and base course materials for flexible Pavements.The C.B.R is a measure of shearing resistance of the material under controlled Density and moisture conditions. The C.B.R is defined as the ratio of the standard Load, expressed as percentage for a given penetration of the plunger.C.B.R = (Total load/ Standard load) x 100.

Where standard load is penetration resistance of the plunger into a standard sample of crushed stone for the corresponding penetration.CBR test apparatus is shown in Fig.2.1.3

Figure 2.1.3 C.B.R test apparatus

2.2. TESTS ON AGGREGATES

All the tests on aggregates carried out as IS 2386.

2.2.1. Aggregate Crushing Value

- Aggregate Passing 12.5 mm & retained over 10 mm IS sieve taken for test and dried in oven at 100-110^{0}C for 3-4 hours;
- Filled up to 10 cm in 3 layers in cylinder by 25 stroke of rod as shown in Fig.2.2.1 (Wt. of sample = A)
- Surface is leveled & then crushing load of 40 Tones applied in 10 minutes;
- Sieved on 2.36 mm IS sieve; and
- Fraction passing the sieve = B

ACV = B/A x 100, ACV < 30% for roads and pavements.< 45% for other structure.

Figure 2.2.1 Aggregate crushing test apparatus

2.2.2. Aggregate Impact Value

- Same procedure as AIV test up to applying loading with apparatus shown inFig 2.2.2
- Here 15 blows of hammer (interval not less than 1 sec);
- Sieved through 2.36 mm IS sieve; and

- Fraction passing through sieve = B

AIV = B/A*100

AIV < 30% for road & pavements

< 45% for other works.

Figure 2.2.2 Aggregate impact test apparatus

2.2.3. Aggregate Abrasion Value

- Machine : Los Angeles shown in Fig:2.2.3
- Grading of Aggregate – given in table;
- Abrasive charge & wt. of sample – in table;
- Wt A' of cleaned and over dried sample taken;
- Machine rotated @ 30- 33 rev/min;
- No. of revolution; and

= 500 (for A, B, C & D samples)

= 1000 (for E, F & G)

Figure 2.2.3 Los-Angels Apparatus

- After revolutions.

a. Material finer than 1.7 mm separated by sieving

b. Coarse portion washed & dried in oven at 105-110 ^{0} C

c. Weight of dried portion = B (retained)

d. Abrasion value = A-B/A*100

AAV < 30% For Pavement works

< 50% for other works

2.2.4. Grain Size Sieve Analysis

Set of sieves used for particle size analysis is shown in Fig.2.2.4.This test is used for classifying the type of soils based on their size.

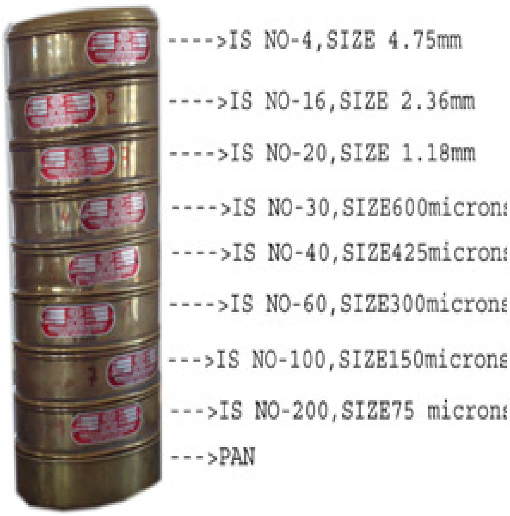

Figure 2.2.4 Set of standard IS sieves

Procedure

- Measure and record the mass of each sieve, including the bottom pan;
- Obtain the appropriate amount of sample;
- Weigh and record the mass of the sample selected;
- Assemble the sieves in order from largest to smallest so that the coarsest is at the top and the finest is on the bottom followed by the pan;
- Place the sample on to the top sieve taking care not to lose any of the mass and place the lid securely on top;
- Place the set of sieves in the sieve shaker and adjust the clamps to secure the sieves;To insure that all the particles passed though the appropriate sieve, tap each sieve over a sheet of paper, starting with the top sieve;
- Measure and record the mass retained in each sieve; and Sum the mass of the material retained on each sieve to verify that there has been no change in the total mass of the sample. (Note: A mass loss of less than 2% is acceptable).

Calculations

Note: Cu: Coefficient of uniformity

Cc: Coefficient of Curvature.

$$C_u = \frac{D_{60}}{D_{10}} \qquad C_c = \frac{{D_{30}}^2}{D_{60} \times D_{10}}$$

2.3. TESTS ON BITUMEN

2.3.1. Determining Penetration of Bitumen

This test is done to determine the penetration of bitumen as per IS: 1203 – 1978. The principle is that the penetration of a bituminous material is the distance in tenths of a mm, that a standard needle would penetrate vertically, into a sample of the material under standard conditions of temperature, load and time. The apparatus needed to determine the penetration of bitumen.

- Penetrometer;
- Water bath; and
- Bath thermometer – Range 0 to 44°C, Graduation 0.2°C.

Figure 2.3.1 Penetrometer

Procedure

- Soften the bitumen above the softening point (between 75 and 100°C). Stir it thoroughly to remove air bubbles and water;
- Pour it into a container to a depth of at least 15mm in excess of the expected penetration;
- Cool it at an atmospheric temperature of 15 to 30°C for $1^{1/2}$ hours. Then place it in a transfer dish in the water bath at 25.0 + 0.1°C for $1^{1/2}$ hrs;
- Keep the container on the stand of the penetration apparatus as shown in Fig 2.3.1;
- Adjust the needle to make contact with the surface of the sample;
- Adjust the dial reading to zero;
- With the help of the timer, release the needle for exactly 5 seconds;
- Record the dial reading; and
- Repeat the above procedure thrice.

2.3.2. Determining the Ductility of Bitumen

This test is done to determine the ductility of distillation residue of cutback bitumen, blown type bitumen and other bituminous products as per IS: 1208 – 1978. The principle is: The ductility of a bituminous material is measured by the distance in cm to which it will elongate before breaking when a standard briquette specimen of the material is pulled apart at a specified speed and a specified temperature and the ductility test apparatus if shown in Fig 2.3.2.

Figure 2.3.2 Ductility testing machine

Procedure to determine the ductility of bitumen

- Completely melt the bituminous material to be tested by heating it to a temperature of 75 to 100^{o}C above the approximate softening point until it becomes thoroughly fluid.
- While filling, pour the material in a thin stream back and forth from end to end of the mould until it is more than level full. Leave it to cool at room temperature for 30 to 40 minutes and then place it in a water bath maintained at the specified temperature for 30 minutes, after which cut off the excess bitumen by means of a hot, straight-edged putty knife or spatula, so that the mould is just level full;
- Place the brass plate and mould with briquette specimen in the water bath and keep it at the specified temperature for about 85 to 95 minutes. Remove the briquette from the plate, detach the side pieces and the briquette immediately;
- Attach the rings at each end of the two clips to the pins or hooks in the testing machine and pull the two clips apart horizontally at a uniform speed, as specified, until the briquette ruptures.
- Measure the distance in cm through which the clips have been pulled to produce rupture. While the test is being done, make sure that the water in the tank of the testing machine covers the specimen both above and below by at least 25 mm and the temperature is maintained continuously within ± 0.5^{o}c.

2.3.3. Determining Bitumen Content

Bitumen Content

This test is done to determine the bitumen content as per ASTM 2172. The apparatus needed to determine bitumen content are shown in Fig 2.33 and it contains:

- Centrifuge extractor; and
- Miscellaneous – bowl, filter paper, balance and commercial benzene. A sample of 500 g is taken.

Figure 2.3.3 Determination of Bitumen content

Procedure to determine Bitumen content

- If the mixture is not soft enough to separate with a trowel, place 1000 g of it in a large pan and warm up to 100^{o}C to separate the particles of the mixture uniformly;
- Place the sample (Weight 'A') in the centrifuge extractor. Cover the sample with benzene; put the filter paper on it with the cover plate tightly fitted on the bowl;
- Start the centrifuge extractor, revolving slowly and gradually increase the speed until the solvent ceases to flow from the outlet;
- Allow the centrifuge extractor to stop. Add 200 ml benzene and repeat the procedure;
- Repeat the procedure at least thrice, so that the extract is clear and not darker than the light straw color and record the volume of total extract in the graduated vessel; and
- Remove the filter paper from the bowl and dry in the oven at 110 + 5^{o}C. After 24 hours, take the weight of the extracted sample (Weight 'B).

3. RESULTS, DISCUSSION AND CONCLUSIONS

All the test required for the design of a highway have been carried as per relevant IS codes as applicable for different materials used for the construction of a highway. General grading requirements and various test results has been shown from Table 3.1 to table 3.14.

3.1. RESULTS

Table 3.1 Compaction requirement for embankment and sub grade

Sl. No.	Type of Work	Relative compaction as percentage of maximum laboratory dry density as per IS:2720 (Part VIII)
1	Sub grade and earthen shoulders	Not less than 97
2	Embankment	Not less than 95
3	Expansive Clays	
a)	Sub grade and 500 mm portion just below the sub grade	Not allowed
b)	Remaining portion of Embankment	Not less than 90

Table 3.2 Grading requirement for filter material for sub surface drain

Sl. No.	Sieve designation	Percent passing by weight		
		Class I	Class II	Class III
1	53 mm	-	-	100
2	45 mm	-	-	97-100
3	26.5 mm	-	100	-
4	22.4 mm	-	95-100	58-100
5	11.2 mm	100	48-100	20-60
6	5.6 mm	92-100	28-54	4-32
7	2.8 mm	83-100	20-35	0-10
8	1.4 mm	59-96	-	0-5
9	710 micron	35-80	16-18	-
10	355 micron	14-40	2-9	-
11	180 micron	3-15	-	-
12	90 micron	0-5	0-4	0-3

Table 3.3 Grading requirement for aggregate drains

Sl. No.	Sieve designation	Percent passing by weight	
		Type A	Type B
1	63 mm	-	100
2	37.5 mm	100	85-100
3	19 mm	-	0-20
4	9.5 mm	45-100	0-5
5	3.35 mm	25-80	-
6	600 micron	8-45	-
7	150 micron	0-10	-
8	75 micron	0-5	-

Table 3.4 Test results for embankment and sub grade

Sl. No.	Description	Existing ground		Borrow material for embankment	
		Frequency	Limits	Frequency	Limits
1.	Sieve analysis			One Test Per 1500 m3	
2.	Proctor compaction		>1.55 gm/cc	One Test Per 1500 m3	1.55 gm/cc Up to 3m Height
				One test per 1500 m3	1.63 gm/cc Above 3 m height
3.	Atterberg limit				
A)Liquid limit			<70		<70
B)Plasticity index			<45		<45
4.	California Bearing Ratio(C.B.R)		>7	As Required	>7
5.	Field test	1 test for 50 m2	>97%	One test per 1000 m2	
7.	Max thickness of layer				< 200 mm
8.	Max size of coarse material				75 mm

Table 3.5 Gradating for coarse graded granular sub-base

Sl. No.	IS sieve designation	Percent by weight passing the IS sieve		
		Grading I	Grading II	Grading III
1	75.0 mm	100	_	_
2	53.0 mm	80-100	100	_
3	26.5 mm	55-90	70-100	100
4	9.50 mm	35-65	50-80	65-95
5	4.75 mm	25-55	40-65	50-80
6	2.36 mm	20-40	30-50	40-65
7	0.425 mm	10-25	15-25	20-35
8	0.075 mm	3-10	3-10	3-10
9	CBR Value	30	25	20

Table 3.6 Grading requirements of coarse aggregates

Grading No.	Size range	IS sieve designation	Percent by weight passing
1	90 mm to 45 mm	125	100
		90	90-100
		63	25-60
		45	0-15
		22.4	0-5
2	63 mm to 45 mm	90	100
		63	90-100
		53	25-75
		45	0-15
		22.4	0-5
3	53 mm to 22.4 mm	63	100
		53	95-100
		45	65-90
		22.4	0-10
		11.2	0-5

Table 3.7 Grading requirements to aggregates for wet mix macadam

Sl. No.	IS sieve designation	Percent by weight passing the IS sieve
1	53 mm	100
2	45 mm	95-100
3	26.5 mm	-
4	22.4 mm	60-80
5	11.2 mm	40-60
6	4.75 mm	25-40
7	2.36 mm	15-30
8	600 Microns	8-22
9	75 Microns	0-8

Specifications as per IRC

Table 3.8 Granular sub-base

Sl. No.	Name of the test	Relevant	Requirements	Frequency of test
II	Granular Sub Base:	As per MOST 400-1	As per MOST 400-1	1 test/200 m^2
1	Atterberg limits	IS:2720-Part 5	LL= Not>25%	1 test/200 m^2
			PL=Not >6%	
2	Density test	IS:2720-Part 8	Not < 1.95 g/cc	1 test/3000 m^2
3	Density of compaction layer	IS:2720-Part 28	98% of MDD	1 test/500 m^2
4	Moisture content Prior to Com,	IS:2720-Part 2	OMC +/- 1%	1 test/250 m^2
5	CBR	IS:2720-Part 16	Grade 1=30%Min	
			Grade 11=25%Min	As required
			Grade 111=20%Min	
6	10 Percent fines value	BS:812-Part III	>50KN	1 test/each Source
7	Deleterious content	IS:2720-Part 27	Nil	As and when required
8	Water absorption of the course aggregate	IS:2386-Part 3	Not>2%	test/each source

Table 3.9 Test results for wet mix macadam

Sl. No.	Name of the test	Requirements	Frequency of test
	Wet Mix Macadam		
1	Gradation (combined and individual)	As per MOST 400-11	1 test/100 m^3
2	Atterberg limits	LL-Not>25%	1 test/25 m^3
3		PL=Not>6%	
4	Aggregate impact value	Max=30%	1 test/200 m^3
5	Loss Angels abrasion value	Max=40%	1 test/200 m^3
6	Flakiness and elongation index		1 test/200 m^3
7	CBR	>100%	As required
8	Density test	As per Design	As required
9	Density of compaction layer	98% of MDD	1 test/500 m^2
10	Moisture content prior to compaction.	OMC +/-1%	1 test/500 m
11	Water abrasion of the course aggregate.	Not>2%	1 test/each source
12	Soundness test	Max=12%(Na_2So_4) Max=18%($MgSo_4$)	1 test/each source

Bituminous Bound Bases

Table 3.10 Rate of application of tack coat

Sl. No.	Type of surface	Quantity of liquid bituminous material in kg per 10 m^2. area
1	Normal bituminous surfaces	2.0 to 2.5
2	Dry and hungry bituminous surfaces	2.5 to 3.0
3	Granular surfaces treated with primer	2.5 to 3.0
4	Non bituminous surfaces	
	a) Granular base (not primed)	3.5 to 4.0
	b) Cement Concrete pavement	3.0 to 3.5

Table 3.11 Grading requirements for mineral filler

Sl. No.	IS Sieve (mm)	Cumulative percent passing by weight of total aggregate
1.	0.6	100
2.	0.3	95-100
3.	0.075	85-100

Table 3.12 Aggregate gradation for dense bituminous macadam

Sl. No.	IS sieve designation	Percent by weight passing the sieve
1	37.50 mm	100
2	26.50 mm	90-100
3	13.20 mm	56-80
4	4.75 mm	29-59
5	2.36 mm	19-45
6	0.80 mm	5-17
7	0.075 mm	1-7

Table 3.13 Test results for coarse aggregate for dense graded bituminous macadam

Sl. No.	Property	Test	Specifications
1	Cleanliness (dust)	Grain size analysis	Max 5% passing 0.075 mm sieve
2	Particle shape	Flakiness and elongation index	Max 30%
3	Strength	Los Angeles abrasion value	Max 35%
4	Durability	Soundness Sodium Sulphate Magnesium Sulphate	Max 12% Max 18%
5	Water Absorption	Water absorption	Max 2%
6	Stripping	Coating and stripping of bitumen aggregate mixtures	Minimum retained coating 95%
7	Water Sensitivity	Retained tensile strength	Min 80%

Table 3.14 Test results for bituminous macadam

Sl. No.	Bituminous macadam	Requirements as per Tec. Spec.	Frequency of test
1	Aggregate impact value.	>30%	2 samples/Lot
2	Los Angles abrasion test	>40%	1 test/50 m^3
3	Flakiness and elongation index	>30%(Com) and Max = 15% each	1 test/50 m^3
4	Stripping value of aggregate	Min. retained coating 95%	1 test/50 m^3
5	Water absorption of the aggregate.	Not>2%	As and when required
6	Soundness test	>12 %(Na2so4) >18%(Mgso4)	1 test/each source
7	Gradation	As per Most-t-500-4	2 test/Day/Plant
8	Binder content	3-3.5 %	2 test/Day/Plant
9	Control of temperature of binder and aggregate for mixing and of the mix at the time of laying and rolling.	Binder =150-163°C Agg. =155-163°C >130-160°C Laying = 120-160°C Rolling = Not<100°C	As regular close intervals
10	Density of compacted layer	Min.95% of Lab Density	1 test/500 m^2 (10% of density tests will be done at edges)

3.2. DESIGN

The design of highway involve the following components after preparing the ground:

3.2.1. Sub-grade

- In a fill section, the sub grade is the top of the embankment or the fill;
- In a cut section, the sub grade is the bottom of the cut;
- The sub grade supports the sub base and/or the pavement section; and
- The rough grade is the top grade of the embankment as built using the provided on the grade sheets.

3.2.2. Select Material

Good quality construction materials make superior pavements. Thickness, performance and efficiency of pavements depend upon quality of highway materials.

- Sub-grade soil;
- Stone aggregates;
- Bituminous materials; and
- Cement and cement concrete

Hence these are the materials that have been selected for the construction of National Highway.

3.2.3. Base Course

- A base course is the layer immediately under the wearing surface;
- This definition applies whether the wearing surface is bituminous or Portland-cement concrete 8 in. or more thick;
- Because the base course lies close under the pavement surface, it is subject to severe loading; and
- Base course must be of higher quality than the under laying ‘basement’ soils.

3.2.4. Pavement

The pavements of the early Roman roads can be divided into three main types, according to the quality of their construction;

- Viae terrenae, the lowest type, which were made of levelled earth;
- Viae glareatae, which had gravelled surfaces; and
- Viae munitae, the highest type, which were paved with rectangular polygonal stone blocks.

A road pavement is a structure of superimposed layers of selected and processed materials that is placed on the basement soil or sub grade.

Component layers of flexible pavements

- The uppermost layer of a flexible pavement is called the surfacing;
- The primary function of this layer is to provide a safe, smooth, stable riding surface, i.e. a carriage way, for traffic; and
- The secondary functions are to contribute to the structural stability of the pavement and protect it from the natural elements.

Component layers of a rigid pavement

- The cross-section of a rigid roadway comprises a pavement superimposed upon the sub grade, and most usually this pavement is composed of a cement concrete slab on top of a sub base;
- Concrete slabs in rigid pavements are either jointed unreinforced or reinforced; and
- If the sub grade is strong then, technically, a sub base can be omitted from the pavement.

3.3. DISCUSSION

Based on the design above, the quantity of various materials required for the construction for a four lane highway is formulated below:

- Economically the construction of highway design is very high;
- The construction of highway have been referred from IS 2720; and
- This highway constructions will be taking much time to complete the project.

3.4 CONCLUSION

The total quantity of materials required for a highway at Kadapa to Kurnool are as given below:

- The designed cross-section of highway compares very well that of the design of NH 18;
- This highway road increases the speed efficiency of the vehicles; and
- By laying this highway we can increase the transportation facilities.

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