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COMPARATIVE STUDY OF AMERICAN CONCRETE INSTITUTE (ACI) AND COUNCIL FOR THE REGULTION OF ENGINEERING IN NIGERIA (COREN) MIX DESIGN MANUALS

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ABSTRACT

COREN mix design method for Nigeria and ACI method are both based on the basic principles and empirical relations, developed after substantial experiments of locally available materials. However, some minor differences are seen in the quantities of the material used for mix proportion, which includes the cement,aggregate (fine and coarse)and water content which attributes to the variation in strength of concrete. In ACI method, the quantities of fine aggregateswere calculated, while the reverse is the case in COREN mix design method. The results indicate that the COREN method of mix design requires higher cement content than ACI method, and the water/cement ratio is higher in ACI method compare to COREN mix method. Although, the coarse aggregate content in COREN mix method is higher than the ACI mix method, from correlation and deviation between design and actual strength, it shows that COREN mix method is reliable and its meet the 25Mpa strength requirements than the ACI mix method.

Keywords: *ACI Mix Method, COREN Mix Method, Ordinary Portland Cement, River Sand, Gravel.*

1.0 INTRODUCTION

Concrete is a material similar in shape and appearance to natural limestone rock but formed by artificial binding together of natural or artificial stone with sand, cement and water [1]. The water cement ratio is usually the governing factor that determines the strength of concrete, other factors such as mix ratio, aggregate grading and quality or type of cement also play significant role to determine the strength of concrete. Due to the significant of mix ratio, mix design is usually done prior to the production of concrete [2].

Development of infrastructure has become the number one priority in the world particularly for developing countries like Nigeria, this has been jeopardized by increase in the price of conventional building materials including cement which is one of the major ingredients used in concrete production and has inevitably put inflationary pressure on the economy as construction materials become more expensive [3]. In designing a concrete mix, the primary objective is to select suitable constituent materials and determine their required amounts in order to produce concrete of specific characteristics and properties as economically as possible [4], [5].

Generally, concrete mix design includes two main steps: Selection of the main components suitable for the concrete (cement, aggregate, water, and additives) and determination of more economical mix ratios to fulfill performance and efficiency requirements [6]. Many international methods of mix designs have been developed by different countries such as American concrete institute (ACI), British Standard (BS) methods, India Standard (IS) which will not give the same strength if used in another area as a result of the difference in the properties of materials locally available in the country.

Concrete mix design is a process of specifying the proportion of ingredients (cement, aggregates, sand and water) required to meet anticipated properties of concrete in both fresh and hardened states [5], [7]. Concrete mix design is a well-established practice around the world. All developed countries, as well as many developing countries, have standardized their concrete mix design methods.

ACI and COREN are mostly based on empirical relations, charts, graphs, and tables developed as outcomes of extensive experiments and investigations of locally available materials. All of those standards and methods follow the same basic trial and error principles [1]. In 2017, the Council for the Regulation of Engineering in Nigeria, **COREN**, present the concrete mix design manual for Nigeria, thus, the scope of this study is to compare ACI and COREN recommended mix design guidelines [8].

The scope of this work is to compare ACI concrete mix design method and COREN concrete mix design guidelines which involves determination of the physical properties of aggregates, determining the proportions of the materials in both mix design methods and the determination of the compressive strengths. The scope of this work is limited to absolute volume and concrete mixdesign for compressive strengths less than 40MPa.

2.0 LITERATURE REVIEW

Fresh or hardened concrete behaviour depends basically on the characteristics of its components and the relationship between them. Therefore, obtaining a concrete with certain properties depends fundamentally on the concrete mix design [4],[6]. Generally, concrete mix design includes two main steps:

a. Selection of the main components suitable for the concrete (cement, aggregate, water, and additives).
b. Determination of more economical mix ratios to fulfill performance and efficiency requirements [6].

Currently, there are many international methods locally approved for mix designs such as American Concrete Institute (ACI) and British Standard (BS) methods.Some of the prevalent concrete mix design methods are:

a) ACI Mix Design Method,
b) USBR Mix design practice,
c) British Mix design Method, and
d) ISI Recommended guidelines.

Some research works have been carried out which gives some basic ideas about comparison of BIS (Bureau of Indian Standards) and ACI(American Concrete Institute) method of concrete mix design. Deepak [9], investigated the comparison of BIS (Bureau of Indian Standards) and ACI (American Concrete Institute) methods ofconcrete mix design.However, both methods are built on the basis of some basic principles and empirical relations but some minordifferences exist between them. M25, M35 and M45 grades of ordinary strength, medium strength and higher strength were chosen. 27cubes specimens (15 cm sides) and 27cylindrical specimens (15 cm diameter, 30 cm height) were prepared by BIS and ACI concrete mixdesign methods respectively.

These specimens were tested after 7days, 14 days and 28 day of curing. Materials (ordinary portland cement, coarse aggregates of 10mm and 20mm, natural river bed fine aggregates, sika viscocrete 4005 and water) quantities (M25, M35 and M45) required formanufacturing one cubic meter concrete by both methods were calculated numerically under codal provisions. Some

differences werefound in quantities calculated by both methods. Major differences were noticed in compressive strengths of specimens made by bothmethods. It was also noticed that cracked specimens of both methods show a great similarity in their cracking pattern.
Greatersimilarities were found between the shapes of brokenspecimens after 28 days compressive strength test. It was alsoobserved that M25 samples collapse by gentle crushing. M35samples and M45 samples get fractured by sudden brittlefracture. It was also observed that the shape of brokenspecimens changes with respect to increase in strength.

Nataraja [10],examined the procedure ofcalculating the material quantities of both methods and drewan idea that in case of ACI method, fine aggregate should be calculated after calculating the coarse aggregate content. Healso found that as the strength requirement increases, the sandrequirement goes on decreasing due to the relative low grade of available cement at the time in India and also due to limited research data during the time of research.

Singh and Verma [11],suggested that thehighest amount of aggregates should be used in BIS method and least in ACI method. For M25 grade the BIS method shows avast increment in the split tensile strength as compared toM20 and achieved highest strength among the rest of themethods.Generally, the behavior of M20 in terms ofmechanical properties of concrete wasbetter than that of the M25, the performance ofconcrete designed for ACI method was useful forthis grade of concrete.
Deepa [12], carried outcompressive strength of concreteusing different mix design methods and reported that the fine aggregate content in ACI is morethan the BIS method of concrete mix design. He also observed that in BIS method of concrete mix design the coarseaggregate content is more than that of ACI method.

3.0 MATERIALS AND METHODS

3.1 Materials
For the purpose of this research the materials used includes; ordinary portland cement, river sand, gravel of 20 mm size and water. The ordinary portland cement used in this study was obtained from a mini depot in Minna, Niger State,while the river sand and gravel were obtained from a supplier at kpakungu road in Minna, Niger State. The water used was obtained from the tap, it was colourless, odourless and free from organic materials.

3.2 Methods
The tests carried out are;

i. Sieve analysis test (determination of the particle size distribution).
ii. Specific gravity
iii. Bulk density
iv. Slump test
v. Compressive strength test of concrete cubes

3.2.1 Sieve analysis

This test is a method of separation of soil into fractions based on the particle size. It expresses quantitatively the proportion by mass of various sizes of particle present in a soil. Material retained in the number 4 sieve (4.75mm) is considered as coarse aggregate; material passing in the number 200 sieve (75µm) is considered as fine aggregate and is referred as micro-fines [8].

3.2.2 Specific gravity
The determination of specific gravity test was carried out according to BS 1377 (2016). It is the ratio between the unit mass of solid particles and water. Determination of the volume of a mass

of dry sample particles was obtained by placing the soil particles in a glass density bottle filled completely with the desired distilled water.

The density bottle and the stopper were weighed to the nearest 0.001g (M_1). The air-dried soil was transferred into the density bottle. The bottle content and the cover were weighed as M_2. Water was then added just enough to cover the soil; the solution is gently stirred to remove any air bubble, the bottle was then filled up and covered, wiped dry and weighed to the nearest 0.001g (as M_3). The bottle was subsequently emptied and filled completely with water, wiped dry and weighed to the nearest 0.001g (M_4). The specific gravity was calculated using equation (3.1).

$$G_s = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_1)} \quad (3.1)$$

where:
G_s is the specific gravity
M_1 is the weight of density bottle (g)
M_2 is theweight of density bottle and dry sample (g)
M_3 is theweight of bottle, sample and water (g)
M_4 is theweight of bottle and water only (g)

3.2.3 Slump test

Slump test is one of the tests used in the determination of workability of fresh concrete, to ensure the fresh concrete is in adequate consistency for placement.

3.2.3.1 Casting of concrete cubes

The fresh concrete was poured into a lubricated metal moulds in three layers of 50mm, each layer was compacted using the tempering rod by distributing the strokes in a uniform manner in the mould for each of the three layers (35 strokes per layers). The concrete surface was marked for easy identification and allowed to set for 24 hours before demoulding of the concrete cube which was then immersed in water in the curing tank in accordance to BS1881: part 108: 1989.

3.2.3.2 Curing of Concrete Cubes

Curing is the process of keeping concrete moist which promotes hydration in concrete. All concrete requires curing in order for cement hydration to proceed and also to allow for development of strength, durability and other mechanical characteristics [13]. All cubes were submerged in water for 28 days in the curing tank.

3.2.4 Bulk density test

Bulk density is the total mass of soil per unit total volume of soil. A bulk density of 2400 kg/m^3 was used as recommended by COREN for all mixes using normal weight aggregates. The fine and coarse aggregate content are determined by obtaining the proportion of fine aggregate in the total aggregate content.

3.2.5 Compressive strength test

The capacity of the concrete to withstand axially directed load is determine by compressive strength. The compressive strength test was carried out to determine the maximum load the concrete cube can withstand before failing. All concrete requires curing so as to allow for development of strength, durability and other mechanical characteristics [11], [13]. All cubes were submerged in water for 28days in the curing tank. The compressive strength was determined from concrete cubes obtained and tested for 28 days. The concrete cube was tested to
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determine its compression strength which is an important property of the hardened concrete which was determined by a compressive strength test on the cured concrete cubes.This test was carried out to determine the consistency, wetness or fluidity of fresh concrete.

3.3 Mix Design

The mix designs were carried out in accordance with COREN concrete mix design manual (2017) and ACI 211 (2002). Concrete mix design is the procedure by which the proportions of constituent materials are suitably selected so as to produce concrete, satisfying all the required properties for the minimum cost.

3.2.3 Determination of water cement ratio

Concrete strength depends on its water cement ratio, as cement requires water for the hydration of cement to take place. It is generally accepted as a rule ofthumb that every 1% increase in quantity ofwater added reduces the strength of concrete by 5% (COREN), [8].
Water/cement ratio was determined using the equation of strength verse water/cement graph (Figure 3.1) and Table 3.1 for grade 32.5 cement for ($0.3 \leq r \leq 0.9$).

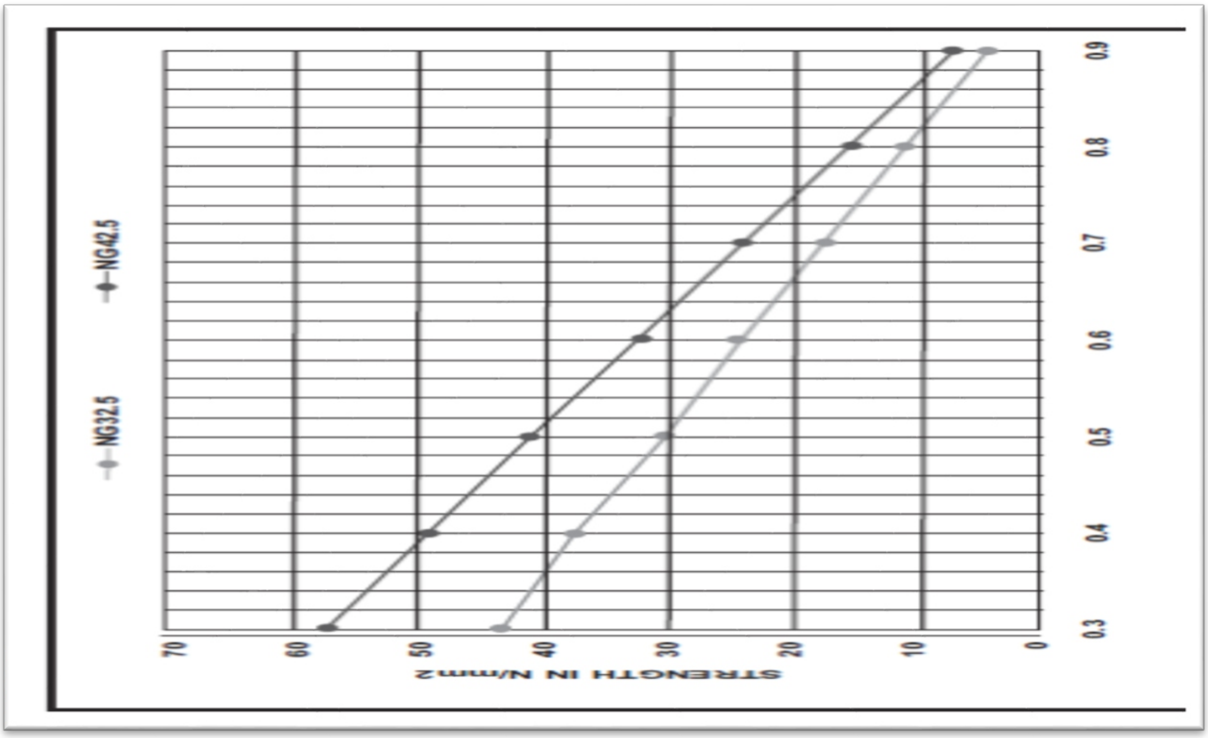

Figure 3.1: Strength versus Water Cement ratio for Nigeria cement (COREN, 2017).
Table 3.1: Relationship between Water Cement Ratio and Mass

	Water-Cement Ratio	
Compressive strength at 28 days (N/mm^2)	Non-air entrained concrete	Air entrained concrete

40	0.42	_
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.70

Source; ACI211.1-91 [11].

3.2.3 Determination of water content

In concrete the water content largely depends on the type and maximum size of concrete to give a required workability. The range of slump recommended according to COREN manual was used while the approximate free water contents required to give various levelsof workability according to ACI[14], was also used.

3.2.4 Determination of aggregate content

To determine the total aggregate content, an estimate for density of the fully compacted concrete was knownfrom the tests carried out, a density value of 2400kg/m^{3}was recommended for use for all mixes using normal weight aggregates. The fine and coarse aggregate content are determined by obtaining the proportion of fine aggregate in the total aggregate content.

4.0 RESULTS AND DISCUSSIONS

4.1 Laboratory Results

Fineness modulus is the summation of the cumulative percentage mass retained on sieve 4.75mm to 150µm divide by 100. Fineness modulus of 3 was obtained for the sieve analysis carried out for the fine aggregate. The sieve analysis test is presented on Table 4.1 and the particle size distribution curve is shown on Figure 4.1.

Table 4.1: Sieve Analysis Test for Fine Aggregate

S/N	Sieve size	Mass retained (g)	Percentage mass retained (g)	Cumulative Percentage mass retained (%)	Percentage mass passing (%)
1	12.5mm	-	-	-	100
2	8.0mm	-	-	-	100
3	4.75mm	13.90	2.78	2.78	97.22
4	2.36mm	47.10	9.42	12.20	87.80
5	1.18mm	131.70	26.34	38.54	61.46
6	600µm	134.30	26.86	65.40	34.60
7	300 µm	82.20	16.44	81.84	18.16
8	150 µm	61.70	12.34	94.18	5.82
9	75 µm	4.90	0.98	95.16	4.84

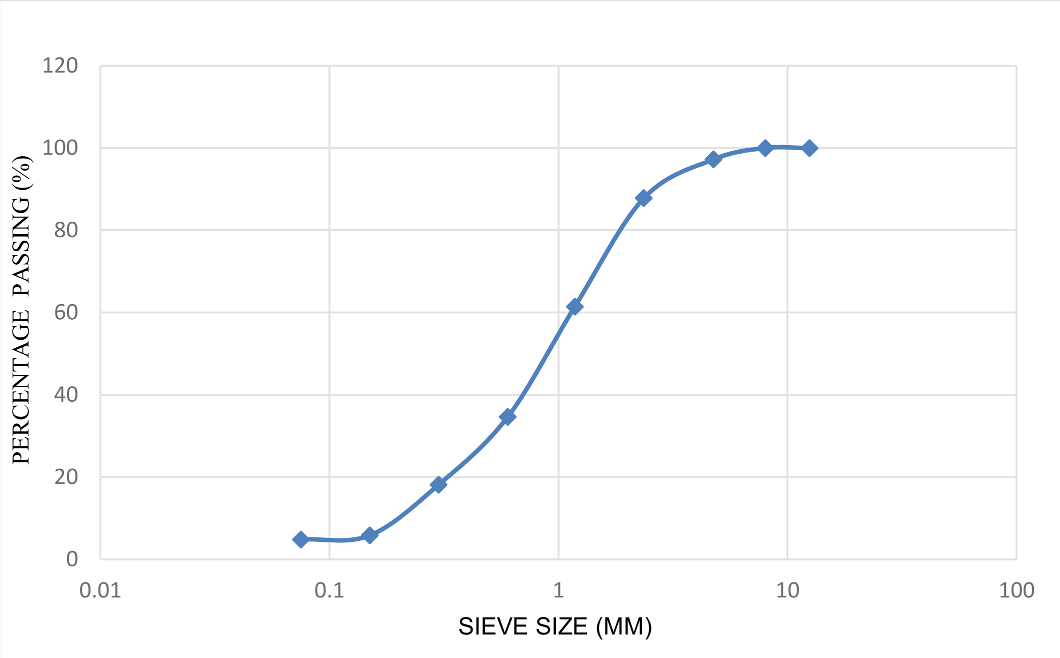

Figure 4.1: Particle size distribution curve

The specific gravity obtained for test carried out for fine and coarse aggregate are 2.67 and 2.68 kg/m^3 respectively according to IS:10262 [16], and it is within the range required for aggregates[15], [16]. The bulk density results obtained for fine aggregate from compacted and uncompacted aggregates are 2.75kg and 2.5kg respectively. While the bulk density results for coarse aggregates (compacted and uncompacted) are 2.71kg and 2.45kg respectively. This is why a concrete that is hardened or stronger than necessary for its intended use is not economical, and one that is not strong enough can be dangerous. The higher the cement content, the greater the tendency of shrinkage cracks.

4.2 Slump Test

4.2.1 COREN:A slump of 120mm was obtained from the mix design carried out which is in the range of 60mm-180mm as recommended in COREN GUIDE for a water content of 235.

4.2.2 ACI:A slump of 140mm was obtained from the mix design carried out which is in the range of 150mm-175mm as recommended in ACI CODE for a water content of 216.

4.3 Compressive Strength

The target mean strength for COREN is 25.52, while for ACI is 25.00 N/mm^2. The strength was determined for 3 days, 7 days and 28 days respectively. There was a rapid increase at 28 days (27.92N/mm^2) [17], [18], which meets up with COREN mix design method, while ACI does not meet with the requirements of ACI mix design method at 28 days. Table 4.2 indicates the compressive strength of concrete cubes obtained for the two mix design methods carried out and Figure 4.2 shows the compressive strength of concrete using ACI and COREN guide.

Table 4.2: Summary of the Compressive Strengths and Mix Proportions

Mix Design Method	Characteristic Strength (N/mm^2)	Target Mean Strength	3days Mean Strength	7days Mean Strength	28days Mean Strength	Mix Proportion
COREN	20	25.52	14.99	19.80	27.92	1:1.5:2.8
ACI	20	25.00	13.12	15.22	23.39	1:2.8:3.1

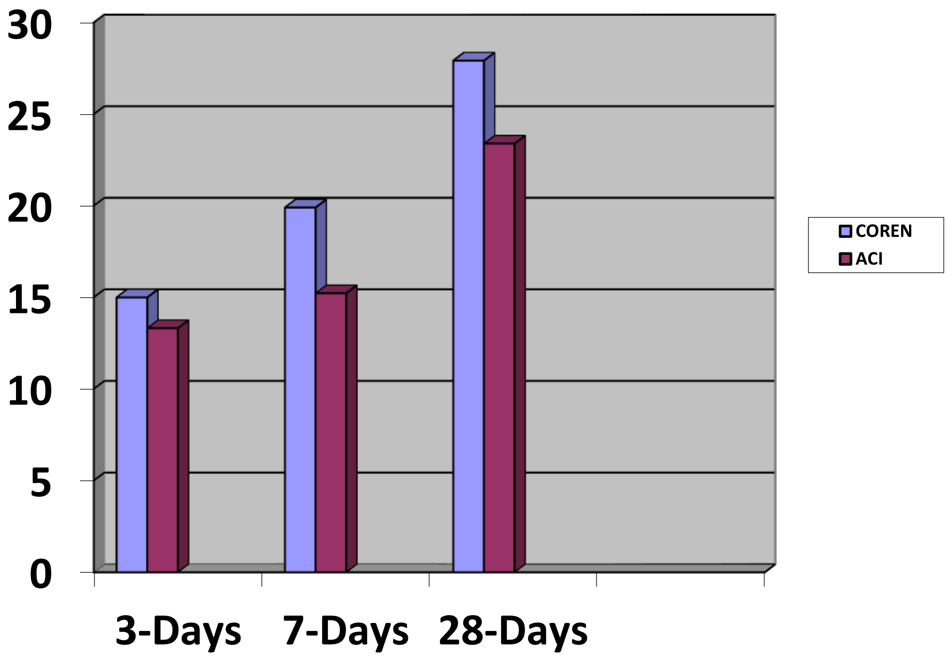

Figure 4.2: Compressive strength of concrete using ACI and COREN guide

4.4 Similarities between COREN and ACI Mix Design Method

COREN and ACI methods of mix design are based on empirical relations that are derived in different countries based on the available local materials within. Tables 3.1 which shows the relationship between water cement ratio and mass and Figure 3.1 graph which shows the relationship between strength and water cement ratio for Nigeria cement are used during the design process and selection of materials through a logical means for the determination of the target mean strength and ingredients.

The determination of cement content of both methods is based on the relationship of two perimeters: W/C and the cement content are derived separately and independently. Workability of both methods is determined using slump test.
Workability is used to measure the degree at which a fresh concrete can flow, this allows for ease of compaction and placing of the concrete. The result obtained shows that COREN and ACI mix proportion are of high workability.

4.5 Differences between COREN and ACI Mix Design Method

The differences between COREN and ACI mix design method is presented on Table 4.3 and Table 4.4. Water-Cement ratio (W/C) in the ACI method is determined with the combination of two parameters: the target strength and the concrete type (air or non-air entrained) which is obtained from Table 3.1 While W/C ratio for COREN is obtained from Figure 3.1. Coarse and fine aggregate content for ACI method is obtained without knowing the absolute volume of the fine aggregate.

Table 4.3: Mix Design Calculated for 1m^3 of Fresh Concrete

Ingredients	ACI (N/mm^2)	COREN (N/mm^2)
Water(kg)	210.66	224.33
Cement(kg)	305.30	393.50
Fine aggregate(kg)	854.84	590.36
Coarse aggregate(kg)	946.26	1101.1
Water/cement ratio	0.69	0.57

Table 4.4: Analysis of 28-Days Compressive Strength

Target Strength (N/mm^2)	Average Strength (N/mm^2)		Strength Deviation (N/mm^2)	
	ACI	COREN	ACI	COREN
25	23.39	27.92	-1.61	2.91

CONCLUSIONS

This research work was carried out to compare ACI and COREN mix design method using materials of the same properties to determine the strength of concrete cubes cast and cured for 3,7 and 28 days. The following conclusions were drawn:

1. It was observed that the ACI mix method requires higher water content than COREN mix to be able of have a workable concrete.
2. COREN mix design gives higher strength development than ACI mix.
3. Concrete made using ACI mix design can be of low strength.
4. More quantity of cement is required in the use of COREN as compared to ACI mix.

Therefore, COREN mix design method should be used in the proportioning of concrete mix.

RECOMMENDATIONS

The following recommendations are made:

1) COREN mix design method should be used in the proportioning of concrete mix.
2) Mix design such as USBR Mix design practice, British Mix design Method, and ISI Recommended guidelines IS, should be compared with COREN mix design

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