Best Practice in Civil and Structural Engineering Works

Efficiency, Consistency and Sustainability in Concrete Production

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Abstract
In manufacturing concrete readymix & precast, there are factors which affect variation in things such as material, manufacturing process & testing method. Hence manufacturing concrete becomes inefficient and inconsistent. To overcome this problem, a computer software has been created to optimize gradation of aggregate thus the mortar factor can be determined (improvement of overall concrete performance)
Three graphs used for optimizing aggregate grading are:

- Individual percent retained chart
- Coarseness factor chart
- 0.45 power chart.

For all of the above, construction requirements that affect mortar should be considered when optimizing a mixture.

Keywords : Efficiency, consistency, sustainability, individual retained chart, coarseness factor chart, 0.45 power chart, Mortar Factor.

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1. Introduction

Aggregate gradation in concrete mixtures has been shown to affect constructability, strength, durability, pavement smoothness, and economy, as well as segregation, water requirements,and admixture dosage requirements. Optimized gradations are those that have been enhanced in some manner, such as making the material more well-graded, in order to enhance some property of the concrete. Additionally, shape has been mentioned as a possible factor in the successful use of optimized gradations and mortar factor.

The potential benefits resulting from using optimized gradations can be significant. Initial costs may be reduced if cement paste content can be lowered, as well as required air entraining agent dosage. If required water content can be lowered, shrinkage can be reduced along with potential cracking. If constructability is enhanced, then durability and smoothness can be improved, resulting in both lower initial and life-cycle costs.

When concrete production is efficient, consistent and sustainable, required aggregate gradation optimization can be measured through computer programs. This article focuses on how a computer program can produce good concrete mix through three graphs (Individual percent retained chart, Coarseness factor chart and 0.45 power chart) with Mortar Factor determined on all of them.

2. Three graphs in aggregate gradation optimization

2.1 The individual percent retained chart

The Percent Retained chart is a plot of the percentage of aggregate retained on each individualsieve. The chart can be used to indicate mixes that should be workable and have a reasonablylow water demand.

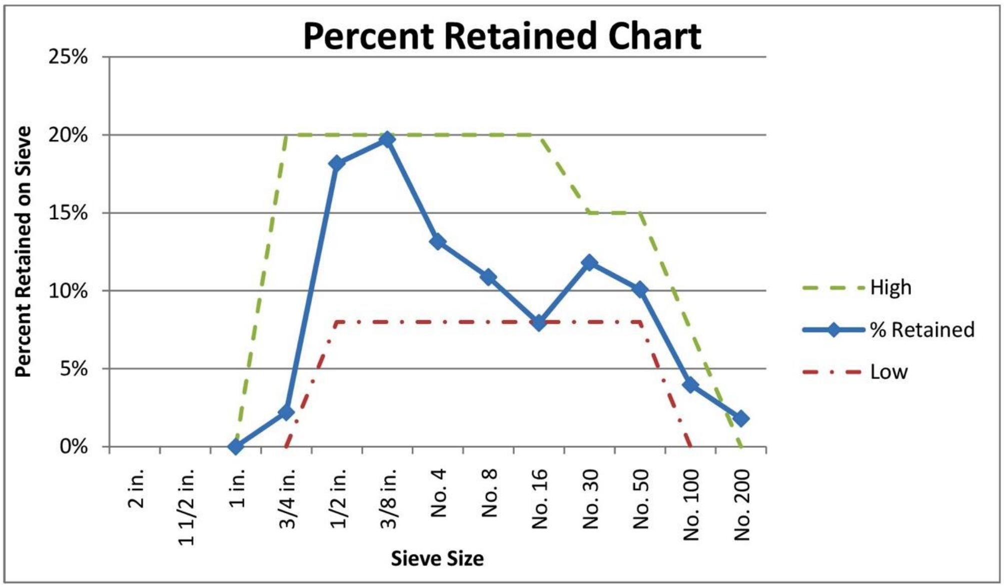

Fig. 1. Percent Retained Chart

2.2 Coarseness Factor Chart

The workability box shown is a reasonable target for the combined aggregate for many mixes. The workability box is defined by the corners coordinates shown. Combination that fall into the workability box have a higher probability of satisfying the project needs both during placement and for the long term.

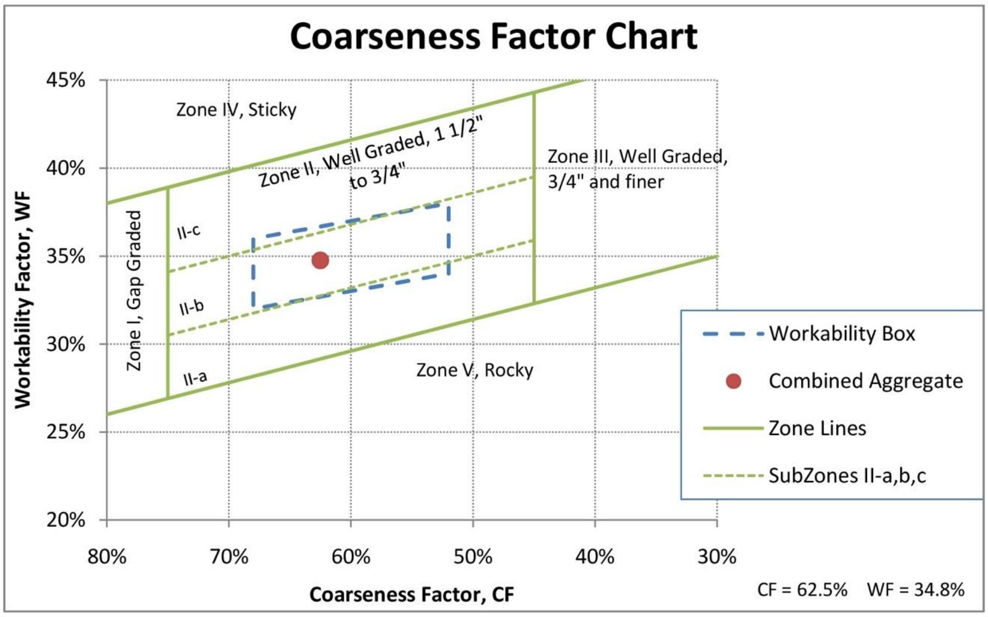

Fig.2.Coarseness Factor Chart

2.3 0.45 Power Chart

The Power Chart is a plot of the percent passing each sieve size and the sieve size in microns to the 0.45 power. A well graded, tight packing aggregate that produces a maximum density will approximately plot along a straight line.

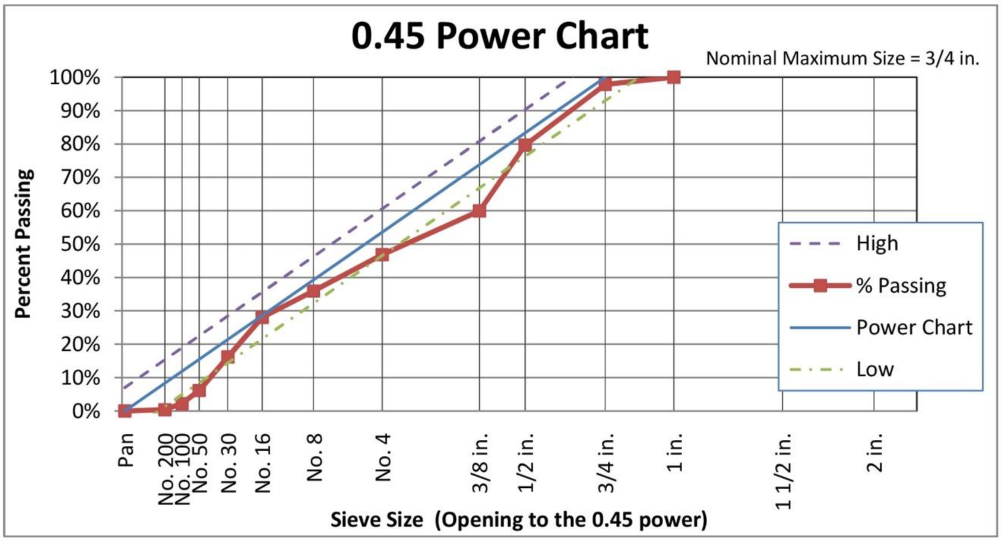

Fig. 3. 0.45 Power Chart

Combined aggregates that tend to plot above the Power Chart line will tend to be stiff and mayrequire high doses of high range water reducer. Blends that plot far below the Power Chart lineare too coarse and tend to segregate.

3. Mortar Factor

The Mortar Factor is an extension of the Coarseness Factor Chart. The mortar consists of fine sand (minus no 8 (2.3 mm) sieve) and the paste. With reasonably sound aggregates properly distributed, it is fraction of the mixture that has a major affect upon the engineer's interest in strength, drying shrink-age, durability and creep. It is also the segment that provides the contractor's need for workability, pumpability, placeability and finishability. Thus, it is the amount of mortar that is at the center of conflict of interests.

Construction requirements that affect mortar needs should be considered when optimizing a mixture. There are no fixed mortar factors, as they are influenced by particle shape, texture, and distribution. Approximate needs for ten construction classifications are shown below:

a. **Class 1** : Placed by steep sided bottom drop bucket, conveyor or paving machine. Approximate mortar required = 48 to 50 percent
b. **Class2** : Placed by bottom drop bucket or chute in open vertical construction. Approximate mortar required = 50 to 52 percent.
c. **Class 3** : Placed by chute, buggy, or conveyor in an 8 in (200mm) or deeper slab. Approximate mortar required = 51 to 53 percent.
d. **Class 4** : Placed by 5 in (125 mm) or larger pump for use in vertical construction, thick flat slabs and larger walls, beams, and similar elements. Approximate mortar required = 52 to 54 percent.
e. **Class** 5 : Placed by 5 in (125 mm) pump for pan joist slabs, thin or small castings, and high reinforcing steel density. Approximate mortar required = 53 to 55 percent.
f. **Class 6** : Placed with a 4 in (100 mm) pump. Approximate mortar required = 55 to 57 percent.
g. **Class 7** : Long cast-in-place pilling shells. Approximate mortar required = 56 to 58 percent
h. **Class 8** : Placed by pump smaller than 4 in (100 mm). Approximate mortar required = 58 to 60 percent
i. **Class 9** : Less than 3 in (75 mm) thick toppings. Approximate mortar required = 60 to 62 percent.
j. **Class 10** : Flowing fill. Approximate mortar required = 63 to 66

4. Efficient

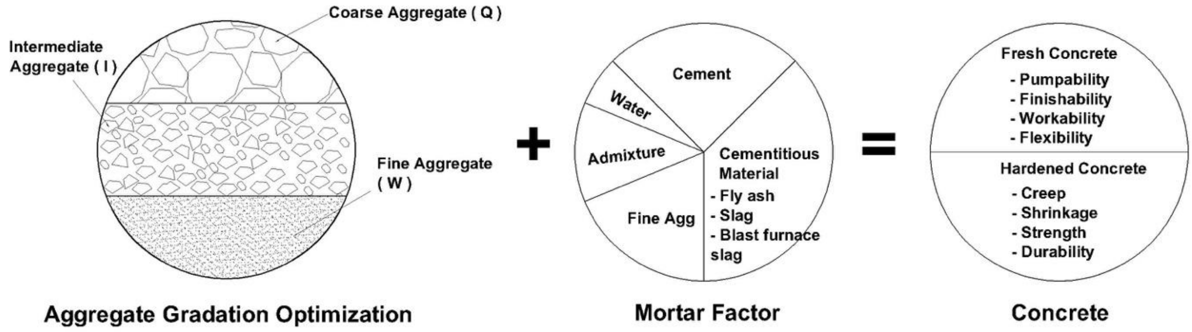

Fig. 4. Efficiency concrete flowchart

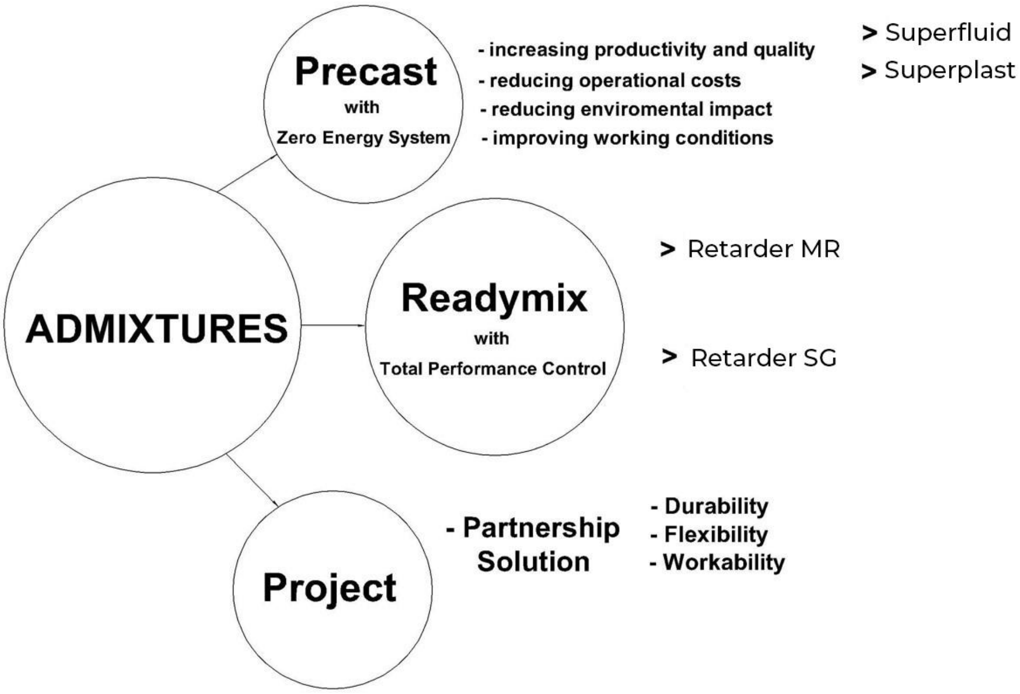

Fig. 5. Admixture Systems

Optimizing concrete aggregate in the mix design can have several benefits including increasedworkability, reduced segregation, reduced cracking, and reduced cement content. In manycase the end product can be improved with little additional cost and potential cost savingsfrom reduced cement usage.

To maintain the water cement ratio constant, the total cementitious materials factors will vary according to the mortar content. Thus, concrete with a higher mortar content should cost more than placed under restricted conditions. Decisions to use concrete with lower mortar and limited mobility should not be made arbitrarily. A requirements for a low mortar concrete can affect not only direct placement cost but also time of completion and added project overhead.

Calculated mortar content is heavily influenced by water and entrained air/ admixture. An entrained air tolerance of ± 1 percent of the volume is the equivalent of allowing the volume of water to vary slightly more than 33 lb/yd' (20 kg/m'). content by 0.02 percent and contribute to problems. In addition, as entrained air varies, water demand varies so the effect of the combined tolerances can be significant and cause construction problems.

The mortar factor can be used to judge the adequacy of the water provided in initial mixture proportions. ACI 211 provides guidance for selection of water for each aggregate size. This is fairly accurate when adjustments are made for water-reducing admixtures. Generally when W-Adj is high but the mortar is relatively low, there is not enough water provided in the proportions. The mortar factor needed for various construction types varies.

5. Consistent

5.1 Multigrade Multivariable Cusum

A major benefit of good control is earlier detection of problems. Specifications the world over deal with analyzing a number of 28 day results. It is crucial that actions are taken priorto low 28 day results. A downturn in mean strength can usually be detected in 3 or 4, 7 days results using cumulative sum graphing. The cause may be detected even earlier than this using cusum graphs of 24 hr density/unit wt, slump and temperature, batch plant error or sand grading.

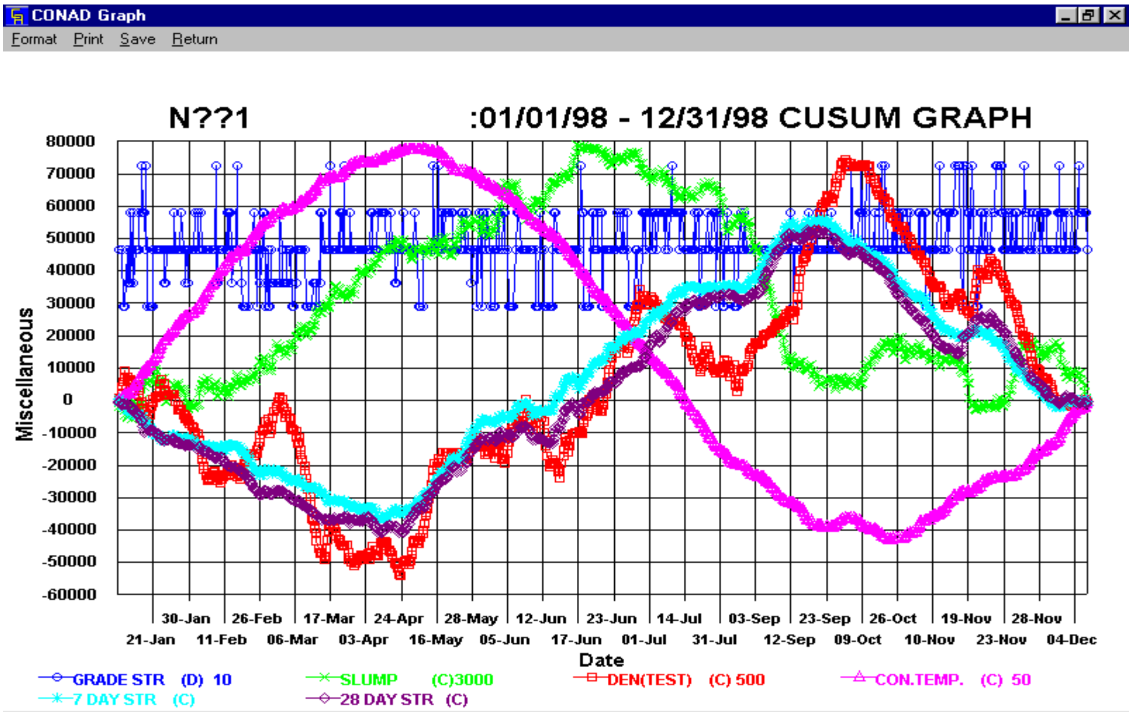

Fig. 3.Cusum Graph

5.2 Standard Deviation

Variability in compressive strength, as measured by standard deviation (S), is an excellent indicator of a company's quality. The sources of strength variation can be broadly categorized into three parts: material, manufacturing and testing. Under each category, there are many possible reasons for concrete variability. So to reduce the strength variability, standard deviation the material, manufacturing and testing variations need to be lowered.

5.3 Variation in concrete due to Batching

Concrete plants may have to be tuned, continually monitored & adjusted when necessary. If this is not practiced, two possible errors may occur:

1. Over batching material means giving material away & increased material cost per cubic yard produced.

2. Batch weights that are highly variable can cause significant variations in yield, strength & other performance characteristic of concrete.

Improving batching accuracy can help reduce over batching and thus reduce material cost per cubic yard produced, can help attain more consistent performance for fresh and hardened concrete properties, including variation of compressive strength of concrete and possible to quickly detect plants that have just had a breakdown or where one is about to occur, so helps reduce plant downtime and maintenance.

Many variability in the manufacture of concrete and concrete performance requirements are expected. In order to make concrete efficiently and consistently, a computer program is thus created which also helps to optimize aggregate gradation and assist early detection of decrease or increase in the quality of concrete.

6. Sustainability

A sustainable concrete structure is one that is constructed such that the total societal impact during its entire life cycle is minimal. Designing with sustainability in mind includes accounting for the short-time and long-time consequences of the structure. An integrated sustainable design process can reduce the projects costs and operating costs of the development.

6.1 Life cycle assessment (LCA)

LCA provides a method to quantify and evaluate potential environmental impacts throughout a product's life cycle from raw material purchase through production, use, end-of-life treatment, recycling to final disposal, commonly called cradle to grave (ISO, 2006). For LCA parameter three impact categories and resource indicators below are considered to be the most relevant :

- Cumulative energy demand — MJ
- Global warning potential — Kg CO_2-eq
- Eco indicator — Points

6.2 Environmental Product Declaration (EPD)

An EPD is an independently verified and registered document that communicates transparent and comparable information about the life-cycle environmental impact of product.

Table 6.1 Mixture proportioning comparison (steel troweled interior floors subjected to vehicular traffic)

	Conventional Concrete	Athletic Concrete
Cement	635 lb (290 kg)	575 lb (260 kg)
Sand	1200 lb (540 kg)	1080 lb (490 kg)
Coarse Aggregate	1850 lb (840 kg) No.67 (5 to 20 mm)	2100 lb (950 kg) No.467 (5 to 50 mm)
Water	305 lb (140 kg)	275 lb (125 kg)
Air content (entrapped)	1.5 %	1.5 %
Admixture	20 ± oz. (590 ml) Type A	HRWR-type F 40 ± oz. (1200 ml) or as required
w/cm	0.48	0.48
Slump	5 in (125 mm) maximum	Initial : 2 to 3 in (50 to 75 mm) Final : 5 to 7 in (125 to 180 mm) After addition of HRWR

Table 6.2.The LCA Parameter for Conventional Concrete

LCA Parameter				
	Cumulative Energy Demand (MJ)	CML 2001 (Kg CO_2-eq)	Input Water (kg)	Eco-Indicator 99 (Points)
Cement	888.421	206.242	0.00	3.686
Admixture	0.000	0.000	0.35	0.000
Additive	0.000	0.000	0.00	0.000
Water	0.000	0.000	140.00	0.000
Agregate	291.908	19.115	0.00	19.042
Transport	0.000	0.000	0.00	0.000
Total	**1180.329**	**225.357**	**140.35**	**22.728**

* Specicifications per 1 m^3

Table 6.3.The LCA Parameter for Athletic Concrete

LCA Parameter				
	Cumulative Energy Demand (MJ)	CML 2001 (Kg CO_2-eq)	Input Water (kg)	Eco-Indicator 99 (Points)
Cement	796.515	184.907	0.00	3.305
Admixture	0.000	0.000	0.72	0.000
Additive	0.000	0.000	0.00	0.000
Water	0.000	0.000	125.00	0.000
Agregate	318.532	20.554	0.00	21.187
Transport	0.000	0.000	0.00	0.000
Total	**1115.048**	**205.461**	**125.72**	**24.492**

* Specicifications per 1 m^3

7. Conclusion

The complexity of the parameters and the variability in the manufacturing of concrete lies within these 3 factors:

- Material
- Testing
- Batching

We need to catch up to the rest of the developed world when it comes to concrete production. In order to accomplish this we need to do the following:

- Let (or force) concrete producers handle their own quality control. If you go into Ford Motor Company and tell them you want to do QC on the car they are building for you I guarantee you won't get past the Detroit Looney bin. There is a saying that no one can control quality except the man doing the work. This is not a case of the fox guarding the henhouse. This is a case of a professional company putting out a product that performs as advertised. Owners can still do quality assurance testing, but let the concrete producer do the real QC. Producer QC departments would become certified to make certain that they perform capably and responsibly.

- Get rid of fixed-weight concrete recipes and allow the producer to change materials and weights as needed to produce more uniform concrete. If you were to walk into a cement plant on Jan. 1 and tell them they had to use a fixed proportion of materials for the rest of the year they would laugh you out of the plant. Steel, paper, petrochemicals and foodstuffs are the same. The materials that come in today are not the same as those that will come in next week. We need to adjust accordingly.
- Designers should specify concrete based on performance, not prescriptive requirements. Admittedly some performance requirements we can't yet define but we are getting better at it. I know there is concern in the slab industry about issues such as curling, shrinkage and segregation, but if a design/build/maintain approach or a partnering technique can be implemented where all parties share in the risk and reward, maybe improvements can be made to that process.
- Replace or retrofit batch plants with just 2 or 3 aggregate bins to allow the use of 5 or more aggregates in a single mix design. Combined aggregate gradings could be reproduced that would be best suited to appropriate particle shape and texture.
- Implement education and certification requirements for concrete producers so they can rise up from the "trucker" mentality. There is still a place for the Mom and Pop producer, but usually not on a 70MPa high-rise. In a recent research it was stated that during the recent economic downturn the concrete companies that were the most stable were the Mom and Pops.
- Recognize the importance of outsourcing functions that Mom and Pops can't reproduce.
- Switch from a "low bid" mentality to a "lowest responsible bid" mentality where a concrete producer must demonstrate an ability to produce the required class of concrete in order to be able to bid on a job.
- Apply similar changes to Contractors. There is no place on a commercial project for a Contractor who assigns a laborer to watch concrete going into a pump and spray water from a hose into the pump hopper when the concrete looks "dry".

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