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Challenges in performance testing of asphalt mixes

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Presentation outline

Challenges to be faced by laboratories with performance-based tests, and possible solutions

- Complexity of testing machines
- Lack of repeatability of performance-based tests
- Complexity of the test configuration and long duration of the test
- Compatibility with “new” materials
- Future challenges



Complexity of testing machines



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Dynamic Testing Machines

- Developed in Universities from the '60s
- Designed to perform the widest ranges of asphalt and unbound materials tests
- First based on pneumatic actuation, then gradually replaced by servo-hydraulic actuators
- Designed to be flexible and upgradable to multiple test configurations



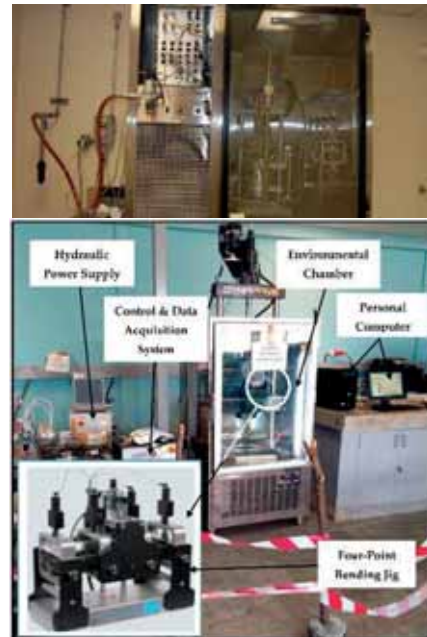
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Challenges 1/2

- Complicated machines, composed by different parts (frame, cabinet, controller, pump, PC) and requiring multiple connections and cables to be operative
- Multiple components require large areas in laboratories (typically >3m width)
- Hydraulic pumps are quite noisy, so long term use in laboratory environment could cause issue with workers' comfort



Challenges 2/2

- Complexity of the machine configuration and the need to setup multiple parts require skilled technicians
- Current servo-pneumatic and servo-hydraulic systems require frequent maintenance (filter replacement, leakage check, oil replacement)
- The complexity of the system is associated to high acquisition and maintenance costs



Solutions – 1. Fully integrated machines 1/3

- Two separate projects in the 90s by National Cooperative Highway Research Program (NCHRP) in United States brought to the development in 2002 of a fully integrated dynamic testing machine, called Simple Performance Tester (SPT)
- The target of the project was the development of a fully integrated, quick, simple, repeatable and easy to use testing equipment able to automatically perform the candidate performance tests defined by NCHRP Project 9-19
- It was then renamed Asphalt Mixture Performance Tester (AMPT)
- IPC Global was the only manufacturer succeeding in developing SPT in 2002



Solutions – 1. Fully integrated machines 2/3

- Due to these new features, AMPTs were (and still are) very successful in American market, but few limitations apply to this machine:
 - Despite the all-in-one approach, the machine includes all the component of a traditional servo-hydraulic system, with all the disadvantages in terms of cost, complexity and maintenance
 - AMPT is designed to perform a limited range of tests to ASTM/AASHTO standards, so it's not applicable to EN standard or bigger accessories (see 4PB)



Solutions – 1. Fully integrated machines 3/3

- The first development came in terms of universal use, with the development of an “international” version of AMPT, called AST (Asphalt Standards Tester) combining “all-in-one” approach of AMPT with a more traditional frame and cabinet
- Suitable for the performance of most common standard tests, including bending tests, both to ASTM/AASHTO, and European Standard too
- BUT still with disadvantages coming from use of servo-hydraulic application



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Solutions – 2. All-in-one Electro-mechanical machines 1/2

- Evolution in high-performance brushless motor technology allows their use for dynamic applications
- Electromechanical actuators now grant a level of performance (load capacity, waveshape accuracy) comparable with current state-of-the-art servo-hydraulic actuators based on labyrinth actuators
- Quick and simple installation without the complexity of hydraulic systems, clean and with no associated noise
- Virtually maintenance-free (only greasing)
- No need of hydraulic oil or refrigerants



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Solutions – 2. All-in-one Electro-mechanical machines 2/2

- New fully electric systems allow more cost effective and less complicated solutions (all the power parts involved in servo-hydraulic systems, such as actuator, servo-valve, pipes, pump, filter and oil – are replaced by an electric motor and a screw)
- The all-in-one electromechanical systems are available with different load ranges (up to 15 or 30kN), covering all EN, ASTM or AASHTO test applications for both quality control or research applications



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Lack of repeatability



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Challenges 1/2

- Most of performance-based tests (typically fatigue cracking and permanent deformation tests) have a low repeatability and require multiple test repetitions
- For most of performance tests, to have homogeneous, uniform and repeatable specimens can be challenging
- The way specimens are prepared (compacted, cut or cored) have a big effect on test repeatability, and this is often not sufficiently defined by standards



Challenges 2/2

- Multiple test performance affects their possibility to be included in Technical Specifications
- Multiple test repetition increases the duration of the test sessions, the number of needed specimens and generally the cost of the test



Solutions – 1. Improvement of specimen preparation 1/3

- With performance testing, specimen preparation has become a critical parameter for affordable test results
- Specimen preparation should ideally match the same conditions as how the pavement will be constructed in the field
- Lab prepared specimens needs to have the same particle orientation, air void distribution and density homogeneity as field samples
- The effect of the operator should be reduced as much as possible



Solutions – 1. Improvement of specimen preparation 2/3

- The use of high capacity laboratory mixers allows to have large asphalt mix batches, suitable to compact and prepare multiple specimens with homogeneous mix properties
- Gyratory, slab or shearbox compactors, having a closer particle orientation to on-site asphalt and allowing larger specimens, should be preferred to impact compactors
- These compactors also allow a strict control of the compaction parameters and to compact specimen with precise volumetric properties (target density or voids)



Solutions – 1. Improvement of specimen preparation 3/3

- When larger specimens are required to be cut to smaller specimens, automated cutting machines allow to get smooth and regular cuts
- Accessories and cutting jigs grant accurate cut with minimum effort (e.g. cut cylinders to halves for Semi-Circular Bend - SCB tests)
- Laboratory coring machines allow both axial or transversal overcoring on cores taken from the road



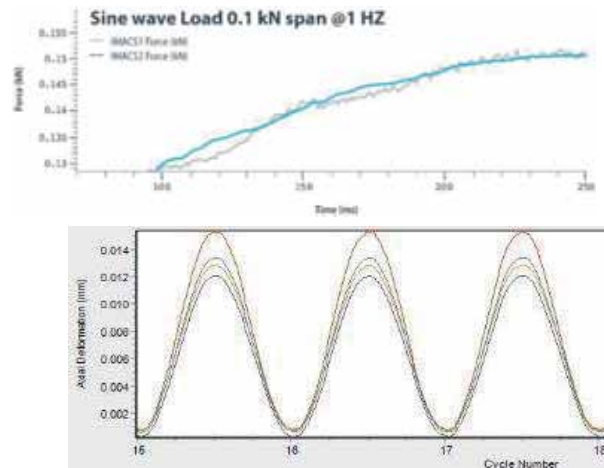
Solutions – 2. Improvement of testing systems 1/3

- Dynamic testing machines deliver testing results thanks to dedicated controllers, able to control the test performance and to grant the machine to carefully control and measure all the test parameters
- Test performance is typically done by dedicated software modules, developed to allow an easy test setup and clear test results



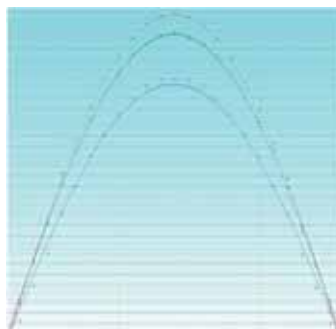
Solutions – 2. Improvement of testing systems 2/3

- Latest generation electronics dramatically improve the quality of waveshapes and transducer readout, allowing more precise and repeatable results
- For example, at 25 Hz, the single waveshape can be defined up to 8000 points with a 200 kHz sampling rate
- Systems with full 24-bit resolution 2^{24} can measure down to $1/16,777,216^{\text{th}}$ of transducer's span
- Oversampling helps to obtain “clean” data



Solutions – 2. Improvement of testing systems 3/3

- On the software side, possibility to apply fitting algorithm based on regression on continuous (e.g. sinusoidal) waveshapes, to have more reliable results, mainly on parameters depending on timing (e.g. phase angle)
- On the hardware side, systems with smart auto-recognition of “plug & play” transducers reducing operator errors (e.g. using the wrong transducers)



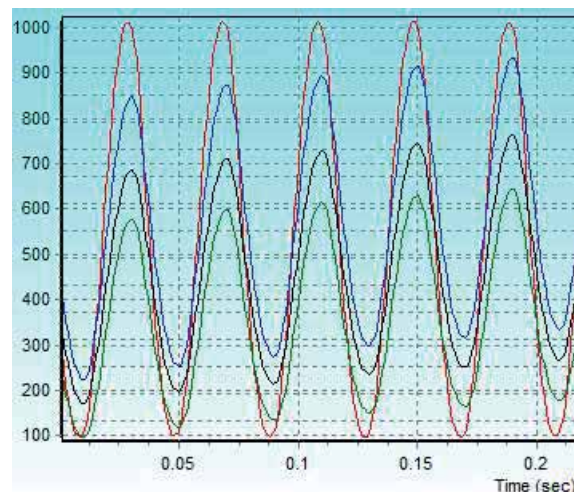
Solutions – 3. Improvement on test specifications 1/3

- Over the last years, several standards tried to address in a stricter way the parameters more impacting on the test repeatability
- This process is typically done when a new method is implemented
- This process can also be performed on existing test methods, but it's time consuming since it requires round robins to address the issue and to validate the updated specification
- A couple of examples are shown in the next slides



Solutions – 3. Improvement on test specifications 2/3

- When AMPT was released, one of the critical parameters in AMPT E* Dynamic Modulus was the accuracy of the load sinusoidal waveshape
- Current AASHTO T378 standard and AMPT specifications include an admissible error on the load waveshape, defined at 10%
- This error limit easily allows the user to identify conforming and non-conforming tests, while visual check of sinusoidal waveshape quality is critical



Solutions – 3. Improvement on test specifications 3/3

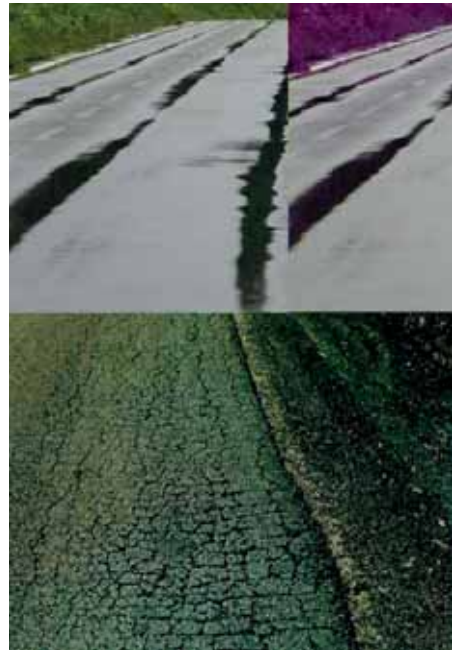
- NCHRP funded an experimental program to address all the potential issues with Hamburg Wheel Tracker
- A report was released in 2015, including many recommendation on improvement on the method, mainly on the control of the wheel sinusoidal movement
- In 2019, an updated version of AASHTO T324 including most of the recommendations (e.g. limits to RMSE parameter, to define the wheel movement) was issued



Complexity and duration of tests

Challenges 1/2

- Performance-based tests are typically associated to complex and time-consuming testing procedures, reducing their possibility to be used for quality or production control
- Test simulating long term distresses (permanent deformation, fatigue cracking) require long duration tests and multiple test repetitions



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Challenges 2/2

- Some tests (e.g. wheel tracking test, 4PB) require large specimens and complicated specimen preparation procedure, with the need of big and expensive compaction equipment.
- This typically reduces specimen homogeneity and dimensional uniformity, affecting test repeatability and increasing the need of additional tests
- Large specimen dimensions don't allow to test specimen coming from existing pavement, especially for top layers



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Solutions – 1. Use of smaller specimens 1/2

- Some test configurations have limited effect of the specimen dimensions, so test results are almost independent from the size of the specimen
- Typically, push/push, push/pull or pull/pull tests on cylindrical specimens have this type of behavior
- Small scale specimen geometries performance is not significantly different than full-size in most cases
- In United States there is an ongoing process on developing existing test methods on smaller specimens, typically 38mm (or 50mm) diameter x 110mm tall



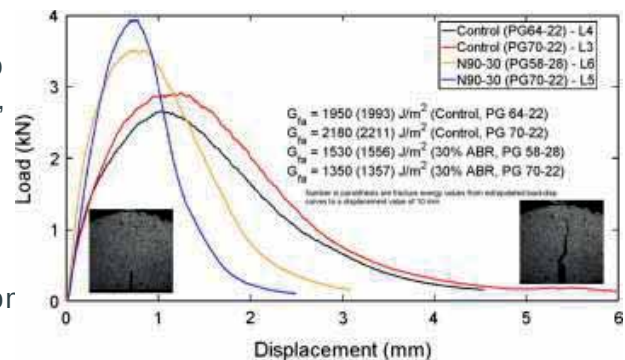
Solutions – 1. Use of smaller specimens 2/2

- Dynamic Modulus, Flow Number and Uniaxial Fatigue testing procedures have been released (AASHTO TP132 and TP133)
- Specimens can be obtained by multiple axial coring of 150mm gyratory specimen, granting high specimen repeatability
- Conditioning and gluing time are much shorter than full-size specimens
- Small size is compatible with specimens taken from cores, for evaluation of existing pavements
- Max T 40°C is recommended



Solutions – 2. New QC-oriented methods 1/3

- To have the possibility to include performance-based tests in Technical Specification, there's an ongoing process to include new tests suitable for QC purposes, correlating well with standard cracking or rutting tests
- These tests typically:
 - include energy-based evaluation criteria
 - are performed on specimens coming from cylinders (gyratory, or even Marshall)
 - are performed in few minutes and are compatible with standard Marshall or variable speed testers



Solutions – 2. New QC-oriented methods 2/3

- Most common methods for fast determination are SCB (Semi-Circular Bend) tests
- These tests are widely used with different test parameters to different standards (EN 12697-44, ASTM D8044, AASHTO T393, ...)
- The 150mm specimen is cut in two parts, and a notch is cut
- The energy-based evaluation allows to correlate with other cracking tests or with field performance, and to discriminate the use of RAP and alternative materials



Solutions – 2. New QC-oriented methods 3/3

- Other new methods include IDEAL-CT test to ASTM D8225, where energy-based Semi-Circular Bend (SCB)-type criteria are applied to standard 150mm indirect tensile configuration, avoiding the need to cut specimen and notch
- On the other hand, new IDEAL-RT test, to brand new ASTM D8360 standard, is a constant-speed test on 150mm cylindrical specimen to determine the rutting properties of the mix, and the results correlate well with field rutting performance



New materials

Challenges

- Increasing popularity of new technologies, such as polymer modified binders, alternative materials, asphalt rubber and recycled asphalt, warm mixes, creates the need to adapt existing testing methods to different parameters (load, temperature,...) to match the needs of new materials
- Use of cold mixes using bituminous emulsions, because the presence of water during compaction, can create safety issues because of accidental contact with electric parts of testing machines



Solutions – Adaptation of existing testing machines 1/2

- Development of flexible machines, or adaptation of existing ones, suitable for use with different materials.
- For example, asphalt mix compactors such as gyratory or slab compactors are now suitable for use with cold mixes – they include a system to separate, collect and weight leaking water
- Additionally, systems are ready for use with alternative materials, such as gyratory compactors suitable to test fresh zero-slump concrete, conforming to Nordtest NT Built 427



Solutions – Adaptation of existing testing machines 2/2

- Binder testing machines allow to adjust testing parameters to adapt to different binders: for example, RTFOT ovens allow to set target temperatures different from standard 163°C, up to 200°C to be used with PMB binders
- Traditional tests such as ductility meters can be upgraded with load cells to measure the elongation energy for modified binders, to EN 13589



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Future challenges



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Challenges 1/2

- During the last 20 years, a range of factors have brought to an increased popularity of performance-based testing methods. This is due to many factors, including:
 - Improved knowledge on material properties
 - Improved availability, technology and lower cost of testing machines
 - Increased use of new materials requiring performance testing to determine the change of properties
 - Need to perform tests able to address specific on-site distresses



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Challenges 2/2

- However, few factors are still limiting a real large-scale applications of performance testing, sometimes limited to research applications or special projects
- Among these factors, the ones still to be widely faced are:
 - “Dispersion” of test methods – single property is defined by multiple tests
 - Lack of shared Technical Specifications based on performance testing



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Dispersion of test methods – 1/3

- Unlike many other mechanical properties, most of performance-based properties can be measured by alternative test methods
- For example, EN 12697-26 standard for determination of stiffness properties includes 6 (in reality 7) different alternative test configurations to measure the same parameter
- At the same time, a correlation among the same property measured by different test configurations is not always available

Type of loading	Force function: F [N]	Mass factor: α [s]
ITB-TB	$\frac{15P}{80(1-\lambda_1^2)} \left[2 - \frac{3\lambda_1}{\lambda_2} \left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2} \right) \right]$	$4.103 M \times 10^{-6}$
ITB-EB	$\frac{F_0}{80}$	$\frac{M}{2} \times 10^{-6}$
ITB-EB	$\frac{32P}{75(1-\lambda_1^2)} \left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2} \right)$	$\frac{M}{2} \times 10^{-6}$
ITB-EB	$\frac{F_0 A \left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2} \right)}{80 \left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2} \right)}$	$8.103 \left(\frac{M}{\lambda_1^2} - \frac{M}{\lambda_2^2} \right) \times 10^{-6}$
IT-CY and IT-EB	$\frac{1}{8} (a + 0.27)$	—
IT-CY	$\frac{15}{10}$	$\frac{M}{2} \times 10^{-6}$
IT-CY IT-EB	1	0

Dispersion of test methods – 2/3

- Additionally, different international standards, such as ASTM/AASHTO and European Standards, define different methods to measure performance properties
- As a result, different geographical areas, even in the same region, use different methods to measure the same properties, and this limits a shared knowledge on asphalt material properties and technologies



Dispersion of test methods – 3/3

- In Europe, there's an ongoing process to widely review Construction Products Regulation (CPR) and, among the new inputs, there's a request to define a single property by a single method, or equivalent ones
- Two possible roads are available for future:
 - Selection and reduction of the number of alternative methods to define the same property
 - Development of correlations between alternative test methods, to allow the use of multiple test configurations



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Lack of Technical Specifications – 1/7

- Probably an effect of the previous issue, there's also a lack of shared and common performance-based Technical Specifications
- Unlike binder testing, where - in United States - Superpave Performance Grading (PG) created a common base for performance-based binder classification, a shared framework is still missing, or only limited to Volumetric Mix Design
- In Europe only single Countries have Technical Specifications that partially include performance-based tests as main verification tool



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Lack of Technical Specifications – 2/7

- National Cooperative Highway Research Program (NCHRP) tried to address this issue with a dedicated Task Group, and the result was the definition of a framework called Balanced Mix Design (BMD)
- BMD is defined in AASHTO PP105, released in 2020, as “asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress taking into consideration mix aging, traffic, climate and location within the pavement structure”.
- One of the targets of BMD is the design of a mix granting a durability both to cracking and rutting distresses.



Lack of Technical Specifications – 3/7

- Balanced Mix Design currently includes 4 alternative approaches
- BMD approaches vary from level A to level D, varying from a more conservative to a less conservative and potentially innovative approach
- Level A is an approach where Optimal Binder Content (OBC) is defined only with traditional Volumetric Mix Design, then tested with performance testing to assess cracking and rutting properties
- At the opposite, Level D is an approach where the mix components and proportions are only defined by performance testing, and no volumetric mix design is involved

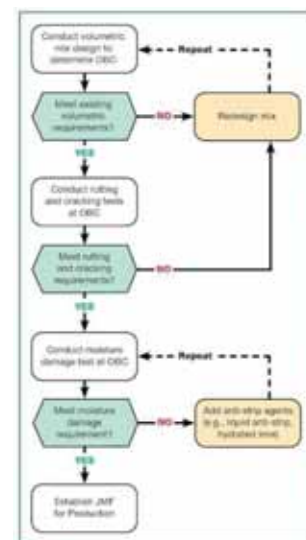


Figure 1. Graphical Illustration of the Volumetric Design with Performance Verification Approach (Approach A)

Lack of Technical Specifications – 4/7

- Balanced Mix Design must include performance tests to assess both cracking and rutting behavior
- Tests and criteria are defined in AASHTO MP46, even if current version (2022) doesn't include recommended criteria for all available test methods
- Current Balanced Mix Design specifications include 7 alternative methods for rutting assessment and 14 alternative methods for cracking assessment



Lack of Technical Specifications – 5/7

- The main rutting tests included in BMD are:
 - AMPT Flow Number (AASHTO T378)
 - Hamburg Wheel Tracking (AASHTO T324) – also suitable for moisture damage
 - Incremental Repeated-Load Permanent Deformation (iRLPD – AASHTO TP116)
 - Stress Sweep Rutting (SSR – AASHTO TP134)
 - Also IDEAL-RT is considered by DOTs



Lack of Technical Specifications – 6/7

- The main cracking tests included in BMD are:
 - Direct Tension Cyclic Fatigue (AASHTO T400/TP107), also on small diameter 38mm diameter specimens (AASHTO TP133)
 - Flexural Bending Beam Fatigue (AASHTO T321)
 - SCB, I-FIT method (AASHTO T393/TP124) or Intermediate temperature (ASTM D8044)
 - IDEAL-CT (ASTM D8225)
 - Overlay (Tex-248-F)



Lack of Technical Specifications – 7/7

- Balanced Mix Design is an example on how to create a framework for Mix Design based on performance-based testing
- Still an ongoing process to identify the best procedure, choice of tests and criteria
- BMD framework also includes corresponding QC/QA specifications
- But strictly related to American traffic and environmental conditions, and test methods: need of an equivalent process on global scale



Takeaways 1/2

- Complexity of testing machines – New electromechanical testing machines allow to deliver performance tests with simpler and most cost-effective testing units
- Lack of repeatability of performance-based tests – New generation specimen preparation devices, combined with updated testing equipment and, possibly, improved test specification, allow to deliver more repeatable testing results
- Complexity of test configuration and long duration of the test – New test methods, based on QC-oriented approach and on the use of smaller specimens, allow to grant affordable performance testing results in simpler and faster way



Takeaways 2/2

- Compatibility with “new” materials – Existing test methods and consolidated testing machines can be adapted to use with innovative materials with minimal updates
- Future challenges – A wider and more effective use of performance-based tests goes through an improvement of current testing specification, in order to reduce alternative test methods or to improve correlations among them. Consequently, there's the need to improve current performance-based asphalt mix specifications.





Thank you

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