EVALUATION OF THE BUILDING CODE APPLICATION IN MEXICO CITY

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SUMMARY:
The Mexico City Building Code (MCBC-2004) is a state-of-the-art code and the most comprehensive and advanced set of requirements in the country, so it is used as a model for codes of other regions. However, it is known that there are not enough official mechanisms for supervising the design and construction of new structures. The purpose of this study is to evaluate the current practice and its comparison to the guidelines of the MCBC-2004 using a sample of structures randomly selected from a database of buildings constructed after 2004. A group of 150 buildings was randomly selected for performing sidewalk inspections. Structural analysis and design revisions were made for the sample of 20 buildings using the information provided by the authorities and in site detailed inspections, including, in some cases, concrete testing and scan of reinforce steel to verify the original specifications.

Keywords: Mexico City Building Code, seismic design, new structures

1. INTRODUCTION

Building codes issued by authorities have the basic aim of guarantee a correct performance of structures during seismic events and prevent human life losses; therefore, they must include the experience and knowledge generated by previous seismic events and by research from the country and all around the world. The last version of the Mexico City Building Code (MCBC), published in 2004, is a state-of-the-art code and the most comprehensive and advanced set of requirements in Mexico, so it is used as a model for codes of other regions.

The MCBC-2004 also contains modifications to the legal proceedings for construction, making enough with present a building declaration, and inhibiting the faculty of delegations for expediting building licences. Also in 2004, it was decreed a law for urban regulation known as "Bando Dos" which basically promoted the constructions in zones with medium-high seismic hazard. These changes in the building law increased rapidly the housing and urban development in the city, particularly in zones of medium-high seismic hazard. However, there are not enough official mechanisms for supervising the design and construction of new structures. The security, vigilance and responsibility of the MCBC-2004 rely only over the Building Responsible Director (BRD) and their Structural Security Co-responsible (SSC). The generalized opinion of experts in Mexico City is that many of those buildings do not achieve the requirements established in the MCBC-2004, therefore, the probability of an inadequate behaviour of structures increase, consequently the risk for their occupants.

The purpose of this study is to evaluate the current practice and to compare with the guidelines of the

MCBC-2004 using a sample of structures randomly selected from a database of buildings constructed after 2004, with the final goal of proposing a set of recommendations that help to correct the observed deficiencies in construction.

2. BUILDING DATABASE FOR MEXICO CITY

2.1 Assembling the building database

The Institute of Engineering at UNAM has worked on the elaboration of digital maps and databases on GIS (Geographic Information System) formats. This database includes detailed information about structural characteristics and structural damage due to past earthquakes (1957, 1979, and 1985) complemented with hundreds of inspections. The information on a GIS platform improves storing, manipulating, analyzing, managing and presenting all the geographically referenced data, however, the number of buildings contained in the dataset represents a extremely low percentage of the buildings of Mexico City.

A database of building information was obtained from the Mexico City government, based on the property land tax database. The building information includes year of construction, number of stories, construction area, occupancy of the building and type of structural system. The database was analyzed and used to assemble a GIS data set. The quality of the database of property land tax was verified. It was emphasised that interpretation of data and criteria used were adequate and consistent with information contained in database. This process was done with support of the Ministry of Finances staff of Mexico City.

To verify the structural information of the database, quick visits were made to some buildings and comparisons with the information compiled through the years by the Institute of Engineering at UNAM. From this activities, it was concluded that the information contained in the database of property land tax is reliable and adequate for the aim of this study.

2.2 Sample of random buildings

Once the database has been reviewed and verified, the next step is to select a sample of buildings to carry out the inspections. In order to chose the buildings that will be part of the sample, it must have the following characteristics:

- Location in the Delegations with the highest seismic hazard (Benito Juarez, Cuauhtemoc or Venustiano Carranza)
- Use of housing
- Number of stories equal or greater than four. Buildings with less stories have had an adequate behaviour in past seismic events in Mexico City
- Built after 2004, when MCBC-2004 and "Bando Dos" became effective

The total number of buildings that achieve these conditions were 13,428 (Table 1); and from this universe, a random sample of 150 buildings were selected to perform sidewalk inspections. The location of this sample of buildings is shown in Fig. 1. A second sample of 20 buildings was chosen from the 150 buildings selected to review their structural plans and notes, and to perform detailed inspections and structural analysis (see red dots in Fig. 1).

Table 1. Number of new buildings (constructed after 2004) in the selected delegations

DELEGATION	BUILDINGS	%	BUILDINGS VISITED
Cuauhtemoc	5,477	40.79	61
Benito Juarez	6,105	45.46	68
Venustiano Carranza	1,846	13.75	21
TOTAL	13,428	100.00	150

Figure 1. Location of the 150 buildings selected to make street inspections (black dots) in the three Delegations of Mexico City. Red dots represent the 20 buildings which were evaluated in more detail

3. STRUCTURAL PLANS AND NOTES

According to the MCBC-2004, a copy of structural plans and notes must be submitted to the authorities while the BRDs must keep another set for at least ten years after the building is concluded. The structural plans should contain a complete and detailed description of the structure and should include information about essential design parameters (*i.e.* live loads, seismic coefficients, quality of materials, etc.). The structural notes should describe the structural criteria used by a specialist, the main results of the performed analyses and design. This information should be detailed enough to be evaluated by an external specialist, and it will include the values of design loads, models and procedures used in the project. In this section the information contained in the structural plans and notes of the sample of 20 buildings will be reviewed to evaluate if they follow the MCBC-2004 provisions.

3.1 Information provided by authorities

The information of the 20 buildings randomly selected was proportionated by the Government of Mexico City authorities. This information was submitted by the BRDs with the building declaration under penalty of perjury that the MCBC-2004 provisions are achieved. The conclusions of detailed reviews are shown in Fig. 2.

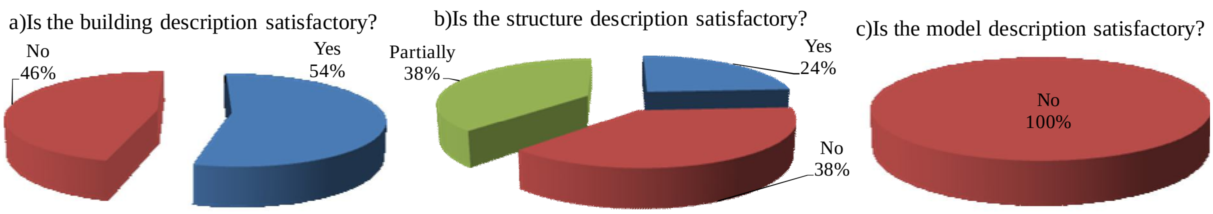

Figure 2. Statistics of inspection of structural notes

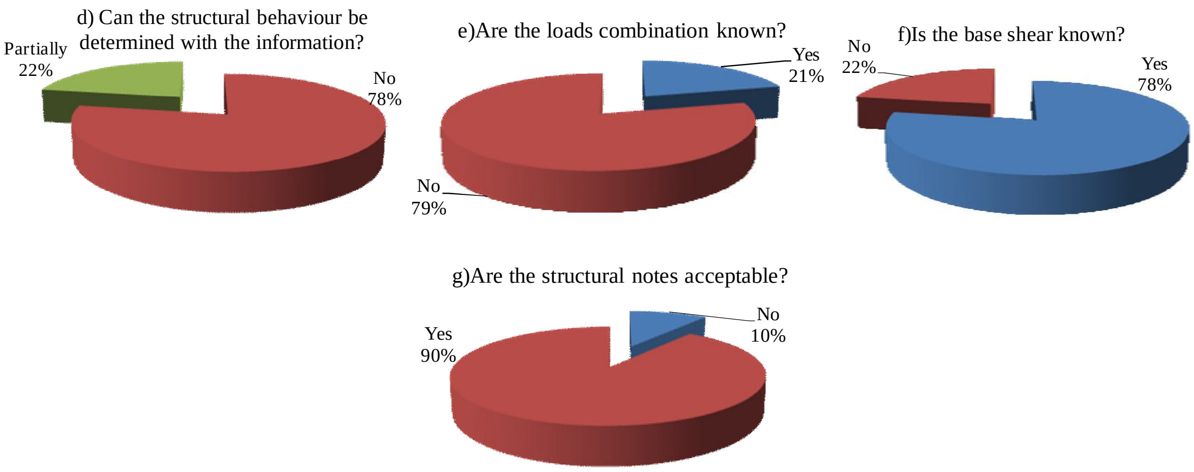

Figure 2. Statistics of inspection of structural notes *(Continuation)*

3.2 Information provided by Building Responsible Directors

It is common in Mexico City's practice that the project suffers changes during the construction process due to unforeseen circumstances, lack of engineering planning, or even deficient construction planning. Therefore, it is that the constructed building be different to the project submitted to the authorities. Usually, the documentation keep by the BRDs include the improvements made to the original project. For this reason, the structural plans and notes were also requested to the BRD's; this information was compared with the information given by the authorities. Only for 8 buildings (40% of the requested) was possible to obtain information available to make the comparisons. From these, in 3 of the 8 sets of information were different. The principal differences consisted in information with more detail in structural sections and some structural elements added.

4. INSPECTION OF BUILDINGS

Once the structural plans and notes were analyzed, the next step was to inspect the sample of 150 buildings by means of sidewalk inspections performed by a staff of three engineers equipped with photo and video cameras. In the sample of 20 buildings, it were requested authorizations to the owners to realize the next: 1) detailed visual inspections from inside, 2) extract concrete cores, and 3) scanning the reinforce steel in some structural elements.

4.1 Sidewalk inspections

These inspections were done from outside of the buildings, at the sidewalk, because it was considered adequate to observe the main structural characteristics of the sample of 150 buildings. The main structural aspects reported, besides the number of stories and the structural type (masonry, concrete frames, and concrete walls), were irregularity conditions such as: 1) pounding possibility, 2) soft first story, 3) vertical irregularities, 4) short columns, and 5) corner configuration. These conditions have historically caused many structural failures in Mexico City and all around the world (Rosenblueth and Meli, 1986; Esteva, 1988; Esteva, 1992; Searer and Fierro, 2004; Guevara and García, 2005). The statistics result of the sidewalk inspections are shown in Figure 3.

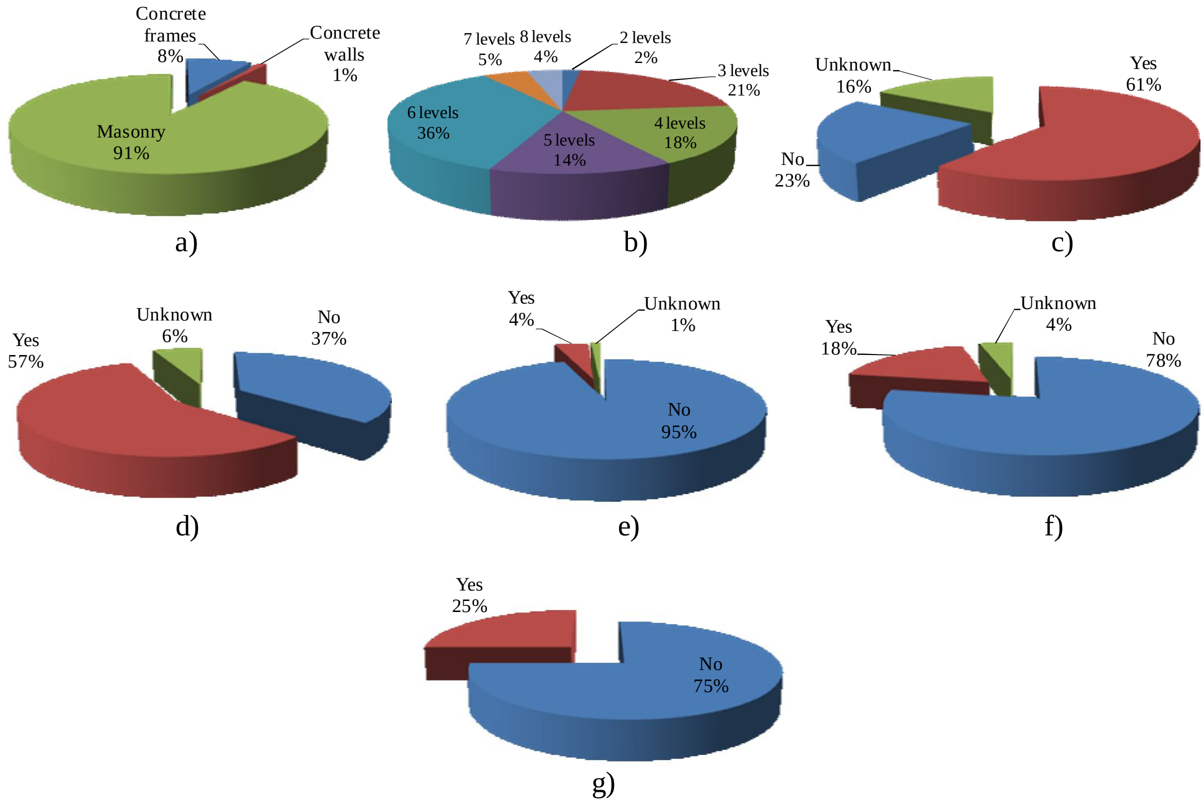

Figure 3. Statistics of structural aspects observed in the sidewalk inspections: a) structural system, b)Number of stories, c) pounding possibility, d)soft first story, e) vertical irregularities, f)short columns, and g) corner configuration.

4.2 Detailed visual inspections

In the sample of 20 buildings, authorizations were requested to owners to perform detailed inspections inside the buildings. Only in 8 of the 20 buildings was of interest from the owners on inspections. The detailed inspection consisted in fill out a form with information about the geometry of structural elements, structural reparations, evident damage in structural and non structural elements, and performance of the building during past seismic events. Some of the buildings presented damages in non structural elements; however, it was remarkable one case where the building had important structural damage.

4.3 Extracting of concrete's cores and scanning of reinforce steel

Tests to concrete elements in 7 of the 20 buildings were done with the aim of verifying if they achieved with the project specifications. It was determined the resistance to compression, the module of elasticity and the volumetric weight in some columns and beams of the first levels according to Mexican standards (NMX C-169-1997-ONNCCE and NMX C-128-1997-ONNCCE). Also, scanning of reinforce steel were done and the results were compared with the steel configuration in the structural plans. In the guidelines of MCBC-2004 for Design and Construction of Concrete Structures (NTC-Concreto, 2004) are established the limit values of resistance to compression, module of elasticity and volumetric weight that the concrete must achieve:

-Concrete Class 1:

Resistance to Compression: $f'c \geq 250$ kg/cm^2

Module of Elasticity:

Limestone aggregate	Non Limestone Aggregate
$E \geq 14,000\sqrt{fc}$	$E \geq 11,000\sqrt{fc}$

Volumetric Weight: $g \geq 2.2$ Ton/m^3

-Concrete Class 2:

Resistance to Compression: $200\ kg/cm^2 \geq f'c < 250\ kg/cm^2$

Module of Elasticity:

$$E \geq 8{,}000\sqrt{f'c}$$

Volumetric Weight: $1.9\ Ton/m^3 \geq g < 2.2\ Ton/m^3$

In Figs. 4 to 6 are shown the results of the comparison between the concrete specifications of the projects and results of laboratory tests. It can be seen in Table 2 that only 3 of 7 buildings achieved into specifications of the projects. If the module of elasticity is less than the specified in the project, the stiffness of structure will be minor and the displacements of the buildings will be greater to those estimated in the design, so the risk of damage in elements (structural and non structural) and people will increase.

Table 2. Comparison between the class of concrete specified in projects (where it was available) and the obtained in the laboratory tests

BUILDING CODE	PROJECT	LABORATORY	ACHIEVE
AP-146	Class 1	Class 2	×
L-75	Class 1	Class 2	×
P-858	Class 2	Class 2	✓
M-132	Class1	Class 2	×
JB-7	Class 2	Class 2	✓
BC-132	Class 1	Class 2	×
NSJ-1664	Class 1	Class 1	✓

On the other hand, the results of scanning of reinforce steel showed that the configuration of the steel in concrete elements is agreed with the structural plan specifications.

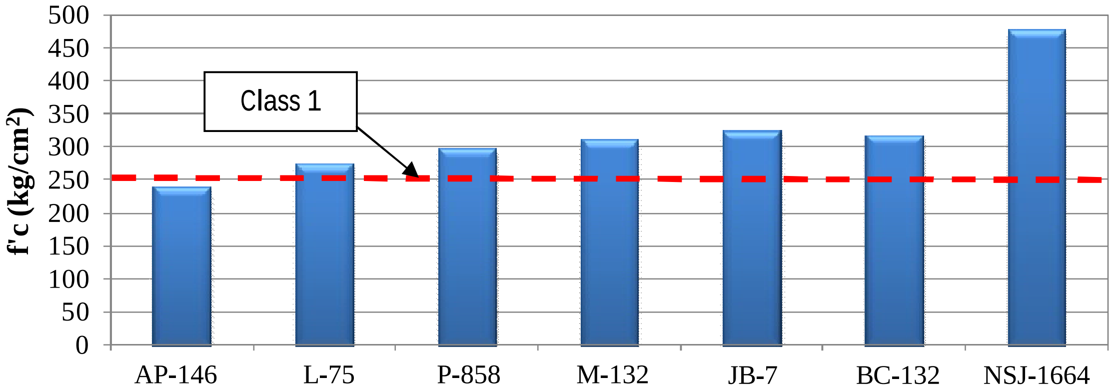

Figure 4. Mean resistance to compression, f'c, obtained in laboratory. The dash represents the limit value established in the MCBC-2004 for concretes Class 1

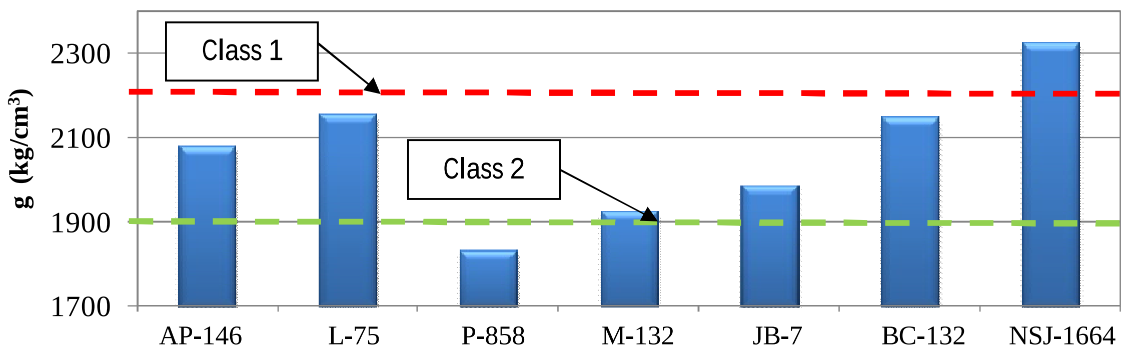

Figure 5. Mean volumetric weight, g, obtained in laboratory. The dash represents the limit value established in the MCBC-2004 for concretes Class 1 and Class2

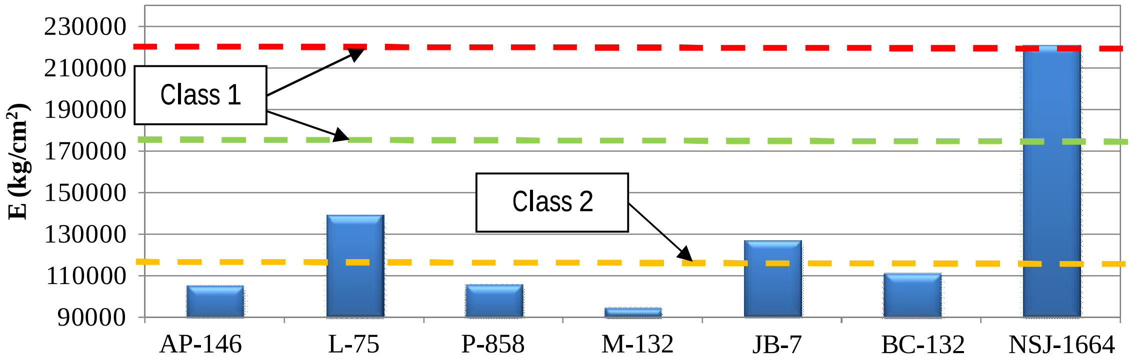

Figure 6. Module of elasticity, E, obtained in laboratory. The dash represents the limit value established in the MCBC-2004 for concretes Class 1 and Class2

5. MODELLING AND STRUCTURAL ANALYSIS

Structural analysis (by 3D models) and design revisions were made for the sample of 20 buildings using the information provided by the authorities, in site detailed inspections, and, where were available, the results of concrete testing and scan of reinforce steel. The analysis consisted in: establishing the design considerations, geometry and transversal section used, and reviewing the service and ultimate limit states according to the seismic guidelines included in the MCBC-2004 (NTC-Sismo, 2004).

The results of the revisions are shown in Fig. 7. The buildings that do not achieve to any of the limit states could have an inadequate behavior during seismic events.

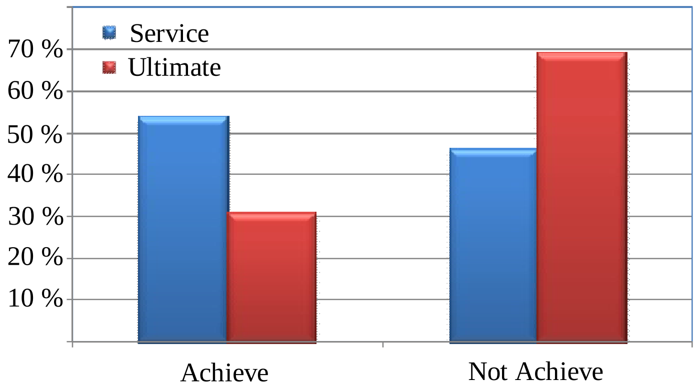

Figure 7. Achievement frequency of the limit states of: a) service, and b)ultimate of the analyzed buildings by 3D models and according to the seismic guidelines included in the MCBC-2004

6. FINAL DISCUSSION

This study confirms that a large number of new buildings in Mexico City do not leave a reliable record of technical information, so it is impossible or very expensive to analyze them to assess their performance; other buildings have so limited information that it is not also possible to re-analyze the response of the structure. The analysis performed for those buildings whose information was available exhibit that many of them could not have an adequate performance during an intense earthquake since they do not meet the minimum requirements established by the MCBC-2004.

The specific aspects that led to this general conclusion are:

1. In spite of the established in the MCBC-2004, there is not enough technical information about existent buildings. The structural notes, generally, are ambiguous and frequently do not have basic information to reproduce the structural models and verify the design and structural response of the buildings. Therefore, the authorities do not have enough information to evaluate the actual seismic risk of the buildings in Mexico City.

2. The authorities do not have an actualized record of Building Responsible Directors (BRD) and their Structural Security Co-responsibles (SSC), despite they have all the responsibility about the structural security of the building. The BRD and SSC are, in general, professionals with modest incomes that represent a very low percentage of the total cost of the building, and without civil responsibility insurance, so in case of building damage they could not take the responsibility in an adequate way. This situation leads that real winners be the urban developers because they receive most of the profits without any responsibility about the structural security.

3. There were not records about supervision during or after construction in the revised buildings. So, the quality of the materials and procedures used were not guaranteed. After the laboratory tests to the concrete elements it were obtained that in most of the buildings, the module of elasticity and the volumetric weight do not achieve to project specifications, reducing the structural capacity.

4. Just 8 of the 20 chosen buildings had authorization from the owners to evaluate the structural elements (concrete and reinforce steel). In general, during the process of this study the response of the owners was poorer than expected, particularly in those buildings that looked apparently without problems. These elements can be used as an indicator of the interest and involvedness of society about the structural security of their buildings. In opinion of the authors, this attitude could be related with the total confidence of the owners in the authorities and technical staff (i.e. engineers, architects) involved during building process.

5. According to the results of the structural analysis performed, 36% and 71% of the buildings do not achieve with the service and ultimate limit state, respectively, established in MCBC-2004. Even if the collapse of these buildings is something difficult of predict due to all the uncertainties involved, it is for sure that the structures will present an inadequate performance during the strong motion produced by an earthquake. These unsuitable behaviors are related to the abuse of structural configurations evidently irregular and to the values of the module of elasticity obtained from laboratory tests.

The impact of these deficiencies are magnified by the impunity in the code violations, because there are not sanctions or even records of evident irregularities and their responsibles.

When a seismic risk evaluation is performed every specialist uses the approach and criteria that believe are adequate, so it could be possible that a building evaluated by various specialists had different results. In the opinion of the authors it is necessary to propose an official approach to evaluate the seismic risk of the buildings which would allow implementing the same criteria in evaluations even if they would be performed by different professionals.

7. KNOWLEDGEMENTS

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