FEATURE: A SEISMIC RESPONSE ANALYSIS TOOL FOR URBAN AREAS IN THE PHILIPPINES

P. E. Quinay[(1)], R. N. Grutas[(2)], C. Protacio[(3)], I. Brotamonte[(4)]

[(1)] Associate Professor, Institute of Civil Engineering, University of the Philippines Diliman, pbquinay2@up.edu.ph
[(2)] Senior Science Research Specialist, DOST-Philippine Institute of Volcanology and Seismology (DOST-PHIVOLCS), rhommel.grutas@phivolcs.dost.gov.ph
[(3)] Science Research Specialist, FEATURE Project, DOST-PHIVOLCS, caprotacio@up.edu.ph
[(4)] Science Research Specialist, FEATURE Project, DOST-PHIVOLCS, ivbrotamonte@up.edu.ph

Abstract

This study aims to develop a tool for seismic analysis of urban areas in the Philippines, called FEATURE, or (F)eature-based (E)arthquake (A)nalysis (T)oolset for (U)rban Area (R)esponse (E)stimation. FEATURE is designed to provide overall quantitative estimates of response of buildings in the study area by summing up coarse approximations of individual building responses. This is achieved by including in the modeling the physical parameters which are known to influence the building dynamic response. This building-specific approach is suitable for the case of the Philippines, where there are multiple building types exposed to different level of seismic hazard. FEATURE, through its developed modules, performs the tasks of input data processing, time-history ground motion generation, building dynamic analysis, and postprocessing. The required inputs are parameters that influence the dynamic response of soil and building structures. The main outputs are displacements and story drifts that are needed to analyze the variability of response of the different buildings in a city. To manage the expected large computation cost, the FEATURE toolset was implemented with parallel computing techniques. Data partitioning from model generation is implemented to divide the workloads for the subsequent tasks of ground motion generation, building analysis, and postprocessing.

As a demonstrative example, FEATURE was applied to the simulation of seismic response of school buildings due to a recent earthquake event, the April 22, 2019 M_w 6.2 Central Luzon Earthquake. Results of FEATURE were compared to reported information from a conducted field investigation. Validation of the settings that were automatically generated by the toolset to the number of floor levels and typology of the buildings on site was conducted. In addition, simulation results were used to identify the building types that may have responded significantly to the earthquake.

In another example, the building models in cities in Metro Manila were analyzed for a M_w 7.2 scenario earthquake for the West Valley Fault. MDOF analysis models were set to represent structure types that vary in heights and floor areas. From the comparison of results for four selected cities, the parameters, soil condition, structure type, and distance from epicenter, have significantly influenced the distribution and variation of story drifts for structures with different number of storeys. This shows that the developed tool can account for the effect of variability in the parameters in estimating the overall seismic response of a city.

Keywords: urban area seismic response, building-specific analysis, earthquake simulation

1. Introduction

The Philippines has many active faults which can generate strong ground shaking in populated urban areas. Across the country, buildings of different structural types and configurations are common and some of these buildings are situated close to a fault or in a soil type which can amplify ground motion. Metro Manila is one example, where many buildings are close to active faults. Some areas of the metropolis also have soil types that may amplify ground shaking. For allocation of resources and preparation of stakeholders due to a scenario earthquake that is expected to cause significant ground shaking in its cities, the number of structures or buildings that may be damaged in an event of a strong earthquake is an important input. However, it is a challenge to account for the wide variability in building parameters, such as material properties, vintage, and structural design code used, in addition to local soil types and distance from faults. To aid the stakeholders, the Philippine Institute of Volcanology and Seismology (PHIVOLCS), guided by its in-house-developed tool, the Rapid Earthquake Damage Assessment System, or REDAS software, developed an area-based damage estimation methodology which combines hazard information, exposure information, and fragility curves derived from historical and simulated data of damage [1]. The output of this methodology can be mapped to visualize the distribution of damaged states per building type, which can be used directly by local government units.

With the availability of large computing resources, Hori, et al. [2] discussed the advantages of another approach, the simulation-based approach for quantifying the seismic response of cities. In this approach, an estimate of the overall response of a city can be obtained by combining the peak responses at the building level that were computed using numerical simulations of building dynamic responses. Because high resolution and reliable data of structures and site conditions can be used, critical areas for specific earthquake scenarios can be identified. Many tools following the simulation-based approach have been introduced and applied to different cities [3, 4, 5, 6, 7, 8, 9].

To develop the simulation-based approach for seismic analysis of urban areas, the data to be used for model generations must have finer spatial resolutions than those defined by political boundaries. Features, which are entities described by attributes such as type, orientation, and coordinates, can be extracted from GIS data and are applicable for this purpose. A building's shape can be described by features using combination of polygons/surfaces or by volumes/solids. But a major challenge in this approach is the significant computer resource that may be required to process and store information (input and output data) for thousands of buildings. As demonstrated by the tools mentioned, implementing computing techniques to utilize multi-core processors, high memory, and large disk space, has advantage in solving large-scale problems.

This study aims to develop a tool, following the simulation-based approach, for seismic analysis of urban areas in the Philippines. The tool, called FEATURE, or (F)eature-based (E)arthquake (A)nalysis (T)oolset for (U)rban Area (R)esponse (E)stimation was developed. In FEATURE, physical parameters which are known to influence the ground motion and building dynamic response are included in the modeling. This building-specific approach is suitable for the case of the Philippines, where there are multiple building types exposed to different level of seismic hazard.

2. FEATURE Tool

FEATURE employs the (building-specific) analysis framework developed in [9], which includes the tasks of shape and discrete model generation, input ground motion estimation, building dynamic analysis, and postprocessing of results. A module for each task was developed. Figure 1 shows the tasks mentioned and the associated modules. The following subsections provide the details of each task.

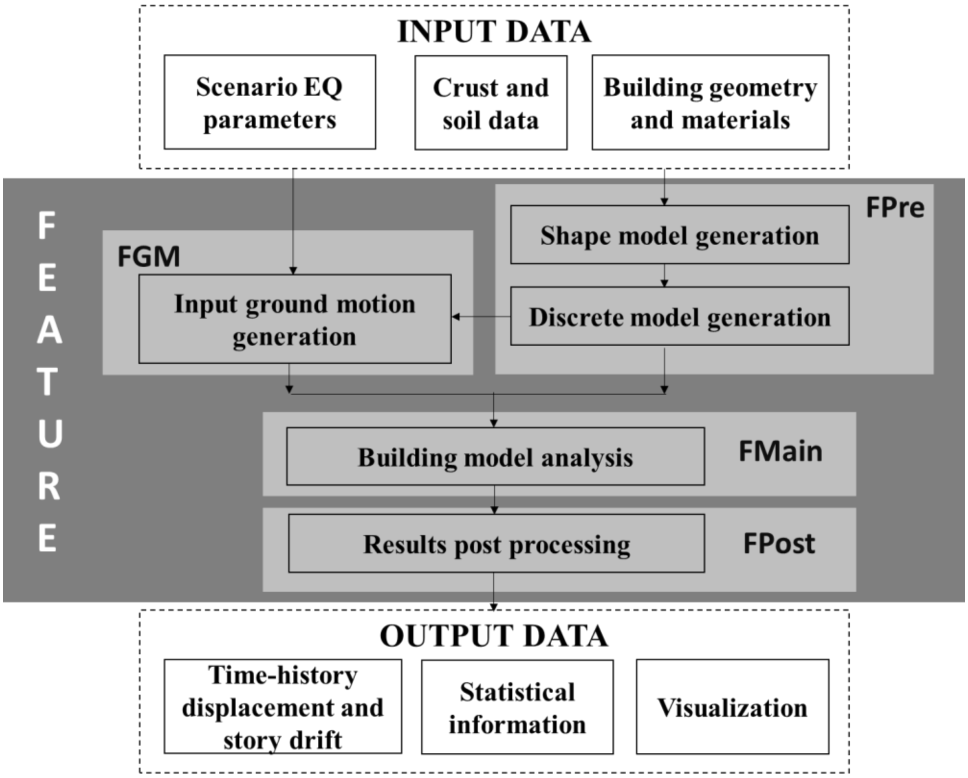


Fig. 1 – FEATURE Toolset: Tasks and the developed modules

2.1 Feature Preprocessing, Shape and Discrete Model Generation

The FPre module is used to process the feature data from available GIS dataset of an urban area/city. Features are entities described by spatial attributes, such as coordinates and orientation. In this module, the features are transformed into shape models which are bound by points that follow the building footprint and height. The procedure is as follows: first, the module reads feature data and point elevation data. The feature data are list of points (given in latitude and longitude coordinates) which are vertices of polygons. The latitude and longitude coordinates of each point are then converted to local coordinates using a reference point (or origin) specified by the user. The point elevation data are compared to ground surface elevation to estimate the height of the feature. The processed information from the two data sources define the shape model. Then, a discrete model is generated by dividing the shape model into horizontal layers to represent floor levels. The discrete models of whole dataset are then compiled and partitioned into separate files. The number of partitions can be set to the number of available processors for parallel processing.

2.2 Input Ground Motion Generation

FGM module is used to generate synthetic ground motions for each building polygon. The main inputs for this module are the earthquake parameters and site/soil data. The module reads the discrete model and computes for the centroid of the base of the model. The centroid is set as the reference in computing for the distance to the epicenter. A lookup table of soil profile data is used as reference for setting the site/soil condition. After setting the required inputs for a building, three-component acceleration time-history data are generated using a selected ground motion estimation tool. After looping through all building polygon data, FGM outputs the dataset of ground motion time history.

2.3 Building (Analysis) Model Generation and Analysis

The FMain module is used to set the analysis type which controls the tasks of analysis model generation, structure response analysis, and visualization. Analysis model generation includes processing the discrete model and setting of parameters related to building typology and material properties. For the structure response analysis, one of the available analysis methods is the multi-degree of freedom (MDOF) analysis. The Integrated Earthquake Simulation (IES) program [3, 6] has optimized modules for MDOF analysis, including postprocessing of results. Thus, FMain was coded to call for the IES executable for MDOF analysis. FMain also includes the setting of parallel processing, such as the number of MPI processes for analysis and generating files for postprocessing. The outputs of FMain are displacement and story drift time-history for all the points in the analysis model.

2.4 Postprocessing of Results

The FPost module is used to postprocess the outputs of the FMain module. Peak displacement and story-drift of each building model are extracted, and then used as inputs to a statistical analysis to obtain the overall response of the urban area/city to a scenario earthquake. It also outputs statistical information from the analysis model, such as distribution of building types, number of stories, and floor area. Acceleration and velocity time history can also be obtained by processing the displacement results.

2.5 Implementation of Computing Techniques

It is expected that a city response analysis will require large memory and disk usage. For example, Metro Manila has close to 1.4 million structures, and it is estimated that a single earthquake scenario will require up to hundred Gigabytes of memory and a Terabyte of disk usage. To manage the expected large computation cost, the FEATURE toolset was implemented with parallel computing techniques. Data partitioning is implemented starting from FPre module which sets the division of workloads for the subsequent tasks of ground motion generation, building analysis, and postprocessing.

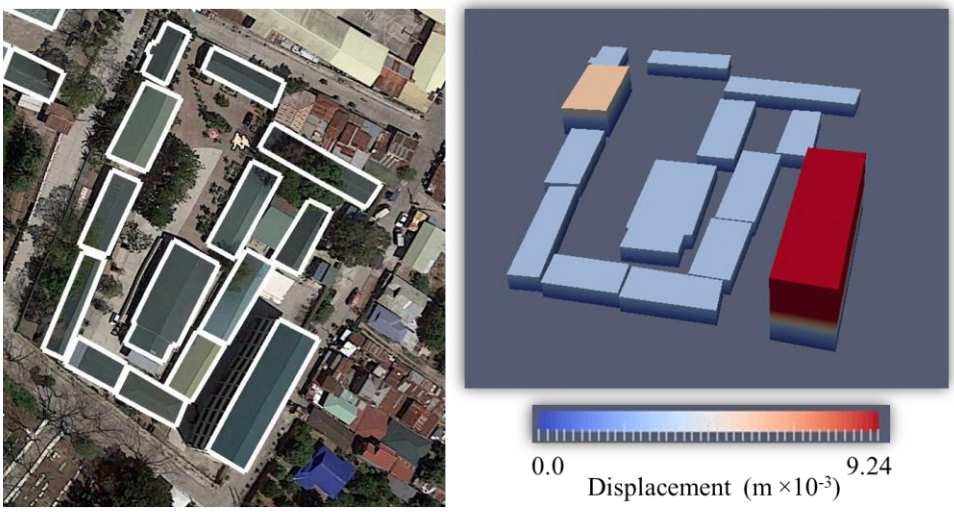
3. Application to Simulation of Building Responses due to April 22, 2019 M_w 6.2 Earthquake

We applied FEATURE to the simulation of seismic response of school buildings due to a recent earthquake event, the April 22, 2019 M_w 6.2 Central Luzon Earthquake. Table 1 lists the parameters for this earthquake. In the study area, there are fourteen (14) buildings that are designed as reinforced concrete moment-frame structures with varying floor levels (one, two, and four storeys). The distance of the buildings to the epicenter of the earthquake is around 21.7 km.

Figure 2(a) shows the building footprint extracted for the target buildings. Together with available height information, the shape models of the buildings were generated (see Fig.2(b)). MDOF analysis models were generated with setting based on the structural design parameters of typical school buildings.

Table 1. Parameters for the scenario earthquake in the application example

Parameter:	Value:
Epicentral Coordinates	(15.02°, 120.34°)
Depth	10 km
Magnitude, M_w	6.2



(a) (b)

Fig. 2 – (a) Building footprints as one of the basis of model generation; (b) generated models and time snapshot of displacement results

Results of FEATURE were compared to reported information from a conducted field investigation. First, we validated the number of floor levels and typology of the buildings on site with the settings automatically generated by the developed tool. Second, we processed the simulation results to interstory drift values. The maximum interstory drifts computed are: 1.6×10^{-3} radian, 2.9×10^{-3} radian, and 3.8×10^{-3} radian for one, two, and four storey buildings, respectively. The results obtained from the two and four storey buildings suggest that the structure may have responded significantly to the earthquake. From the conducted field work, it was reported that only the four-storey building experienced damage, although it was assessed to be non-structural. This shows that the developed tool can be used in identifying possible critical buildings which is an advantage in post-earthquake surveys.

4. Application to Simulation of Metro Manila Cities for a M_w7.2 Scenario Earthquake

2.1 Problem setting

FEATURE was applied to simulation of the response of cities in Metro Manila to a scenario Magnitude 7.2 earthquake originating in the West Valley Fault. Table 2 lists the parameters for this scenario earthquake. For each city high-resolution GIS dataset that are outputs of GMMA READY Project [10] was used. From the dataset, the latitude and longitude coordinates of points that define the features and elevation data were extracted.

FPre module was executed to process each feature. FGM module was executed to generate the input acceleration for each building for a single earthquake source. Here, a stochastic ground motion estimation tool based on Specific Barrier Model [11] was used to synthesize ground motions. Mendoza and Tingatinga

[12] earlier studied the calibration of this tool for generating synthetic ground motions in the West Valley Fault. For this estimation tool, the site condition in terms of NEHRP site class [13] was determined based on the Vs30 data map by Grutas and Yamanaka [14].

FMain module was then executed to generate the analysis model. To set the material types for the analysis models, we assumed structure types based on heights and floor areas. The structure types selected were C1-L, C1-M, C4-H, S4-V, S4-E, and W1-L (the descriptions for these types follow [15, 16]). MDOF analysis of all building models were conducted. Lastly, the FPost module was executed to extract the outputs, and compute the statistical values of displacements and story drifts, and for visualization.

Table 2. Scenario Earthquake Parameters

Parameter	**Value**
Epicentral Coordinates	(14.64798°, 121.0852°)
Depth	4 km
Magnitude, M_w	7.2

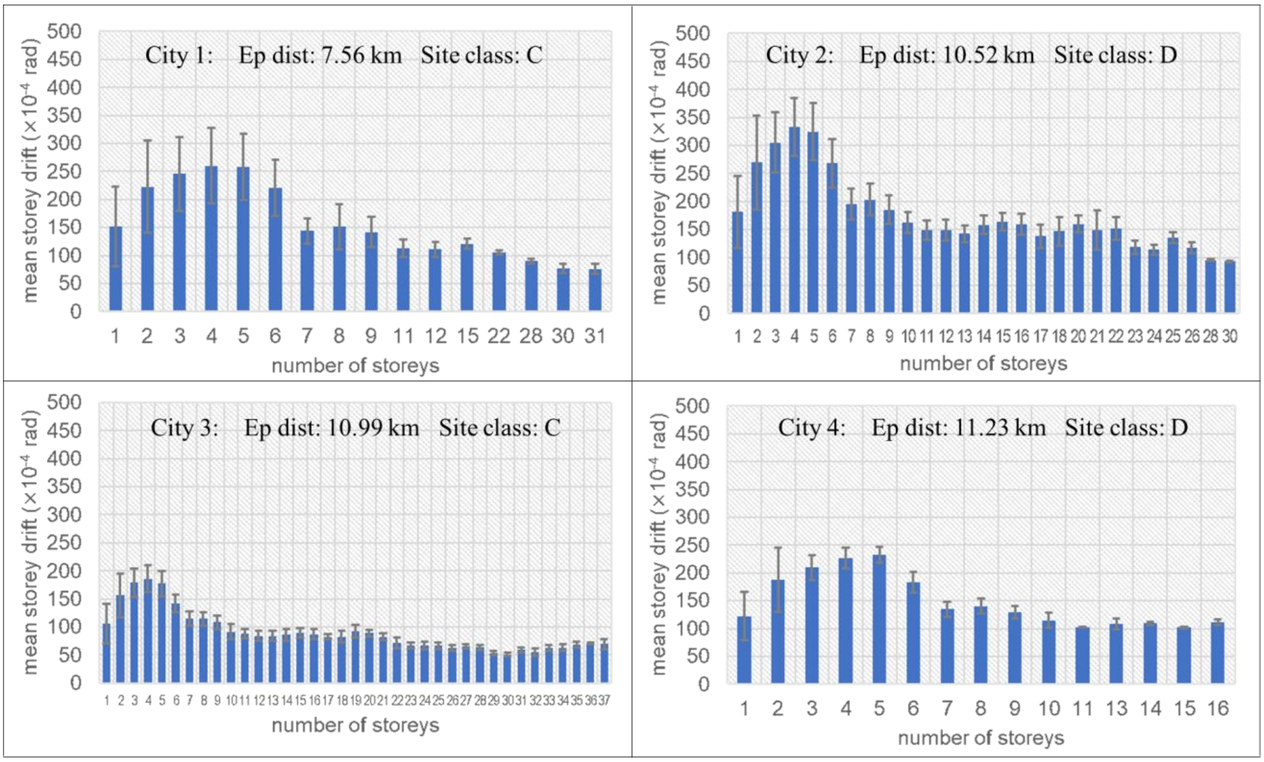


Fig. 3 – Computed story drifts vs. number of storeys, for selected cities with varying epicentral distance (averaged) and soil type

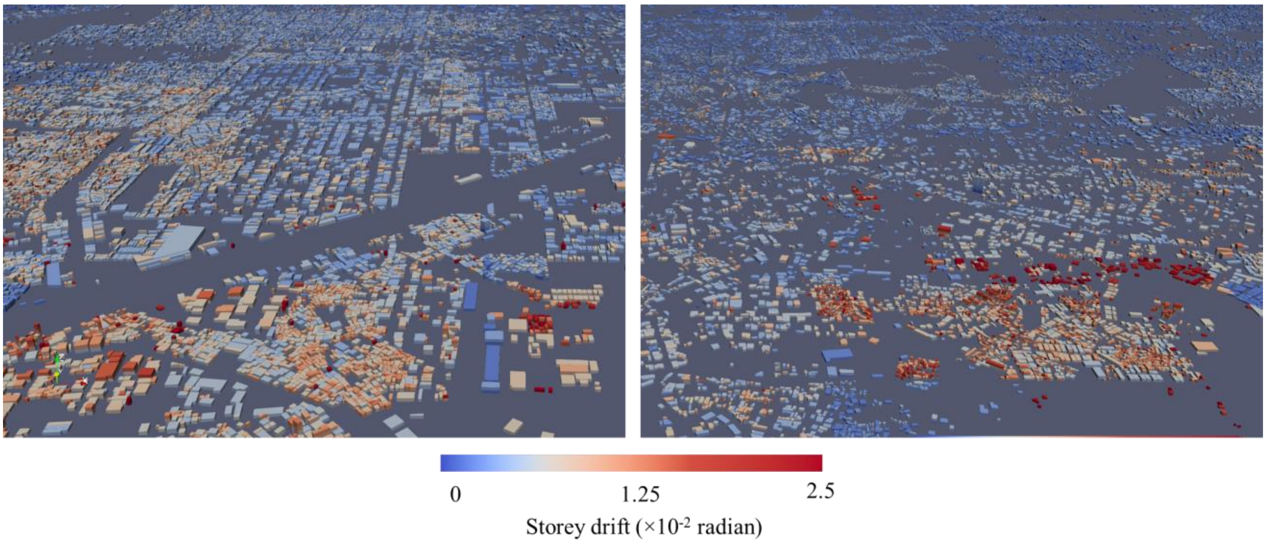


Fig. 4 – Sample snapshots of distribution of storey drift

2.2 Results and Discussion

Figure 3 shows the distribution of computed maximum interstory drifts per number of storeys for selected cities that vary with distance from the epicenter and site conditions. Results show that in all the cities, the moment-frame structures (set with structure types: C1-L, C1-M, W1-L) obtained the largest story drift compared to other building types with higher number of storeys. The low values for higher number of storeys are attributed to the selected structure types with assumed addition of lateral force-resisting elements. It can also be observed that the variation in story drift for low- to mid-rise structures (one to six storeys) are larger than for structures with larger number of storeys. This is due to the use of multiple frame-model types, (C1-L, C1-M, and W1-L) for the low- to mid-rise structures.

Comparing the four cities, it can be observed that the softer soil condition significantly increased the response of the buildings. This is shown for Cities 2 and 4 which have lower Vs30 than Cities 1 and 3, but resulted to larger computed story drift. Note that Cities 1 and 3 are closer to the epicenter than Cities 2 and 4, respectively. On the other hand, for cities with the same site class, the story drift is reduced with increasing distance from the epicenter. Under the same conditions, the reduction in story drift affected all building levels.

Figure 4 shows a sample visualization of results (using IES postprocessing). When visualized in city-view, it is clear that modeling the variation in building configurations result to finer distribution of story drifts. This can aid in identifying the possible critical buildings or areas in preparation for scenario earthquakes.

5. Conclusion

This study aims to develop a tool, following the simulation-based approach, for seismic analysis of urban areas in the Philippines. FEATURE, or (F)eature-based (E)arthquake (A)nalysis (T)oolset for (U)rban Area (R)esponse (E)stimation was developed. FEATURE is designed to provide overall quantitative estimates of response of buildings in the study area by summing up coarse approximations of individual building responses. Parameters which are known to influence the building dynamic response are included in the modeling. This building-specific analysis is suitable for the case of the Philippines, where there are multiple building types exposed to different level of seismic hazard.

Modules of FEATURE toolset were developed to perform the tasks of input data processing, time-history ground motion generation, building dynamic analysis, and postprocessing. The required inputs are parameters that influence the dynamic response of soil and building structures. The main outputs are displacements and story drifts that are needed to analyze the variability of response of the different buildings in a city.

As a demonstrative example, FEATURE was applied to the simulation of seismic response of school buildings due to a recent earthquake event, the April 22, 2019 Mw 6.2 Central Luzon Earthquake. Validation of model generated and predicted structure response were conducted by comparing with results of field investigation. In another example, building models in all cities in Metro Manila were analyzed for a Mw 7.2 scenario earthquake for the West Valley Fault. From the comparison of results for four selected cities, the parameters, soil condition, structure type, and distance from epicenter, have significantly influenced the distribution and variation of story drifts for structures with different number of storeys. This shows that the developed tool can account for the effect of variability in the parameters in estimating the overall seismic response of a city.

In application to seismic response analysis for cities in the Philippines, employing the developed tool gives several advantages. First, the effect of the variability in the setting for each building (such as structure or material type, soil types, and distance from the fault) to the resulting overall city response is accounted for in the analysis. Second, its results (in the form of time-varying or peak values), which are obtained in all models, can be further processed to be used as inputs in other disaster mitigation-related studies such as: locating early response equipment, analysis of lifeline infrastructure and road network, and simulation of evacuation plans for a given earthquake scenario. Third, since results for building models can be visualized in city-view, it can lead effective communication to non-technical stakeholders.

Lastly, the integrated simulation may provide an opportunity for scientists and engineers, who have extensive knowledge and experience in seismology, geotechnical, structural engineering analysis, and computing, to collaborate in aid of improving the city disaster risk reduction efforts.

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