THE FEMA-NIBS METHODOLOGY FOR EARTHQUAKE LOSS ESTIMATION

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METHODOLOGY OVERVIEW

This brief overview of the FEMA-NIBS earthquake loss estimation methodology is intended for local, regional, or state officials contemplating an earthquake loss study.

The methodology was developed over a 4 ½ year period for the Federal Emergency Management Agency (FEMA) by the National Institute of Building Sciences (NIBS) to provide a tool for developing earthquake loss estimates for use in:

- Mitigating the possible consequences of earthquakes,
- Anticipating the possible nature and scope of the emergency response needed to cope with an earthquake-related disaster, and
- Developing plans for recovery and reconstruction following such a disaster.

If developed for areas of seismic risk across the nation, such estimates also will help guide the allocation of federal resources to stimulate risk mitigation efforts and to plan for federal earthquake response.

The methodology was pilot tested in Portland, Oregon and Boston, Massachusetts and calibrated with data from Northridge, Loma Prieta and other earthquakes.

Use of the methodology will generate an estimate of the consequences to a city or region of a "scenario earthquake" -- that is, an earthquake with a specified magnitude and location. The resulting "loss estimate" generally will describe the scale and extent of damage and disruption that may result from potential earthquakes. The following information is provided by the methodology:

- *Quantitative estimates of losses* in terms of direct costs for repair and replacement of damaged buildings and lifeline system components; direct costs associated with loss of function (e.g., loss of business revenue); casualties; people displaced from residences; quantity of debris; and regional economic impacts.
- *Functionality losses* in terms of loss-of-function and restoration times for buildings, critical facilities such as hospitals, and components of transportation and utility lifeline systems and rudimentary analysis of loss-of-system-function for electrical distribution and potable water systems.
- *Extent of induced hazards* in terms of fire, flooding and hazardous materials.

To generate this information, the methodology includes:

- Classification systems for assembling information on the building stock, the components of highway and utility lifelines, and demographic and economic data;
- Methods for evaluating damage and calculating various losses; and

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• Data bases containing information useable for calculations and as default (built-in) data.

These systems, methods, and data have been coded into user-friendly software that operates through a geographic information system (GIS); MapInfo is the software used. An ArcView version of HAZUS is planned for the future. Use of a GIS makes possible the convenient manipulation of loss estimation data concerning building stock, population, and economy. The software permits losses and consequences to be portrayed on spread sheets and maps.

Collecting needed information and entering it via the methodology software are the major tasks involved in generating a loss estimate. The methodology permits estimates to be made at several levels of sophistication -- from relying principally on the default data incorporated into the methodology to entering varying amounts of data from locally conducted studies and regional sources. The better and more complete the information, the more meaningful the results will be. Note that the inventory data gathered will be useful to local and regional governments for a number of other purposes.

Two manuals present detailed information helpful to the user. The *Technical Manual* documents the methods of calculation and default data; the *User's Manual* provides a guide to use of the methodology and the software and includes detailed information on data structures and formats.

In simplified form, the steps for using the methodology are:

• Select the area to be studied. This may be a city or a group of municipalities. It is generally desirable to select an area that is the responsibility of an existing regional planning group.

• Specify the magnitude and location of the scenario earthquake. Consideration should be given to potential fault breaks.

• Add information delineating local soil and geological conditions. The maps for the intensity of ground shaking and the probability of permanent ground displacement are then generated by the software.

• Using formulas embedded in the software probability distributions are computed for damage to different classes of buildings, facilities, and lifeline system components and loss-of-function estimates are made.

• Estimated number of ignitions and the extent of fire spread are generated with a special software subprogram. Specified areas of potential flooding and locations of hazardous materials and the amount of debris are also generated.

• Additional sets of formulas then are used to compute expected direct economic and social losses.

• These direct economic impacts on various segments of the economy then serve as input to a model that estimates the impact on the overall regional economy.

The user plays a major role in selecting the scope and nature of the output of a loss estimate. Numerical results may be examined at the level of the census tract or may be aggregated by zip-code, community or region.

Earthquake Hazards Considered

The earthquake-related hazards considered by the methodology in evaluating casualties, damage, and resultant losses are collectively referred to in the methodology as *potential earth science hazards* (PESH).

Most damage and loss caused by an earthquake is directly or indirectly the result of *ground shaking*. Thus, the methodology evaluates the geographic distribution of ground shaking resulting from the specified scenario earthquake and expresses the ground shaking using several quantitative parameters such as peak acceleration.

Three other features of earthquakes that can cause permanent ground displacements and have an adverse effect upon structures, roadways, pipelines, etc., also are considered:

• *Fault rupture*: While the cause of ground shaking, fault rupture can reach the surface of the earth as a narrow zone of ground offsets.

• *Liquefaction*: This sudden loss of strength and stiffness in soils can occur when loose, water-saturated soils are shaken strongly and can cause settlement and horizontal movement of the ground.

• *Landsliding*: This refers to large downhill movements of soil or rock that are shaken free from hillsides or mountainsides and that can destroy anything in their path.

Tsunamis (waves moving across oceans) and seiches (oscillatory waves generated in lakes or reservoirs) are also earthquake-caused phenomena that can result in inundation or waterfront damage. In the methodology, potential sites of these hazards may be identified but they are evaluated only if special supplemental studies are performed.

The choice of scenario earthquake is not just a matter of earth science; hazard management and political factors must be considered as well. Planning for mitigation and disaster response generally is based on large, damaging events, but the probability that such events will occur also should be considered. In a region of high seismicity, the *maximum credible earthquake* is generally a suitable choice. In areas of lower seismicity, it may not be prudent to assume a very large but also very unlikely earthquake even though it is realized that such an event is possible. In such regions, it often is most appropriate to choose an earthquake with a *specified mean recurrence interval* such as the "500 year earthquake." Consideration should be given to repeating loss calculations for several scenario earthquakes having different magnitudes and locations and different probabilities of occurrence since these factors are a major source of uncertainty.

The *User's Manual* provides guidance concerning the selection of scenario earthquakes, and - data concerning past earthquakes is provided within the methodology software. It is almost always desirable to consult local earth science experts during the process of choosing scenario events.

The software contains several options for determining the effect of soil type on ground motions for a given magnitude and location. The user may select the default relations or choose an alternative.

Types of Buildings and Facilities Considered

The buildings, facilities, and lifeline systems considered by the methodology are as follows:

• *General building stock*: Buildings in the general building stock are not considered individually. Instead, they are grouped together into 36 model building types and 28 occupancy classes and degrees of damage are computed for groups of buildings. Examples of model building types are light wood frame, steel braced frame, concrete frame with unreinforced masonry infill walls, and unreinforced masonry. Each model building type is further subdivided according to typical number of stories and apparent earthquake resistance (based primarily upon the age of the structure). Examples of occupancy types are single family dwelling, retail trade, heavy industrial, and churches.

• *Essential facilities*: Essential facilities, including medical care facilities, emergency response facilities and schools, are those vital to emergency response and recovery following a disaster. School buildings are included in this category because of the key role they often play in housing people displaced from damaged homes. Because there generally are so few of each type of essential facility in a census tract, damage and loss-of-function is evaluated on a building-by-building basis even though the uncertainty in each such estimate is large.

• *Transportation lifeline systems*: Transportation lifelines, including highways, railways, light rail, bus systems, ports and harbors, ferry systems and airports, are broken into components such as bridges, stretches of roadway or track, terminals, and port warehouses. Probabilities of damage are computed for each component, and losses are aggregated over all components of each lifeline. Although the methodology cannot now evaluate total *system* performance (for example, how well traffic might be able to move from point A to point B after an earthquake), outputs from supplemental analyses of system performance can be entered into the methodology.

- *Utility lifeline systems*: Utility lifelines, including potable water, electric power, waste water, communications, and liquid fuels (oil and gas), are treated in a manner similar to transportation lifelines. Examples of components are electrical substations, water treatment plants, tank farms and pumping stations.

In any region or community there will be certain types of structures or facilities for which the methodology will not evaluate damage and losses unless supplemental studies specific to these facilities are carried out. These omitted structures are referred to as *high potential loss facilities*. Such facilities include dams, nuclear power plants, natural gas facilities, military installations, and large one-of-a-kind residential or commercial structures. Given the nature of these facilities it would be potentially misleading and politically and legally unwise to estimate damage and losses unless a detailed engineering analysis was performed with the agreement of the owner of the facility. Hence, the approach is to call attention to these facilities and indicate a potential for loss. Outputs from supplemental studies, however, can be entered into the methodology.

METHODOLOGY FLEXIBILITY

To provide flexibility, the methodology estimates losses at three levels. For each level, the several hazards and the various types of buildings and facilities can be selectively used as appropriate to meet the needs and desires of the local or regional user.

Level 1

A Level 1 analysis uses only the default data bases built into the methodology for information on building numbers and value, population characteristics, costs of building repair, and certain basic economic data. Only losses associated with the general building stock (and possibly hospitals) are computed. Transportation and utility lifelines are not considered and limited attention is given to possible fires. Indirect economic effects for the region are not calculated. One average soil condition is presumed for the entire study region, and effects of possible liquefaction and landsliding are ignored. Table 1 summarizes the output that can be obtained from a Level 1 analysis.

Other than defining the study region, selecting the scenario earthquake(s) and making some decisions concerning the extent and format for the output, a Level 1 analysis requires essentially no effort from the user. As indicated, however, estimated losses are incomplete and, since actual local conditions are not considered, involve very large uncertainties. Thus, a Level 1 analysis is suitable primarily for preliminary evaluations or for crude comparisons among different regions.

Augmented Level 1

Results from a Level 1 analysis can be improved greatly with a minimum amount of locally developed input. Such an effort might involve:

- Development of soil, liquefaction, and landsliding maps;

- Use of locally available data or estimates concerning the square footage of buildings in different occupancy classes;

- Use of local expertise to modify, primarily by judgment, the data bases concerning percentages of model building types associated with different occupancy classes;

- Preparation of a detailed inventory for all essential facilities; and/or

- Use of locally available data concerning construction costs.

An augmented Level 1 analysis will lead to much more accurate and useful estimates for losses associated with the general building stock and critical facilities. It will not provide, however, either estimates of the costs and inconvenience related to lifeline damage or estimates of indirect economic costs.

Table 1
LEVEL 1 ANALYSIS OUTPUT

Maps of seismic hazards

- Contour maps of intensities of ground shaking

Characterization of damage to general building stock

- Structural and nonstructural damage probabilities by census tract, building type and occupancy class

Essential facilities

- For hospitals and medical centers in a limited default data base: damage state probabilities, cost of repair or replacement and loss of beds

Facilities of special concern

- Location of dams from the National Inventory of Dams
- Location of facilities with hazardous materials from a data base by FEMA

Fire following earthquake

- Number of ignitions by census tract

Debris

- By weight and type of material

Social losses

- Displaced households
- Number of people requiring temporary shelter
- Casualties in four categories of severity

Dollar losses associated with general building stock

- Cost of repair or replacement
- Loss of contents
- Business inventory damage or loss
- Relocation costs
- Business income loss
- Loss of rental income

Level 2

This is the generally intended level of implementation. Studies at this level can involve one or more of the following types of input supplied by the user:

- Locally generated maps for soil conditions affecting ground shaking and for liquefaction and landsliding potential for evaluation of the effects of these local conditions upon damage and losses.

- Locally developed data concerning the nature of the building stock and economic conditions.

- Data concerning the location and nature of essential facilities.

- Data for evaluation of losses and lack of function in various transportation and utility lifelines.

- Data for evaluation of the probable extent of areas affected by fires.

- Inundation maps.

- Information concerning high potential loss facilities and facilities housing hazardous materials.

- Data for calculation of indirect economic impacts upon the study region.

Depending upon the size of the region and the number of these features selected by the user, one to six months may be required to assemble the required input. The effort put into preparing the inventory of the building stock can range from relatively small to enormous, depending upon the desire to reduce uncertainty in computed results. Assembling and entering required data for lifelines also can involve considerable effort but the user can choose to omit some lifelines.

It generally will be necessary to employ consultants to develop the various soil-related maps and the data needed for the indirect economic analysis.

Table 2 summarizes the output that can be obtained from a Level 2 analysis; however, there is no standard Level 2 analysis and, hence, no minimum or standard amount of input. The

User's Manual provides guidance concerning potential sources and procedures for developing data concerning inventories of buildings and other facilities and other possible input as well.

Level 3

A Level 3 study takes advantage of the methodology's ability to accept special purpose software input concerning the vulnerability of specific high-potential-loss facilities, expected repair/replacement costs and numbers of households displaced as a result of fire or inundation or other studies. It also is possible to add the output of loss estimates performed using locally developed traffic models with links limited to a specific number of damaged bridges. Similar analyses of links can provide information on water distribution or other pipeline systems.

UNCERTAINTIES IN LOSS ESTIMATES

Although HAZUS offers the user the opportunity to prepare comprehensive loss estimates, it should be recognized that, even with state-of-the-art techniques, uncertainties are inherent in any such estimation methodology.

HAZUS contains extensive databases and default values for methodology parameters, thus, making it possible to estimate losses with little additional effort to assemble information concerning geological hazards or inventory of the infrastructure. While potentially useful for preliminary estimates, results evaluated in this manner are considerably uncertain. Preparation of locally-applicable maps for soil-related hazards is especially important for reliable loss estimates.

History has taught that the next major earthquake to affect a U.S. city or region will likely be quite different from the "scenario earthquake" anticipated as part of an earthquake loss estimation study. The magnitude and location of the earthquake and the associated - faulting, ground motions and landsliding will not be precisely what was anticipated. Hence, the results of an earthquake loss study should not be looked upon as a *prediction* but rather as an indication of what the future may hold. This is particularly true in areas where seismicity is poorly understood. Obviously, the better the seismic regime of a region is understood, the closer to future reality the loss estimates may be.

Any region or city studied will have an enormous variety of sizes, shapes, and structural systems of buildings and other facilities constructed over the years under diverse seismic design codes and many different types of components that make up transportation and utility lifeline systems. Due to this complexity, relatively little is known concerning the structural resistance of most buildings and other facilities. Further, there simply are not sufficient data from past earthquakes or laboratory experiments to permit accurate predictions of damage based on known ground motions even for specific buildings and other structures. To deal with this complexity and lack of data, the methodology lumps buildings and components of lifelines into categories, based upon key characteristics. Limited data and available theories are used to establish relationships between a few key features of ground shaking and *average* damage and associated losses for each category. While state-of-the-art, these relationships involve uncertainties and estimated losses thus depend upon the "law of averages."

Application of the methodology to individual structures or facilities, especially those with the potential for large losses, may lead to misleading results

The possible range of losses is best evaluated by conducting multiple analyses, varying certain of the input parameters to which losses are most sensitive. The *User's Manual* gives guidance concerning the planning of such sensitivity studies.

Although considerable effort has been expended to create HAZUS, it should still be considered an ongoing work. For example, various components of HAZUS require further calibration based on data from other earthquakes besides Northridge and Loma Prieta. In addition, among the desirable future revisions to HAZUS are to:

Table 2
LEVEL 2 ANALYSIS POTENTIAL OUTPUT

Maps of seismic hazards
- Contour maps of intensities of ground shaking
- Contour map of permanent ground displacement
- Liquefaction probability
- Landsliding probability

Characterization of damage to general building stock
- Structural and nonstructural damage probabilities by census tract building type and occupancy class

Transportation and utility lifelines
- For all components of all lifelines: damage state probabilities, cost of repair or replacement and expected functionality for various times following earthquake
- For potable water system: percent service reduction to serviced areas
- For electric power systems: probabilistic estimate of service outages

Essential facilities
- Cost of repair or replacement
- Loss of beds in hospitals and medical facilities

High potential loss facilities
- Location of dams
- Location of nuclear plants
- Location of military installations
- Others

Fire following earthquake
- Number of ignitions by census tract
- Percentage of burned area by census tract

Inundated areas
- Exposed population and exposed dollar value of facilities

Hazardous material sites
- Location of facilities with hazardous materials

Debris
- By weight and type of material

Social losses
- Displaced households
- Number of people requiring temporary shelter
- Casualties in four categories of severity

Dollar losses associated with general building stock
- Cost of repair or replacement
- Loss of contents
- Business inventory damage or loss
- Relocation costs
- Business income loss
- Loss of rental income

- Compute probabilistic or annualized loss by embedding 150,000 USGS seismic hazard curves in HAZUS.

- Improve estimation of ground motions resulting from rupture of non-vertical and segmented faults.

- Develop full Level 2 capability for estimating damage to lifelines.

- Base damage to bridges and buildings forming part of lifeline systems on spectral parameters instead of peak ground acceleration.

Certain results generated by HAZUS are not yet completely acceptable because aspects of loss estimation are not resolved, for example:

- Results for earthquake scenarios below Mag. 6.0 and above Mag. 7.5: The implications of very short and very long durations of motion upon damage are still poorly understood for these events.

- Results for non-structural damage: Damage coefficients for non-structural are based on less complete data than that available for structures since collection of data following earthquakes has generally concentrated on structural damage.

- Results generated by the Casualties Module: The Casualties Module is based primarily on earthquake events that occurred in suburban locations at times of the day when people were generally not occupying commercial structures. Until further data is available, casualty results for urban scenarios will be less certain than for suburban scenarios.

APPLYING METHODOLOGY PRODUCTS

The products of the FEMA-NIBS methodology to estimate earthquake losses have several pre-

earthquake and/or post-earthquake applications in addition to estimating the scale and extent of damage and disruption.
Examples of pre-earthquake applications of methodology output are as follows:

• *Development of earthquake hazard mitigation strategies* as a countermeasure against earthquake losses and disruptions indicated in the initial loss estimation study.
Strategies can involve rehabilitation of hazardous existing buildings (e.g., unreinforced masonry structures), the development of appropriate zoning ordinances for land use planning in areas of liquefiable soils, and the adoption of advanced seismic building codes.

• *Development of preparedness (contingency) planning measures* such as identification of alternate transportation routes and planning earthquake preparedness and survival education seminars.

• *Anticipation of the nature and scope of response and recovery efforts* including: identifying alternative housing and the location, availability and scope of required medical services; and priority ranking of water and power resources for restoration.

Post-earthquake applications of the methodology would include:

• *Projection of immediate economic impact assessments for state and federal resource allocation and support* including supporting the declaration of a state and/or federal disaster by calculating direct and indirect economic impact on public and private resources, local governments, and the functionality of the area.

• *Activation of immediate emergency recovery efforts* including search and rescue operations, rapid identification and treatment of casualties, provision of emergency housing shelters, control of fire following earthquake, and rapid repair and availability of essential utility systems.

• *Application of long-term reconstruction plans* including the identification of long-term reconstruction goals, the institution of appropriate wide-range economic development plans for the entire area, allocation of permanent housing needs, and the application of land use planning efforts and ordinances.

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EARTHQUAKE LOSS ESTIMATION METHODOLOGY STUDY

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Under a cooperative agreement with the Federal Emergency Management Agency (FEMA), NIBS has developed a nationally applicable standardized methodology for estimating potential earthquake losses on a regional basis. The methodology, embodied in a geographical information system (GIS) MapInfo-based software called HAZUS, is scheduled to be released at three training workshops for state and U.S. territory emergency managers on March 10, March 24 and April 7, 1997. The release will include a user's manual for explaining the methodology to local, state, and regional officials and other users, and a technical manual describing the methodology background for use by engineers.

Earthquake loss estimates generated by HAZUS are intended to be used by local, state, and regional officials for planning and stimulating mitigation efforts to reduce losses from earthquakes and preparing for emergency response and recovery following an earthquake. The methodology may also be used to prepare a rapid loss estimate following an earthquake event. Secondary purposes of the estimates are to provide the basis for an assessment of the nationwide risk of losses from earthquakes and to provide a basis for allocation of national resources for future seismic disasters and emergency funds based on a rapid loss estimate.

Past loss estimation studies have served the hazard mitigation and disaster preparedness planning process at the local level. Understandably, the studies' methodology, assumptions, and approaches differed, making them unsuitable for consistent nationwide use The NIBS Earthquake Loss Estimation Methodology Study is built on these studies to achieve a nationally applicable standardized approach.

The study, begun in October 1992, was sponsored by FEMA as part of its leadership role under the National Earthquake Hazards Reduction Program (NEHRP). The NEHRP is the federal government's program to address the nation's earthquake threat. Under the program, the government seeks to answer two basic questions: how earthquakes will affect the nation and how best to apply our resources to reduce earthquake's impacts.

An eight-member Project Work Group (PWG) consisting of earthquake experts chaired by Robert Whitman, a professor of civil engineering at the Massachusetts Institute of Technology, provided technical oversight and an 18-member Project Oversight Committee (POC) chaired by Henry Lagorio, a professor of architecture at the University of California at Berkeley, represented user interests in the earthquake community and provided user/client input. Over 80 POC corresponding members representing user and technical interests reviewed earlier drafts of project reports. In 1993, the PWG and POC defined the components of the loss estimation methodology, prepared an extensive set of objectives for developing the methodology, and generated a standardized list of earthquake-caused economic and social losses as methodology outputs.

Parallel to this effort, NIBS contracted with a joint venture between Risk Management Solutions, Inc. (RMS) and the California Universities for Research in Earthquake Engineering (CUREe) to identify and evaluate the potential of existing studies for use in developing the standardized loss estimation methodology. FEMA publication 249, *Assessment of the State of the Art Earthquake Loss Estimation Methodologies*, was published in Spring of 1994. This report reflects a comprehensive survey of literature identifying studies relevant to loss estimation, an evaluation of the potential of existing studies for use in developing the standardized loss estimation methodology, and identification of gaps in current loss estimation technology.

Between the end of 1993 and the end of 1994 Risk Management Solutions, Inc. (RMS) of Menlo Park, CA, under contract to NIBS, developed the earthquake loss estimation methodology and HAZUS software including. categorization of building and infrastructure inventory; estimations of potential earthquake hazard, seismic damage to buildings and lifelines, and induced damage from floods, fire and hazardous material release; and estimations of social and direct and indirect economic losses. As a major feature of HAZUS, an inventory data collection module was developed to provide guidance to emergency managers, planners and local officials in collecting inventory data required for regional multi-hazard (earthquake, hurricane, flood and tornado) loss estimation. Methodology calibrations utilizing existing literature and damage data from Northridge, Loma Prieta and other previous earthquakes were conducted by RMS between 1994 and 1997. Pilot testing of the inventory data collection module is being conducted by the California Office of Emergency Services (OES) in the East Bay (Oakland) region and by the U.S. Army Corps of Engineers for select military bases..

Dames & Moore initiated the first pilot study of the methodology in early 1995 in Portland, OR and EQE International initiated a second in Boston, MA in early 1996. Collection of inventory data and preparation of a preliminary and final damage and loss reports based on two scenario earthquakes were completed for both pilot studies. For Portland, the final report was delivered in January, 1997. For Boston, the final report will be delivered in Spring, 1997.

Although the earthquake methodology has been completed, improvements and updates will continue under the guidance of an expanded PWG. Currently, four major initiatives are planned or in progress:

1) A mitigation module to enable users to select mitigation alternatives based on losses calculated with HAZUS, and then to determine the cost effectiveness of alternatives selected by recalculating losses.

2) A PC-based ArcView platform for HAZUS to initiate a means of enabling communities with ArcInfo databases to employ the Earthquake Loss Estimation Methodology GIS software. A study conducted by NIBS concluded that ArcInfo is the leading GIS system used in the states and that eleven of the 38 states in earthquake-prone regions of the country use ArcInfo.

3) A training course on mitigation planning using HAZUS, including two pilot courses, to be conducted for state, regional and local officials and individuals in the private sector.

4) Expansion of the Earthquake Loss Estimation Methodology into a multi-hazard methodology by initiating development of nationally applicable standardized modules for estimating potential losses from wind (hurricanes, tornados and gales) and flood (riverine and coastal) hazards. Committees are being assembled to prepare work plans for developing each module including its coordination with the earthquake module. FEMA's *National Mitigation Strategy* recognizes that mounting dollar losses cannot be adequately addressed by a fragmented approach to natural hazards. Instead, estimated losses for other hazards are needed to support programs such as FEMA's risk-based approach to mitigation and emergency preparedness, and comprehensive mitigation programs by local communities.

A single standardized approach for estimating earthquake (and in the future wind and flood) losses will allow state and local governments to work more effectively with the federal agencies. By collecting and analyzing data using a consistent method, it will be possible to predict the level of resources needed more accurately and to more effectively allocate available resources.

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