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Guidance for Generating Flood Loads Data from Floodplain Modelling and Mapping Studies to Support Flood-Resistant Buildings Initiative

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Acknowledgements

The guidance discussed in this report was expected to advance the work related to the generation of flood loads data from select case studies and development of prescriptive requirements for the design of flood-resistant buildings and improving flood-resistance for existing buildings for the National Building Code of Canada. This initiative was planned through a joint collaboration between the NRC and Coulbourne consulting from the US, with guidance and oversight from two technical committees consisting of experts from the private, government and academic sectors, i.e. the Technical Committee for Flood-Resistant Buildings and the Steering Committee on Flood Resilience of Buildings. All members of both committees are gratefully acknowledged for their guidance and oversight. The two guidelines documents which are the main deliverables of this collaborative initiative are expected to evolve overtime as more focused new information on flood characteristics and flood-resistant design of buildings will become available in the future. The guidance on generating flood loads was compiled by the NRC with assistance from Dave Kriebel and Bill Coulbourne and that is very much appreciated.

Executive Summary

The National Research Council Canada (NRC) is leading the Climate Resilient Buildings and Core Public Infrastructure (CRB-CPI) project to build resilience in the Canadian CPI (i.e. roads, bridges, water and wastewater systems, and rail transit) and buildings against projected climate change and extreme weather events, including floods, by updating model codes, standards, guides and decision-support tools. Within the CRB-CPI project, enhancing flood-resilience of existing buildings and design of new flood-resistant buildings by developing appropriate guidelines was identified as an important research initiative. Coulbourne consulting, that had considerable prior experience with the development of flood design requirements in the US, was tasked to lead this initiative. For flood design requirements, detailed information on flood loads that are typically experienced in riverine, urban and coastal environments in Canada was required. For this purpose, the NRC initiated flood loads data generation case studies in collaboration with Canadian consulting firms. To generate flood loads data from these case studies, the NRC developed a systematic guidance in consultation with the Coulbourne consulting team. This guidance is documented in this report.

This short report consists of just three main chapters and a section on references. Chapter 1 of the report presents a general introduction to the CRB-CPI project, flood loads data generation case studies initiative, the history of floodplain mapping in Canada, and the scope and limitations of the report. Chapter 2 describes the guidance on flood loads data generation from floodplain modelling and mapping case studies, selected from riverine, urban and coastal environments. Documenting this guidance was the main focus of this report. Expected outcomes of the case studies are discussed in Chapter 3, followed by a list of cited references. It is important to note that the guidance on flood loads data generation was developed early on in 2020, but was documented in the form of a report only in April 2021.

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List of Acronyms

Acronym	Description
ASCE	American Society of Civil Engineers
CPI	Core Public Infrastructure
CRB-CPI	Climate Resilient Buildings and Core Public Infrastructure
DEM	Digital Elevation Model
FDRP	Flood Damage Reduction Program
IWD	Inland Waters Directorate
LiDAR	Light Detection and Ranging
NBC	National Building Code
NDMP	National Disaster Mitigation Program
NRC	National Research Council Canada
SEI	Structural Engineering Institute

1 Introduction

1.1 Background

The National Research Council Canada (NRC) is leading the Climate Resilient Buildings and Core Public Infrastructure (CRB-CPI) project to build resilience in the Canadian CPI (i.e. roads, bridges, water and wastewater systems, and rail transit) and buildings against projected climate change and extreme weather events, including floods, by updating model codes, standards, guides and decision-support tools (Infrastructure Canada 2016; Global News 2017). Public Safety of Canada's records (https://www.publicsafety.gc.ca/) reveal that over the last two decades, Canada has seen a notable increase in flooding, resulting in billions of dollars of damages and flood payouts. Recent examples include 2013 Alberta flood, 2017 Montreal-Gatineau flood and 2019 southern Ontario and Quebec floods. Therefore, within the CRB-CPI project, enhancing flood-resilience and performance of buildings was identified as an important research area. Coulbourne consulting from the US was tasked to spearhead the development of flood provisions for the National Building Code (NBC) in collaboration with NRC researchers, in addition to developing two guidelines, one related to the development of design requirements for flood-resistant buildings and the other related to improving flood-resistance for existing buildings. To support this initiative, detailed information on expected flood loads across Canada in riverine, urban and coastal conditions was required. In many parts of the world, this information is closely tied with floodplain maps and what is shown on those maps.

Following the approach suggested in American Society of Civil Engineers Standards ASCE/SEI 7-16 (ASCE/SEI 7-16, 2017), it was suggested in Khaliq et al. (2018) that in Canadian floodplains, flood loading for building design must be determined at a minimum for (i) flood depth, (ii) flood velocity, (iii) waves generated by moving water in coastal locations, and (iv) the impact of debris, including that from ice. Flood provisions in ASCE/SEI 7-16 included those related to: hydrostatic loads caused by depth of water; hydrodynamic loads caused by the impact of moving water; erosion and scour; wave conditions and wave loads; and flood-borne debris and debris impact loads. As mentioned above, many of these aspects are linked with floodplain maps and also with the detailed numerical modelling outputs that support these maps. Therefore, flood maps that show flood extents and spatial patterns of both velocity and depth of flood waters for flood-prone areas are required for estimating flood loads arising from hydrodynamic and hydrostatic forces of flood waters for building design purposes and for developing related codes and guidelines.

To support the efforts of Coulbourne consulting related to the development of two guidelines documents, selected floodplain maps from Alberta, British Columbia, Manitoba, New Brunswick, Newfoundland and Labrador, Nova Scotia, Ontario, Prince Edward Island, Quebec, and Saskatchewan for select communities/regions representing riverine, coastal and urban environments were collected, reviewed and documented in Khaliq and Attar (2017, 2019) and

Khaliq et al. (2018). Some highlights from this effort are discussed below in the context of flood loads and design of flood-resistant buildings.

In 1976, the federal government of Canada started a nation-wide flood protection program, namely the Flood Damage Reduction Program (FDRP), to protect Canadian communities and their assets from flood hazards. This program was led by Inland Waters Directorate (IWD) (IWD 1976; Environment and Climate Change Canada 2016). In 1995/96, when the FDRP ended, most of the flood-prone areas and vulnerable major population centers across the country were flood risk mapped. The majority of flood maps produced within the FDRP was targeted to show just flood extents or flood extents in the form of two zones, i.e. floodway and flood fringe. The floodway is the portion of the floodplain where flood velocities are expected to equal or exceed 1 m/s and/or water depths equal or exceed 1 m (see Figure 1.1). The flood fringe is the remainder of the flood zone where the flood velocities are under 1 m/s and the water depth is below 1 m. In certain regions (e.g. Newfoundland and Labrador), the distinction between floodway and flood fringe is also based respectively on the inundation extents associated with the 20-year flood event and the designated flood event. The latter, however, varies across the country. The designated flood for Alberta, Newfoundland and Labrador, many parts of New Brunswick, Nova Scotia, some parts of Ontario, Quebec and Manitoba is the 100-year flood event. For some parts of Ontario, Manitoba and New Brunswick, the designated flood corresponds to the historically observed significant flood events, simply noted as “historical floods”. In Saskatchewan, the designated flood corresponds to the 500-year event, and in British Columbia, it corresponds to the 200-year event. In some jurisdictions, flood extents corresponding to multiple flood return periods (i.e. 5-, 10-, 20-, 50-, 100-, 200-, 500-, and 1000-year) have also been mapped (e.g. Calgary). Likewise, in some costal environments, flood extents corresponding to multiple return periods are also available (e.g. Nova Scotia and Prince Edward Island). In some regions, new flood maps are being developed for higher than the 100-year protection level (e.g. some parts of Manitoba). It is important to know that nearly all of the flood maps were produced for land use planning and regulation purposes and not for building design purposes.

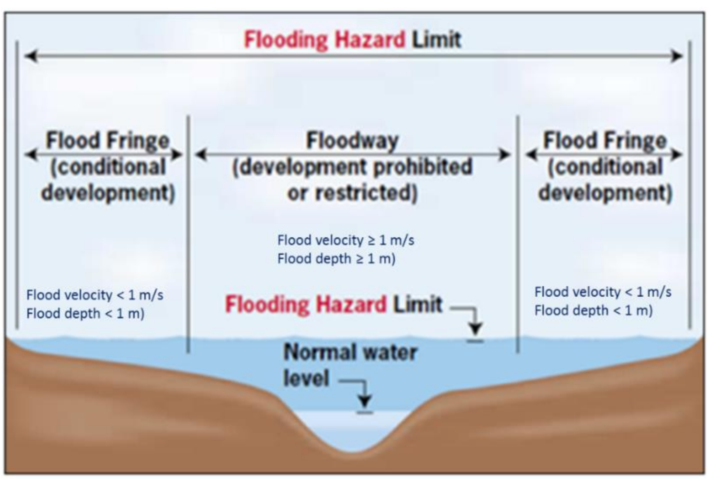

Figure 1.1: A schematic diagram showing floodway and flood fringe. Source: Ontario Ministry of Natural Resources and Forests.

As discussed above, the existing Canadian flood maps were not produced for building design purposes and code provisions. Therefore, these maps are useful only for deriving some preliminary estimates of expected flood loads with respect to the mapped water levels. These maps, however, would also be helpful for identifying areas/regions where detailed flood modelling would be useful. The existing level of available information from Canadian flood maps is inadequate to support quantitative estimates of flood loads and load combinations for building design and retrofitting purposes. Therefore, to support the development of prescriptive requirements for building design, a number of flood loads data generation case studies were designed, to be completed by Canadian consulting firms (see Table 1.1). In support of these case studies, a systematic guidance was prepared with assistance from the Coulbourne consulting team. This guidance is described in Chapter 2 of this report. This guidance was necessary since derivation of flood loads from flood modelling and mapping studies was never attempted before in Canada. It is important to mention that the systematic guidance was developed early on in 2020, but was documented in the form of a report only in April 2021. Additional information on the specific objectives, layout and limitations of this report are discussed below in Section 1.2, Section 1.3 and Section 1.4.

Table 1.1: Selected flood modelling and mapping case studies for flood loading data generation.

Province/Territory	Consulting firm	Target site
Alberta	Northwest Hydraulic Consultant, Edmonton	North Saskatchewan River Peace River
British Columbia	Northwest Hydraulic Consultant, Vancouver	City of Surrey City of Vancouver
Manitoba	Hatch, Winnipeg	Souris River
New Brunswick	CBCL, Halifax	Saint John
Newfoundland and Labrador	CBCL, Halifax	Waterford River
Northwest Territory	Baird, Ottawa	Tuktoyaktuk Hamlet
Nova Scotia	CBCL, Halifax	Mahone Bay Truro
Ontario	Baird, Ottawa	Lake Erie: Long Point and Turkey Point
Quebec	LaSalle | NHC	Beauport River Clair Creek
Saskatchewan	Hatch, Winnipeg	Rafferty and Alameda (Souris River)

1.2 Objectives

The main objective of this report was to document the systematic guidance that was developed early on in 2020 for generating flood loads data from select floodplain mapping studies in collaboration with Canadian consulting firms. For generating flood loads data, the selected studies were required to be extended, where necessary, to simulate several targeted flood scenarios corresponding to 10-, 20-, 50-, 100-, 200-, 500-, 1000-, and 2500-year return periods.

1.3 Organization of the Report

Following a short introduction in Chapter 1 to the CRB-CPI project and history of floodplain mapping in Canada, Chapter 2 of this report presents the guidance for generating flood loads data from flood modelling and mapping case studies. Expected outcomes of the case studies are discussed briefly in Chapter 3, followed by the list of cited references.

1.4 Scope and Limitations

This report presents the guidance that was developed in consultation with the Coulbourne consulting team to generate flood loads data from recently completed select flood modelling and mapping studies from across Canada (referred to here as case studies). This guidance was furnished to all collaborating consulting firms (see Table 1.1) prior to generating flood loads data from all case studies. This guidance was developed under the assumption that the recently completed studies had most likely used up-to-date information on supporting datasets, state-of-the-art hydrologic/hydraulic modelling tools, and coastal models and analyses. For floodplain modelling and mapping studies, supporting datasets could be bathymetry data, LiDAR data, aerial imagery, and historical observations on river flows, waves and storm surge, etc. In relation to the selected case studies, no independent effort was expensed to evaluate the quality of supporting datasets, the technology and the adopted methodologies that were used in completing the original studies. For such evaluations, the NRC depended on the expert judgement and experience of all collaborating consulting firms.

2 Guidance for Flood Loads Data Generation

2.1 General

For the selection of existing floodplain mapping studies for generating data on flood loads, it was proposed to all consultants to invoke their experience and use their best judgement with respect to the choice of modelling tools and the quality of supporting datasets employed in those studies. For instance, potential candidate studies could be those where most of the supporting datasets were readily available and accessible. For a variety of floodplain mapping studies, several datasets are generally employed, e.g. bathymetry data, LiDAR data, DEM (digital elevation model) data, rive cross-sectional information, historical flood events for hydraulic model calibration and evaluation, hydrologic and land use data, precipitation intensity data where applicable, storm surge data, wave conditions, tidal elevations, etc. For selected locations from riverine, coastal and urban environments, including Great Lakes shoreline areas, it was assumed that the calibrated models (i.e. hydrologic, hydraulic/hydrodynamic and wave models or combinations of these and various other models, where applicable) were readily available to the consultants. For generating flood scenarios, the consultants were required to use 10-, 20-, 50-, 100-, 200-, 500-, 1000-, and 2500-year return period events. For mapping water levels, maximum elevations attained for all points for each flood scenario were required to be considered. The information required to be generated from floodplain modelling and mapping studies to support calculation of flood loads is described below separately for riverine and costal conditions, including large lake shorelines.

2.2 Riverine Conditions

The guidance below is written in the form of steps to be undertaken by all consultants and is not written in the form of a narrative. This pattern was followed to keep the guidance simple and to the point for easy comprehension.

For each of the eight desired flooding scenarios noted above, the consultant should create a floodplain map and select about 10 representative transects along the river. For example, if the selected river reach is 5 km long then transects can roughly be half-a-km apart. Each transect needs to be divided into 11 save points (see Figure 2.1 below), covering both floodway and flood fringe partitions of the floodplain. The floodway and flood fringe partitions could be decided based on the velocity and depth criteria discussed in Chapter 1 or the ones already established based on the designated/regulatory flood levels can also be used. Divide the main river channel into 3 save points and the rest of the cross-section into 8 save points, 4 on either side of the river channel. A careful judgement is required to be exercised according to the on-ground situation for deciding the number of save points, e.g. it is possible to have 3 save points on one side of the main channel of the river and 5 on the other side or any other combinations as deemed suitable by the consultant. Similarly, for the placement of transects, the consultant should consider those areas that are likely to experience flooding for certain selected scenarios and those also reflect flooding conditions that are typical for the study area. For placing transects, the areas with levees, dunes, flood walls, etc., should be avoided because they prevent flooding and hence the information from such places is not so useful for deriving flood loads to inform building design.

For each transect, the consultant should record the following information:

- Transect location (latitude and longitude);
- River discharge for the transect;
- Cross-sectional area of the transect (including floodway and flood fringe);
- Mean water level for the transect (with respect to a common datum) at the time of maximum flood;
- Mean flow velocity for the transect (i.e. overall average velocity) at the time of maximum flood;
- Longitudinal location of the transect from a known downstream point (e.g. transect 5 is about 11,500 meters upstream of the confluence of River A and River B or some distance X upstream from a named bridge); and
- Kinetic energy coefficient “alpha” used for each cross-section. See the sketch in Figure 2.2.

For each save point, the consultant should record the following information (corresponding to maximum flood conditions):

- Location (indicating whether the save point is located in flood fringe or floodway, along with the latitude and longitude of the centroid);
- Ground elevation (i.e. the average elevation of ground, reflecting centroid of the channel bottom);
- Water level (local water level from a common datum, e.g. the Canadian geodetic datum);
- Local flood depth (i.e. the section averaged depth and the maximum depth);
- Local flow velocity (i.e. the section averaged velocity and the maximum velocity);
- Local cross-sectional area of each save point trapezoid; and
- Manning’s n for each save point.

For flood loads:

- The consultant should develop summary statistics (e.g. mean and standard deviation) for local flood depth, local flow velocity and maximum velocity at each save point. This is with respect to different return periods for the same save point;
- For each study site (considering all 10 transects together or whatever the number used), the consultant should create a large sample of estimated values of each variable (i.e. local flood depth, local flow velocity and maximum velocity) for 10-, 20-, 50-, 100-, 200-, 500-, 1000-, and 2500-year return periods and a grand sample considering all return periods for each of the considered variables and derive respective summary statistics.

To elaborate further, for a target 200-year return period flood scenario for riverine conditions, the models would start with the 200-year flood and produce results for water elevation and velocity related variables described above for at least 10 transects and 11 save points across each transect.

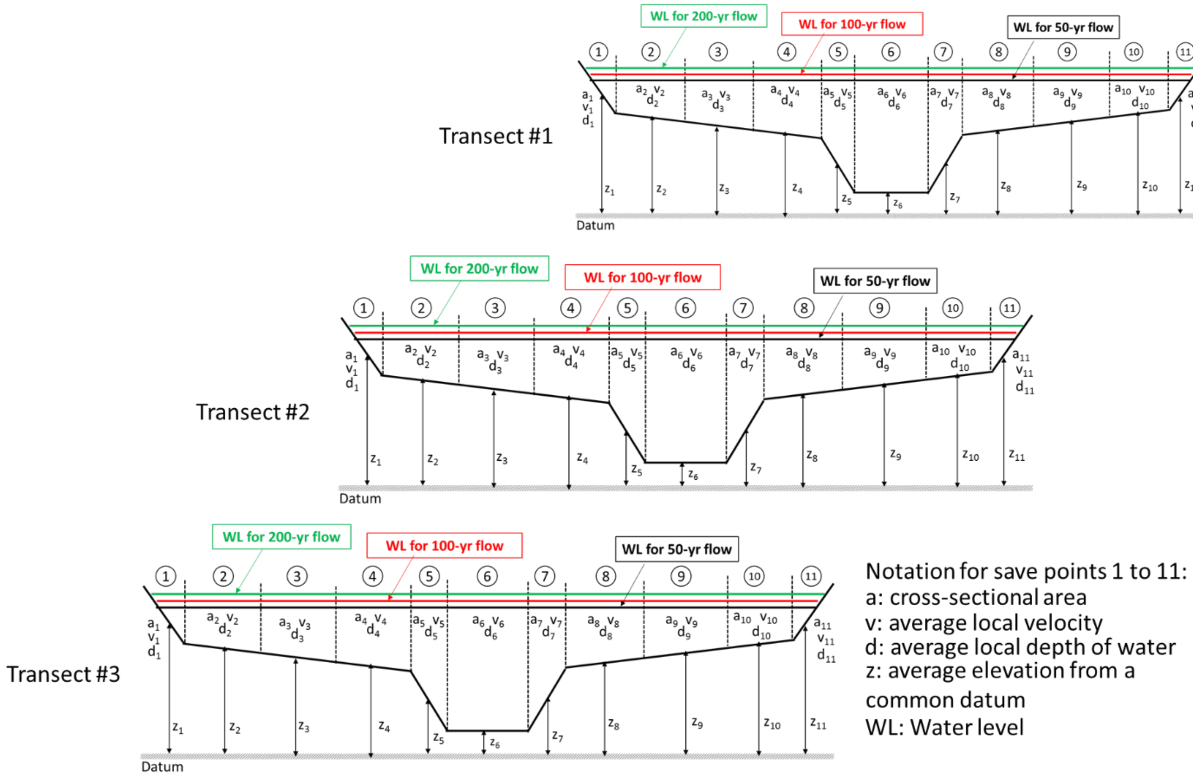

Figure 2.1: A schematic diagram showing water levels and various other variables and parameters corresponding to three designated/design flow values (i.e. Q50, Q100, and Q200 cms, respectively shown in black, red and green) at three different locations (transects #1 to #3) along a river channel. Description of variables/parameters is provided in the graphics.

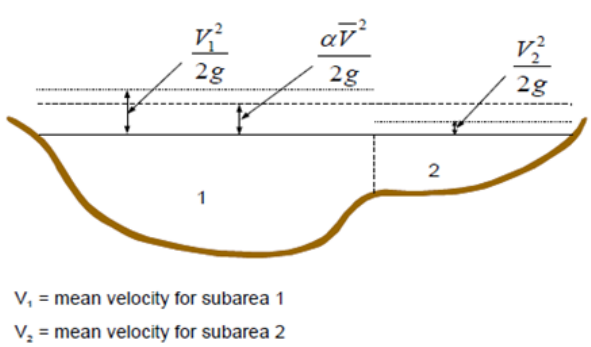

Figure 2.2: A schematic diagram for estimating mean energy and kinetic energy coefficient alpha.

2.3 Coastal/Shoreline Conditions

The guidance below is written in the form of steps to be undertaken by all consultants and is not written in the form of a narrative. This pattern was followed to keep the guidance simple and to the point for easy comprehension.

For each of the eight flooding scenarios corresponding to 10-, 20-, 50-, 100-, 200-, 500-, 1000-, and 2500-year return period events, the consultant should create coastal flood maps and select 10 representative transects perpendicular to the coastline/shoreline. Divide each transect into 11 (or so) save points, giving due considerations to site-specific physical constraints. For the placement of transects, those areas should be considered that actually show flooding and that is typical to the area. Location of transects in areas with levees, dunes, flood walls, etc., should be avoided because they prevent flooding and information from such areas is not so useful for flood load calculations.

For each transect, the consultant should record the following information:

- Transect location (latitude and longitude);
- Mean sea level or lake stage used;
- Tidal condition/elevation considered;
- Wind speed;
- Still water level for the transect (with storm surge effects but without wave setup effects);
- Wave runup limits for the transect;
- Ground elevation for the transect (lowest, highest and the mean elevation from a common datum);
- Water level for the transect (from a common datum);
- Water depth for the transect (local min, max and average values); and
- Water velocity for the transect (local min, max and average values).

For each save point, the consultant should record the following information:

- Ground elevation (average elevation of the ground);
- Local water level (with and without wave setup) from a common datum;
- Local flood/water depth (local min, max and average values);
- Local wave height and period (significant height and some measure of maximum height with breaking); and
- Current velocity.

For flood loads:

- The consultant should develop summary statistics (e.g. mean and standard deviation) for each variable (i.e. local flood depth, local velocity of water, maximum velocity and wave height) at each save point. This is with respect to different return periods for the same save point.

- For each study site (considering all 10 transects), the consultant should create a large sample of estimated values of each variable (i.e. local flood depth, local velocity, maximum velocity and wave height) for 10-, 20-, 50-, 100-, 200-, 500-, 1000-, and 2500-year return periods and a grand sample considering all return periods for each of the considered variables and derive respective summary statistics.

To elaborate further, for the 200-year coastal (or large lake shoreline conditions) flooding scenario, the models would start with S_{200} (where S is storm tide or storm water level) and the consultant would run a wave model (with 200-year return period waves offshore or 200-year return period wind speed to generate waves) to get breaking wave conditions for at least 10 transects and 11 save points.

3 Concluding Remarks

Like snow, ice and wind loads, flood loads are not considered in the current NBC for the design of buildings. For designing a building to resist flood forces and for improving flood-resistance of existing buildings, reasonable estimates of flood loads are required. In general, derivation of flood loads is tied with what is shown on floodplain maps and therefore detailed flood maps are required to support derivation of flood loads for a given project. In Canada, floodplain maps were developed for land use planning and regulation purposes and not for building design and codes development. The existing flood maps are useful only for developing some preliminary estimates of flood loads from the velocity and depth information associated with floodway and flood fringe and that information is not adequate and sufficiently fine to support derivation of flood loads for building design purposes.

To support the development of prescriptive requirements for building design purposes, the NRC planned a number of flood loads data generation case studies, to be completed by Canadian consulting firms, in order to support derivation of flood loads corresponding to a range of flooding scenarios from urban, riverine and coastal environments. In support of these case studies, a systematic guidance was prepared with assistance from Coulbourne consulting. This guidance is described in Chapter 2 of this report. It is important to note that this guidance was developed early on in 2020, but was documented in the form of a report only in April 2021. However, it was provided to all consultants in a timely manner before the initiation of case studies.

The outcomes from the targeted case studies were to be utilized by Coulbourne consulting for developing prescriptive requirements for the design of flood-resistant buildings for the NBC. In addition, the proposed studies and their outcomes and the methodologies are expected to help building designers and regulators for calculating flood loads and related load combinations to inform design of new buildings and retrofitting of existing buildings in riverine, urban and coastal floodplains across the country.

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