METEOR: Bridge to commercial CAT model. Report M3.4c/P

UKSA IPP2 Grant Programme

Open File Report OR/22/025

BRITISH GEOLOGICAL SURVEY

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Glossary

AIR	AIR Worldwide Corporation, formally Applied Insurance Research, is part of the Verisk Analytics family of companies.
BGS	British Geological Survey: An organisation providing expert advice in all areas of geoscience to the UK government and internationally
DMD	Disaster Management Department of the Prime Minister's Office of Tanzania, focused on disaster risk
DRM	Disaster Risk Management; the application of disaster risk reduction policies and/or strategies
EO	Earth Observation; the gathering of information about Earth’s physical, chemical and biological systems via remote sensing technologies, usually involving satellites carrying imaging devices
FATHOM	Provides innovative flood modelling and analytics, based on extensive flood risk research
GCRF	Global Challenges Research Fund
GEM	Global Earthquake Model: Non-profit organisation focused on the pursuit of earthquake resilience worldwide
HOT	Humanitarian OpenStreetMap Team: A global non-profit organisation the uses collaborative technology to create OSM maps for areas affected by disasters
ImageCat	International risk management innovation company supporting the global risk and catastrophe management needs of the insurance industry, governments and NGOs
IPP	International Partnership Programme; the UK Space Agency’s International Partnership Programme (IPP) is a £30M per year programme, which uses expertise in space-based solutions, applications and capability to provide a sustainable economic or societal benefit to emerging nations and developing economies
LDC	Least Developed Country on the Organisation for Economic Co-operation and Development's (OECD) Development Assistance Committee (DAC) list
M	Milestone, related to work package deliverable
METEOR	Modelling Exposure Through Earth Observation Routines; a three-year project funded by the UK Space Agency to develop innovative application of Earth Observation (EO) technologies to improve understanding of exposure and multihazards impact with a specific focus on the countries of Nepal and Tanzania
NSET	National Society for Earthquake Technology: Non-governmental organisation working on reducing earthquake risk in Nepal and abroad
ODA	Official Development Assistance; government aid that promotes and specifically targets the economic development and welfare of developing countries

OED	Open Exposure Data: The exposure data input format supported by the Oasis Loss Modelling Framework and by all models deployed on the Oasis platform
OPM	Oxford Policy Management: Organisation focused on sustainable project design and implementation for reducing social and economic disadvantage in low-income countries
PAGER	Prompt Assessment of Global Earthquakes for Response: An automated system developed by the United States Geological Survey to rapidly estimate earthquake shaking and the scope and impact of earthquakes around the world
SDGs	Sustainable Development Goals; these goals were set up in 2015 by the United Nations General Assembly and are intended to be achieved by the year 2030
UKSA	United Kingdom Space Agency; an executive agency of the Government of the United Kingdom, responsible for the United Kingdom's civil space programme
WP	Work Package; discrete sets of activities within the METEOR Project, each work package is led by a different partner and has specific objectives

Foreword

This report is the published product of a study by ImageCat as part of the Modelling Exposure Through Earth Observation Routines (METEOR) project led by British Geological Survey (BGS).

METEOR is grant-funded by the UK Space Agency's International Partnership Programme (IPP), a >£150 million programme which is committed to using the UK's space sector research and innovation strengths to deliver sustainable economic, societal, and environmental benefit to those living in emerging and developing economies. IPP is funded from the Department for Business, Energy and Industrial Strategy's (BEIS) Global Challenges Research Fund (GCRF). This £1.5 billion Official Development Assistance (ODA) fund supports cutting-edge research and innovation on global issues affecting developing countries. ODA-funded activity focuses on outcomes that promote long-term sustainable development and growth in countries on the OECD Development Assistance Committee (DAC) list. IPP is ODA compliant, being delivered in alignment with UK Aid Strategy and the United Nations' (UN) Sustainable Development Goals (SDGs).

The objective of this report is to summarise the detail associated with the digital dataset M3.4b: Bridge to commercial CAT model – data delivery.

Contents

TABLES

Summary

This report describes a specific piece of work conducted by ImageCat as part of the METEOR (Modelling Exposure Through Earth Observation Routines) project, led by British Geological Survey (BGS) with collaborative partners Oxford Policy Management Limited (OPM), SSBN Limited, The Disaster Management Department, Office of the Prime Minister – Tanzania (DMD), The Global Earthquake Model Foundation (GEM), The Humanitarian OpenStreetMap Team (HOT), ImageCat and the National Society for Earthquake Technology (NSET) – Nepal.

The 3-year project was funded by UK Space Agency through their International Partnership Programme, details of which can be located in the Foreword, and was completed in 2021.

The project aimed to provide an innovative solution to disaster risk reduction, through development of an innovative methodology of creating exposure data from Earth Observation (EO) imagery to identify development patterns throughout a country and provide detailed information when combined with population information. Level 1 exposure was developed for all 47 least developed countries on the OECD DAC list, referred to as ODA least-developed countries in the METEOR documentation, with open access to data and protocols for their development. New national detailed exposure and hazard datasets were also generated for the focus countries of Nepal and Tanzania and the impact of multiple hazards assessed for the countries. Training on product development and potential use for Disaster Risk Reduction was performed within these countries with all data made openly available on data platforms for wider use both within country and worldwide.

This report (M3.4c/P) is the third part of the M3.4 report, specifically on the detail contained in the digital exposure dataset M3.4, generated by BGS for the work package EO data for exposure development (WP3) led by ImageCat. The other 7 METEOR work packages included, Project Management (WP1 – led by BGS), Monitoring and Evaluation (WP2 – led by OPM), Inputs and Validation (WP4 – led by HOT), Vulnerability and Uncertainty (WP5 - led by GEM), Multiple hazard impact (WP6 – led by BGS), Knowledge sharing (WP7 – led by GEM) and Sustainability and capacity building (WP8 – led by ImageCat).

1. METEOR Project

1.1. PROJECT SUMMARY

Project Title	Modelling Exposure Through Earth Observation Routines (METEOR): EO-based Exposure, Nepal and Tanzania
Starting Date	08/02/2018
Duration	36 months
Partners	UK Partners: The British Geological Survey (BGS) (Lead), Oxford Policy Management Limited (OPM), SSBN Limited International Partners: The Disaster Management Department, Office of the Prime Minister – Tanzania, The Global Earthquake Model (GEM) Foundation, The Humanitarian OpenStreetMap Team (HOT), ImageCat, National Society for Earthquake Technology (NSET) – Nepal
Target Countries	Nepal and Tanzania for "level 2" results and all 47 Least Developed ODA countries for "level 1" data
IPP Project	IPPC2_07_BGS_METEOR

Table 1: METEOR Project Summary

1.2. PROJECT OVERVIEW

At present, there is a poor understanding of population exposure in some Official Development Assistance (ODA) countries, which causes major challenges when making Disaster Risk Management decisions. Modelling Exposure Through Earth Observation Routines (METEOR) takes a step-change in the application of Earth Observation exposure data by developing and delivering more accurate levels of population exposure to natural hazards. METEOR is delivering calibrated exposure data for Nepal and Tanzania, plus 'Level-1' exposure for the remaining Least developed Countries (LDCs) ODA countries. Moreover, we are: (i) developing and delivering national hazard footprints for Nepal and Tanzania; (ii) producing new vulnerability data for the impacts of hazards on exposure; and (iii) characterising how multi-hazards interact and impact upon exposure. The provision of METEOR's consistent data to governments, town planners and insurance providers will promote welfare and economic development and better enable them to respond to the hazards when they do occur.

METEOR is co-funded through the second iteration of the UK Space Agency's (UKSA) International Partnership Programme (IPP), which uses space expertise to develop and deliver innovative solutions to real world problems across the globe. The funding helps to build sustainable development while building effective partnerships that can lead to growth opportunities for British companies.

1.3. PROJECT OBJECTIVES

METEOR aims to formulate an innovative methodology of creating exposure data through the use of EO-based imagery to identify development patterns throughout a country. Stratified sampling technique harnessing traditional land use interpretation methods modified to characterise building patterns can be combined with EO and in-field building characteristics to capture the distribution of building types. These protocols and standards will be developed for broad application to ODA countries and will be tested and validated for both Nepal and Tanzania to assure they are fit-for-purpose.

Detailed building data collected on the ground for the cities of Kathmandu (Nepal) and Dar es Salaam (Tanzania) will be used to compare and validate the EO generated exposure datasets.

Objectives of the project look to: deliver exposure data for 47 of the least developed ODA countries, including Nepal and Tanzania; create hazard footprints for the specific countries; create open protocol; to develop critical exposure information from EO data; and capacity-building of local decision makers to apply data and assess hazard exposure. The eight work packages (WP) that make up the METEOR project are outlined below in section 1.4.

1.4. WORK PACKAGES

Outlined below are the eight work packages that make up the METEOR project, which are led by various partners. Table 2 provides an overview of the work packages together with a brief description of what each of the work packages cover.

Work Package	Title	Lead	Overview
WP.1	Project Management	BGS	Project management, meetings with UKSA, quarterly reporting and the provision of feedback on project deliverables and direction across primary stakeholders.
WP.2	Monitoring and Evaluation	OPM	Monitoring and evaluation of the project and its impact, using a theory of change approach to assess whether the associated activities are leading to the desired outcome.
WP.3	EO Data for Exposure Development	ImageCat	EO-based data for exposure development, methods and protocols of segmenting/classifying building patterns for stratified sampling of building characteristics.
WP.4	Inputs and Validation	HOT	Collect exposure data in Kathmandu and Dar es Salaam to help validate and calibrate the data derived from the classification of building patterns from EO-based imagery.
WP.5	Vulnerability and Uncertainty	GEM	Investigate how assumptions, limitations, scale and accuracy of exposure data, as well as decisions in data development process lead to modelled uncertainty.
WP.6	Multiple Hazard Impact	BGS	Multiple hazard impacts on exposure and how they may be addressed in disaster risk management by a range of stakeholders.
WP.7	Knowledge Sharing	GEM	Disseminate to the wider space and development sectors through dedicated web-portals and use of the Challenge Fund open databases.
WP.8	Sustainability and Capacity-Building	ImageCat	Sustainability and capacity-building, with the launch of the databases for Nepal and Tanzania while working with in-country experts.

Table 2: Overview of METEOR Work Packages

1.5. STRUCTURE OF THIS DOCUMENT

This document outlines the detail contained in the digital data associated with METEOR deliverable M3.4b: Bridge to commercial CAT model - data delivery, being the partner deliverable. Section 2 describes the breakdown and detail contained in the two data delivery packages with Section 3 providing detail on the building exposure data for all 47 ODA countries and Section 3.4 providing detail on the OED format exposure data for all 47 ODA countries

2. Building exposure data

Building exposure data is provided for the individual 47 ODA countries as individual country-wide GIS-format shapefile with an associated CSV file, together with metadata XML files for ISO standards ISO19110 and ISO19139. Examples of the full building exposure XML detail for Nepal is provided in ANNEX A.

2.1. BUILDING EXPOSURE SHAPEFILE

The building exposure shapefile (.shp) is a geospatial vector point file containing specific attribute information for individual data points within the specific ODA country:

- UID
- BLD_CNT
- BLD_SIZE_M
- VAL_USD

Detail on these attributes can be found in Section 0. The shapefile can be linked to the building exposure CSV file (detailed in Section 2.2) in order to understand the construction type associated with each vector data point.

2.2. BUILDING EXPOSURE CSV

The building exposure CSV is a comma-delimited text file containing specific information relevant to individual data points within the specific ODA country:

- uid
- contype
- bld_cnt
- bld_size_m
- val_usd

Detail on these attributes can be found in Section 0. The CSV can be linked to the building exposure shapefile (detailed in Section 2.1) in order to understand the distribution of the construction type.

3. Building Exposure Metadata XML file detail

3.1. BUILDING EXPOSURE ISO19110 XML

The ISO19110 XML file for the *_building_exposure_detail_20200805.shp feature catalogue is concise. This relates to a Point Vector file with the following feature attribute detail:

- **Feature Attributes**:
  - FID: internal feature number (Esri)
  - Shape: feature geometry (Esri)
  - UID: unique numerical identification (ImageCat)
  - BLD_CNT: total estimated count of buildings per 15-arcsecrond grid cell (ImageCat)
  - BLD_SIZE_M: total estimated building area in meters per 15-arcsecond grid cell (ImageCat)
  - VAL_USD: total estimated building replacement cost in 2020 USD per 15-arcsecond grid cell (ImageCat)

3.2. BUILDING EXPOSURE DETAIL ISO19110 XML

The ISO19110 XML file for the *_building_exposure_detail_20200805.csv feature catalogue is relatively concise. This relates to a relational CSV table with the following feature attribute detail:

- **Feature Attributes:**
  - uid: unique numerical identification (ImageCat)
  - contype: The construction type uses the GEM building taxonomy. The description of each construction type code can be found in the "Structural Distribution" data lineage processing step of the accompanied vector point shapefile along with the mapping scheme breakdown by development pattern (GEM)
  - BLD_CNT: total estimated count of buildings per 15-arcsecrond grid cell (ImageCat)
  - BLD_SIZE_M: total estimated building area in meters per 15-arcsecond grid cell (ImageCat)
  - VAL_USD: total estimated building replacement cost in 2020 USD per 15-arcsecond grid cell (ImageCat)

3.3. BUILDING EXPOSURE ISO19139 XML

The ISO19139 XML file is a Geographic Information Metadata Implementation Specification for the *_building_exposure_20200805.shp. It provides detail on:

- **Vector spatial representation**: the EPSG reference system identifier associated with the data
- **Abstract**: 'This data was developed as part of the Modelling Exposure Through Earth Observation Routines (METEOR) project and is a Level 1, or a global-quality exposure data set. Minimal country-specific data was collected. The data is intended for CAT modelling and loss estimation. Repurposing this data for any reason other than assessing risk is not recommended. The data presents the estimated number of buildings, building area, and rebuilding value at a 15-arcsecond grid resolution (approximately 500 meters at the equator). This data set is in point shapefile format where the points represent the centroids of the 15-arcsecond grid.' The next section is specific for each country based on the input data for the development. The abstract ends with the detail: Along with the *_buildings_exposure_20200805.shp point shapefile there is a relational table that can be linked using the unique OBJECTID field to the OBJECTID of the [*_buildings_exposure_detail_20200805] CSV table.

- **Purpose**: This data provides an estimate of the number of buildings and replacement cost by construction type posted at a 15 arc-second grid resolution. Estimates are generated using a method of classifying the built environment into "development patterns" using moderate remote sensing data and assigning the proportion of building area in each development pattern to each construction-type. The data is intended for CAT modelling and loss estimation.
- **Credit**: Commissioned by: United Kingdom Space Agency Distributed by: Modelling Exposure Through Earth Observation Routines (METEOR) project Provided or Created by: ImageCat, Inc.
- **Responsible Parties**: detail of the parties responsible for the project and data generation
- **Use Limitation**: The building stock estimates developed in this project spread an estimate of the number of buildings derived from national population statistics including persons per household, households per building type, construction pattern distributions for various development patterns, the homogeneity of various construction patterns, building densities at the grid level as derived through image processing algorithm, and typical replacement costs. The methods described above have been carefully tailored through expert opinion, building area and count aggregates, research, and manual review. However, it is important to recognize that the numbers presented in the datasets are estimates and are not a count or building census. At the cell level, they may not be representative. Mapping schemes and replacement costs are representative of typical building infrastructure and replacement costs for the entire country. Regional variations in costs and building distributions (due to cost of materials and labour) will vary however, the final replacement cost values are calculated per development pattern in the country. Validating the distribution of building counts is a multi-step process. The final section of this limitation detail is country-specific.
- **Geographic Extent**: bounding box of the data
- **Evaluation Method**: Dasymetric Mapping Evaluation: A visual review and adjustment by ImageCat's Senior modeler were conducted. Comparison with several dasymetrically mapped products, including Landscan, GHSL-SAR, GUF, and WorldPop were reviewed with particular attention to low population areas
- **Conformance Result**:
    - Structural Distribution was developed through web reconnaissance by ImageCat engineer sourcing various engineering documents, engineering standards, and ground imagery, were available. In addition, the structural mapping from the national census data was validated through mapping the structural classes and review of the results with ImageCat. The distribution of structural classes closely reflected known patterns of construction practices as verified by country statistics.
    - Persons per household Evaluation: As a level -1 global exposure data set and available national census level data, no additional validation was performed.
- **Measurement Description**: Development pattern evaluation: Several iterations by ImageCat's Senior modeler were conducted to ensure accurate distribution and assignment of development pattern in populated area. A water mask was applied to limit the classification of development patterns in uninhabited areas.
    - **Building Height and Area Evaluation:** Building height and size were generated using national census data, and OSM building height and building footprints area averages aggregated to 15-arcsecond grids. The vast number of buildings are single story. Based on constructions type the average story by low-, mid-, and high-rise was calculated as 1, 4, and 8 stories. The resulting data was reviewed spatially on maps by ImageCat.
    - **Replacement Ccosts Evaluation:** The replacement costs were obtained from the GFDRR Africa Disaster Risk Financing – Result Area 5 Exposure Development: Replacement Cost Refinements to the Exposure data report prepared by ImageCat for the World Bank. Significant literature review, construction manual or developer's estimates, and hazard modelling went into developing the replacement cost values by wall, floor, and roof material and development pattern. Thus, the replacement cost values were used directly with no additional corrective measures taken.

- **Urban-Rural Distribution of Buildings:** In addition to the ratio of people per building, the ratio of buildings in settlements to rural areas is a key parameter. Unfortunately, there are no settlement boundaries that can be used to develop hard ratios to compare with published statistics. However, because buildings are distributed first to settlements, and then distributed to rural areas, there are clear visual cues when the distribution between urban and rural areas is inadequate. The follow are examples of the reviews conducted by analysts: 1) If there were too many buildings assigned to urban areas, and there was a void in rural areas. Thus, these grids were checked against EO data to confirms whether these areas are populated. 2) If there were too few buildings in urban settlements which caused a "donut" effect, where rural populations surrounding urban areas were assigned a greater population than urban areas. This required the adjustment of residential building density for a specific region. 3) Finally, there was a check of reviewing the distribution of buildings in rural areas. The parameters used for spreading agricultural buildings may not capture rural development well, and there were limited points with too many buildings in rural areas. In these instances, the parameters for distributing rural development were adjusted.

- **Lineage**
  - **Input data bibliography:** this section will be specific for the country
- **Process Steps**:
  - **Population Data processing**: The population values are from the national level 2020 Total population estimates from the United Nations World Population Prospects. Population is converted to an estimate of the number of households using the national average estimates of persons per household at the country level collected from various sources including national census, and the UN population database. The national level population and household values were mapped to the national statistics then interpolated to a 15-arcsecond (~500m) grid cell and used to infer the number of buildings. Administrative GIS data was not used to aggregate or allot population or buildings but GADM administrative levels 1 (national), 2 (state), and 3 (county or district) names and numeric code are added to the final result for ease of use by data users.
  - **Dasymetric Mapping**: A machine learning process (CART algorithm (Breiman et al., 1984; Khaled et al., 2014), Random forest (Breiman, 2001), and Support Vector Networks (Cortez et al., 1995)) with a variety of remotely sensed Earth Observation (EO) data products and building footprint aggregates establish the distribution statistics for dispersing buildings by urban density and development pattern type. Each of the EO products, individually or in a combination, act as weights to disperse the known population by structural type to 15-arcsecond grid cells. For determining the weights for distribution several machine learning algorithms were run using the EO to develop a prediction model. For example, in grids designated as a development patterns 1 or 2 (resembling rural or single-family residential communities) an even building distribution of the district is reallocated only to grid cells within the district associated to human settlement. This machine learning exercise informs the estimated building density, replacement cost per meter, and structural characteristics of the building stock, as described in the structural distribution processing step. The following moderate and high-resolution EO data sets used: 1) NOAA night-time light annual composite (VIIRS) 15-arcsecond grid cell (Earth Observation Group NOAA-NCEI (2016)) 2) Oak Ridge National Laboratory Landscan ambient population (LSCAN) resampled from the 30-arcsecond grid cell to 15-arcsecond (Oak Ridge National Laboratory. (2012)) 3) European Commission Joint Research Centre (EC -JRC) Global Human Settlement Layer (GHSL-Landsat) derived from Landsat imagery resampled from the aggregated 250m grid cell to 15-arcsecond (Corbane et al.,(1) 2018) 4) DLR Global Urban Footprint (GUF) resampled from 12-meter grid cells to a 15-arcsecond percentage of human presence raster grid (DLR Earth Observation Center. (2016)) 5) JRC GHSL derived from Sentinel-1 SAR (GHSL-SAR) resampled from 20-meter grid cells to a 15-arcsecond percentage of human presence raster grid (Corbane et al.,(2) 2018) 6) CIESIN-Facebook High

Resolution Settlement Layer (HRSL) resampled from 1-arcsecond grid cells to a 15-arcsecond percentage of human presence raster grid (Facebook Connectivity Lab and Center for International Earth Science Information Network - CIESIN - Columbia University. (2016)) 7) JRC mosaiced Sentinel-1 dual polarization bands (SAR B1, B2, B3) resampled from 20-meter resolution to a 15-arcsecond mean raster grid per band and a maximum mean value of the 3 bands (SAR-MaxMean). (Syrris, V., et. al (2018)) 8) National gridded population from WorldPop 2020 resampled from 3-arcsecond grid cells to 15-arcsecond (WorldPop(1)) 9) An indicator of OSM data throughout the country- building count, area, and maximum building height were calculated from building footprint polygons and aggregated up to create 15-arcsecond grids. (ImageCat, Inc. (2020)) 10) Center for International Earth Science Information Network (CIESIN) Water Mask resampled from 30-arcsecond grid cell to 15-arcsecond (CIESIN, 2018) 11) NASA SRTM elevation aggregated and transformed from 90m resolution elevation to 15-arcsecond slope raster grid. (NASA-NGA. 2014) Data Mask: To prevent unpopulated areas from being considered as settlements the CIESIN water layer was used as a mask for populated and non-populated areas. For populated areas, a development pattern is assigned, and population is dispersed by the weight of the combined EO spectral signature. Development Pattern Creation: Development patterns are patterns of construction in the country that typify the building structure development and density as much as possible. They sometimes correspond with land use, but not always. The development patterns are determined by a structural engineer working with GIS analysts to conduct a web reconnaissance survey of available data regarding the structural type and distribution of the country. Various engineering websites and standards (Prompt Assessment of Global Earthquakes for Response [PAGER], Global Earthquake Model [GEM]), IPUMS, and national statistical housing data were used to establish a preliminary structure type distribution. These preliminary distributions are validated through Google Earth Maps. After the web reconnaissance the structural engineer begins to formulate the development pattern. The intensity of urbanity correlates to both the building density and the structural distribution (see Structural Distribution Processing Step for more details). ImageCat engineer characterized 6 development pattern types (see Structural Distribution Processing Step for more details).

- **Number of Buildings**: The total number of buildings per structural class per grid cell was inferred using a combination of 1:1 number household to buildings based on the national population and housing statistics, EO machine learning, and aggregated OSM building count raster.
- **Structural Distribution**: Using the national population and housing census data mapping schemes were developed using a combination of the building wall, roof, and floor material type. Each combination of wall, roof, and floor material type are mapped to PAGER standard structural types and GEM construction type. The number of households is used to develop a structural distribution. The remainder of this section provides country specific detail
- **Building Height**: The building height values for all development patterns were obtained from the 15-arcsecond aggregated OSM building data (ImageCat, Inc., 2020). These values were used to establish the average building height to average story height per structure type. All low-rise structures are assigned a single story, mid-rise have an average of 4 stories, and high-rises have on average of 8 stories. The OSM based height raster was reviewed and validated by an in-house engineer using images provided of the individual buildings
- **Total Building Area**: The total building area was calculated using 15-arcsecond aggregated OSM building raster data sets. The area per household was estimated based on an extensive assessment of OSM building footprint data and screening based on likely size for buildings. The average size of single-family households was often found to be reasonable, and an average was used for development patterns that are primarily residential.
- **Replacement Cost**: Replacement cost was determined based on Huyck & Eguchi, 2017 and Huizinga et al., 2017. From Huizinga et al., the replacement cost of

residential, commercial, and industrial structures is estimated as a function of GDP. These were updated to 2019 USD (x 1.08) per meter squared and then adjusted based on development pattern based on Huyck & Eguchi, which found that in developing countries residential construction in urban areas was well represented, but that the value of semi-engineered and engineered properties are over predicted by Huizinga et al. when compared to Resettlement Action Plans and local expert opinion. Outer-city areas and smaller settlements are downscaled to 50% of the expected value, and rural construction is 50% of this figure. Urban areas consistent with capital city areas are consistent with the 2019 scaled values from Huizinga et al, 2017, as are industrial areas. These scaling factors are applied in accordance with the development patterns mentioned above. The final part of this section provides detail on the costs associated with each development pattern (in USD).

- **Use Limitation**: The building stock estimates developed in this project spread an estimate of the number of buildings derived from national population statistics including persons per household, households per building type, construction pattern distributions for various development patterns, the homogeneity of various construction patterns, building densities at the grid level as derived through image processing algorithm, and typical replacement costs. The methods described above have been carefully tailored through expert opinion, building area and count aggregates, research, and manual review. However, it is important to recognize that the numbers presented in the datasets are estimates and are not a count or building census. At the cell level, they may not be representative. Mapping schemes and replacement costs are representative of typical building infrastructure and replacement costs for the entire country. Regional variations in costs and building distributions (due to cost of materials and labour) will vary however, the final replacement cost values are calculated per development pattern in the country. Validating the distribution of building counts is a multi-step process. The national statistics data is used for spreading population spatially into buildings. Once buildings are distributed, the absolute number of buildings are aggregated and compared with the population. The numbers were not consistent with the expected rates of people per household and households per building for the nation, thus key parameters of the analysis are adjusted, and the process is re-run. For Afghanistan there were too few populated grids and the EO analysis was re-run to capture more areas of settlement.

3.4. BUILDING EXPOSURE DETAIL ISO19139 XML

The ISO19139 XML file is a Geographic Information Metadata Implementation Specification for the *_building_exposure_detail_20200805.csv. This relates to a relational CSV table and provides detail on:

- **Responsible Parties**: detail of the parties responsible for the project and data generation
- **Abstract**: This data was developed as part of the Modelling Exposure Through Earth Observation Routines (METEOR) project and is a Level 1, or a global-quality exposure data set. Minimal country-specific data was collected. The data is intended for CAT modelling and loss estimation. Repurposing this data for any reason other than assessing risk is not recommended. The data presents the estimated number of buildings, building area, and rebuilding value at a 15-arcsecond grid resolution (approximately 500 meters at the equator). This data set is in a point relational table that can be linked using the unique OBJECTID field to the OBJECTID of the [*_buildings_exposure_20200805.shp] point shapefile
- **Purpose**: This data provides an estimate of the number of buildings and replacement cost by construction type posted at a 15 arc-second grid resolution. Estimates are generated using a method of classifying the built environment into “development patterns” using moderate remote sensing data and assigning the proportion of building area in each development pattern to each construction-type. The data is intended for CAT modelling and loss estimation.

- **Credit**: Commissioned by: United Kingdom Space Agency Distributed by: Modelling Exposure Through Earth Observation Routines (METEOR) project Provided or Created by: ImageCat, Inc.

4. PAGER Mapping for OED Building Exposure

Mapping of U.S. Geological Survey's (USGS), Prompt Assessment of Global Earthquakes for Response (PAGER) taxonomy to common taxonomies (AIR and OED) is provided in ANNEX B. Descriptions of the structural system for AIR and OED can be found in ANNEX B. GEM taxonomy strings are multi-tiered and include properties such as material types, material technologies, material properties, number of stories, etc. The structural description of GEM taxonomies is similar to those described within PAGER.

The mapping from PAGER to GEM, AIR and OED provides a bridge from one taxonomy type to another. Building materials, technologies, lateral force-resisting systems and heights are taken into account to ensure a buildings vulnerability is properly reflected and consistent across all taxonomies. If a specific structural system identified in PAGER is not available for the other taxonomies, the most-representative (if available) is chosen. In cases where this is not applicable, the high-level (e.g. Wood, Masonry, Steel and/or Concrete) taxonomy is chosen.

The PAGER mapping file is provided in conjunction with the OED Building exposure data described in Section 5. The PAGER mapping and related AIR-OED codes can be viewed in ANNEX B.

5. OED Building exposure data

OED import format building exposure data is provided for the individual 47 ODA countries as individual country-wide CSV files for 'acc' and 'loc' together with metadata XML file. Example of the full OED building exposure XML detail for Nepal is provided in ANNEX C.

5.1. OED EXPOSURE 'ACC' CSV

The OED import format exposure 'acc' CSV file contains generic default account information included to meet OED import format requirements.:

- PortNumber: 1
- AccNumber: 1
- AccCurrency: USD
- PolNumber: 1
- PolPerilsCovered: AA1 (all perils)

5.2. OED EXPOSURE 'LOC' CSV

The OED import format exposure 'loc' CSV file contains specific attribute information relevant to individual data points within a specific ODA country:

- PortNumber: 1
- AccNumber: 1
- LocGroup
- LocNumber
- CountryCode
- LocPerilsCovered: AA1 (all perils)
- BuildingTIV
- OtherTIV
- ContentsTIV
- BITIV
- LocCurrency: USD
- OrgConstructionScheme: PAGER
- OrgConstructionCode
- ConstructionCode
- NumberOfBuildings
- FloorArea
- FloorAreaUnit: 12 (Square meters)
- AddressMatch: 0 (Ungeocoded)
- Longitude: in decimal degree
- Latitude: in decimal degree

6. OED Building Exposure Metadata XML file detail

6.1. OED BUILDING EXPOSURE XML

The XML file is a Geographic Information Metadata Implementation Specification file in ISO19139 standard associated with the OED format exposure data. This relates to the *_building_exposure_20200805 file and contains the following attribute detail:

- **Contact**: detail of the parties responsible for the project and data generation
- **Point spatial representation**: the EPSG reference system identifier associated with the data
- **Data identification**: provides a name of the associated *_building_exposure_20200805 file
- **Abstract**: This data was developed as part of the Modelling Exposure Through Earth Observation Routines (METEOR) project and is a Level 1, or a global-quality exposure data set. Minimal country-specific data was collected. The data is intended for CAT modelling and loss estimation. Repurposing this data for any reason other than assessing risk is not recommended. The data presents the estimated number of buildings, building area, and rebuilding value at a 15-arcsecond grid resolution (approximately 500 meters at the equator). This data set is in point shapefile format where the points represent the centroids of the 15-arcsecond grid. The next section is specific for each country based on the input data for the development. The abstract ends with the detail: Additionally, the data is provided in Open Exposure Data (OED) import format, as a pair of CSV files. One CSV file contains the location details, and the other is an "account" file that is filled with default information to satisfy OED format requirements. The OED input files are set to use "All perils" (i.e. "AA1"). All required OED account-related fields are populated with "1" by default (such as PortNumber, AccNumber, PolNumber).
- **Purpose**: This data provides an estimate of the number of buildings and replacement cost by construction type posted at a 15 arc-second grid resolution. Estimates are generated using a method of classifying the built environment into “development patterns” using moderate remote sensing data and assigning the proportion of building area in each development pattern to each construction-type. The data is intended for CAT modelling and loss estimation.
- **Credit**: Commissioned by: United Kingdom Space Agency Distributed by: Modelling Exposure Through Earth Observation Routines (METEOR) project Provided or Created by: ImageCat, Inc.
- **Point of Contact**: detail of the parties to contact on the project and data generation
- **Use Limitation**: The building stock estimates developed in this project spread an estimate of the number of buildings derived from national population statistics including persons per household, households per building type, construction pattern distributions for various development patterns, the homogeneity of various construction patterns, building densities at the grid level as derived through image processing algorithm, and typical replacement costs. The methods described above have been carefully tailored through expert opinion, building area and count aggregates, research, and manual review. However, it is important to recognize that the numbers presented in the datasets are estimates and are not a count or building census. At the cell level, they may not be representative. Mapping schemes and replacement costs are representative of typical building infrastructure and replacement costs for the entire country. Regional variations in costs and building distributions (due to cost of materials and labour) will vary however, the final replacement cost values are calculated per development pattern in the country. Validating the distribution of building counts is a multi-step process. The final section of this limitation detail is country-specific
- **Geographic Extent**: bounding box of the data
- **Conformance Result:**
    - Dasymetric Mapping Evaluation: A visual review and adjustment by ImageCat’s Senior modeler were conducted. Comparison with several dasymetrically mapped

    - products, including Landscan, GHSL-SAR, GUF, and WorldPop were reviewed with particular attention to low population areas
    - Structural Distribution was developed through web reconnaissance by ImageCat engineer sourcing various engineering documents, engineering standards, and ground imagery, were available. In addition, the structural mapping from the national census data was validated through mapping the structural classes and review of the results with ImageCat. The distribution of structural classes closely reflected known patterns of construction practices as verified by country statistics
    - Persons per household Evaluation: As a level -1 global exposure data set and available national census level data, no additional validation was performed.
- **Measurement Description**: Development pattern evaluation: Several iterations by ImageCat's Senior modeler were conducted to ensure accurate distribution and assignment of development pattern in populated area. A water mask was applied to limit the classification of development patterns in uninhabited areas.
    - **Building Height and Area Evaluation:** Building height and size were generated using national census data, and OSM building height and building footprints area averages aggregated to 15-arcsecond grids. The vast number of buildings are single story. Based on constructions type the average story by low-, mid-, and high-rise was calculated as 1, 4, and 8 stories. The resulting data was reviewed spatially on maps by ImageCat.
    - **Replacement costs Evaluation:** The replacement costs were obtained from the GFDRR Africa Disaster Risk Financing – Result Area 5 Exposure Development: Replacement Cost Refinements to the Exposure data report prepared by ImageCat for the World Bank. Significant literature review, construction manual or developer's estimates, and hazard modelling went into developing the replacement cost values by wall, floor, and roof material and development pattern. Thus, the replacement cost values were used directly with no additional corrective measures taken.
    - **Urban-Rural Distribution of Buildings:** In addition to the ratio of people per building, the ratio of buildings in settlements to rural areas is a key parameter. Unfortunately, there are no settlement boundaries that can be used to develop hard ratios to compare with published statistics. However, because buildings are distributed first to settlements, and then distributed to rural areas, there are clear visual cues when the distribution between urban and rural areas is inadequate. The follow are examples of the reviews conducted by analysts: 1) If there were too many buildings assigned to urban areas, and there was a void in rural areas. Thus, these grids were checked against EO data to confirms whether these areas are populated. 2) If there were too few buildings in urban settlements which caused a "donut" effect, where rural populations surrounding urban areas were assigned a greater population than urban areas. This required the adjustment of residential building density for a specific region. 3) Finally, there was a check of reviewing the distribution of buildings in rural areas. The parameters used for spreading agricultural buildings may not capture rural development well, and there were limited points with too many buildings in rural areas. In these instances, the parameters for distributing rural development were adjusted.
- **Lineage**
    - **Input data bibliography:** this section will be specific for the country
- **Process Steps**:
    - **Population Data processing**: The population values are from the national level 2020 Total population estimates from the United Nations World Population Prospects. Population is converted to an estimate of the number of households using the national average estimates of persons per household at the country level collected from various sources including national census, and the UN population database. The national level population and household values were mapped to the national statistics then interpolated to a 15-arcsecond (~500m) grid cell and used to infer the number of buildings. Administrative GIS data was not used to aggregate or allot population or buildings but GADM administrative levels 1 (national), 2

(state), and 3 (county or district) names and numeric code are added to the final result for ease of use by data users.

- **Dasymetric Mapping**: A machine learning process (CART algorithm (Breiman et al., 1984; Khaled et al., 2014), Random forest (Breiman, 2001), and Support Vector Networks (Cortez et al., 1995)) with a variety of remotely sensed Earth Observation (EO) data products and building footprint aggregates establish the distribution statistics for dispersing buildings by urban density and development pattern type. Each of the EO products, individually or in a combination, act as weights to disperse the known population by structural type to 15-arcsecond grid cells. For determining the weights for distribution several machine learning algorithms were run using the EO to develop a prediction model. For example, in grids designated as a development patterns 1 or 2 (resembling rural or single-family residential communities) an even building distribution of the district is reallocated only to grid cells within the district associated to human settlement. This machine learning exercise informs the estimated building density, replacement cost per meter, and structural characteristics of the building stock, as described in the structural distribution processing step. The following moderate and high-resolution EO data sets used: 1) NOAA night-time light annual composite (VIIRS) 15-arcsecond grid cell (Earth Observation Group NOAA-NCEI (2016)) 2) Oak Ridge National Laboratory Landscan ambient population (LSCAN) resampled from the 30-arcsecond grid cell to 15-arcsecond (Oak Ridge National Laboratory. (2012)) 3) European Commission Joint Research Centre (EC -JRC) Global Human Settlement Layer (GHSL-Landsat) derived from Landsat imagery resampled from the aggregated 250m grid cell to 15-arcsecond (Corbane et al.,(1) 2018) 4) DLR Global Urban Footprint (GUF) resampled from 12-meter grid cells to a 15-arcsecond percentage of human presence raster grid (DLR Earth Observation Center. (2016)) 5) JRC GHSL derived from Sentinel-1 SAR (GHSL-SAR) resampled from 20-meter grid cells to a 15-arcsecond percentage of human presence raster grid (Corbane et al.,(2) 2018) 6) CIESIN-Facebook High Resolution Settlement Layer (HRSL) resampled from 1-arcsecond grid cells to a 15-arcsecond percentage of human presence raster grid (Facebook Connectivity Lab and Center for International Earth Science Information Network - CIESIN - Columbia University. (2016)) 7) JRC mosaiced Sentinel-1 dual polarization bands (SAR B1, B2, B3) resampled from 20-meter resolution to a 15-arcsecond mean raster grid per band and a maximum mean value of the 3 bands (SAR-MaxMean). (Syrris, V., et. al (2018)) 8) National gridded population from WorldPop 2020 resampled from 3-arcsecond grid cells to 15-arcsecond (WorldPop(1)) 9) An indicator of OSM data throughout the country- building count, area, and maximum building height were calculated from building footprint polygons and aggregated up to create 15-arcsecond grids. (ImageCat, Inc. (2020)) 10) Center for International Earth Science Information Network (CIESIN) Water Mask resampled from 30-arcsecond grid cell to 15-arcsecond (CIESIN, 2018) 11) NASA SRTM elevation aggregated and transformed from 90m resolution elevation to 15-arcsecond slope raster grid. (NASA-NGA. 2014) Data Mask: To prevent unpopulated areas from being considered as settlements the CIESIN water layer was used as a mask for populated and non-populated areas. For populated areas, a development pattern is assigned, and population is dispersed by the weight of the combined EO spectral signature. Development Pattern Creation: Development patterns are patterns of construction in the country that typify the building structure development and density as much as possible. They sometimes correspond with land use, but not always. The development patterns are determined by a structural engineer working with GIS analysts to conduct a web reconnaissance survey of available data regarding the structural type and distribution of the country. Various engineering websites and standards (Prompt Assessment of Global Earthquakes for Response [PAGER], Global Earthquake Model [GEM]), IPUMS, and national statistical housing data were used to establish a preliminary structure type distribution. These preliminary distributions are validated through Google Earth Maps. After the web reconnaissance the structural engineer begins to formulate the development pattern. The intensity of urbanity correlates to both the building density and the structural distribution (see Structural Distribution Processing Step for more details). ImageCat engineer characterized 6 development pattern types (see Structural Distribution Processing Step for more details).

  - **Number of Buildings**: The total number of buildings per structural class per grid cell was inferred using a combination of 1:1 number household to buildings based on the national population and housing statistics, EO machine learning, and aggregated OSM building count raster.
  - **Structural Distribution**: Using the national population and housing census data mapping schemes were developed using a combination of the building wall, roof, and floor material type. Each combination of wall, roof, and floor material type are mapped to PAGER standard structural types and GEM construction type. The number of households is used to develop a structural distribution. The remainder of this section provides country specific detail
  - **Building Height**: The building height values for all development patterns were obtained from the 15-arcsecond aggregated OSM building data (ImageCat, Inc., 2020). These values were used to establish the average building height to average story height per structure type. All low-rise structures are assigned a single story, mid-rise have an average of 4 stories, and high-rises have on average of 8 stories. The OSM based height raster was reviewed and validated by an in-house engineer using images provided of the individual buildings
  - **Total Building Area**: The total building area was calculated using 15-arcsecond aggregated OSM building raster data sets. The area per household was estimated based on an extensive assessment of OSM building footprint data and screening based on likely size for buildings. The average size of single-family households was often found to be reasonable, and an average was used for development patterns that are primarily residential
  - **Replacement Cost**: Replacement cost was determined based on Huyck & Eguchi, 2017 and Huizinga et al., 2017. From Huizinga et al., the replacement cost of residential, commercial, and industrial structures is estimated as a function of GDP. These were updated to 2019 USD (x 1.08) per meter squared and then adjusted based on development pattern based on Huyck & Eguchi, which found that in developing countries residential construction in urban areas was well represented, but that the value of semi-engineered and engineered properties are over predicted by Huizinga et al. when compared to Resettlement Action Plans and local expert opinion. Outer-city areas and smaller settlements are downscaled to 50% of the expected value, and rural construction is 50% of this figure. Urban areas consistent with capital city areas are consistent with the 2019 scaled values from Huizinga et al, 2017, as are industrial areas. These scaling factors are applied in accordance with the development patterns mentioned above. The final part of this section provides detail on the costs associated with each development pattern (in USD).

- **Use Limitation**: The building stock estimates developed in this project spread an estimate of the number of buildings derived from national population statistics including persons per household, households per building type, construction pattern distributions for various development patterns, the homogeneity of various construction patterns, building densities at the grid level as derived through image processing algorithm, and typical replacement costs. The methods described above have been carefully tailored through expert opinion, building area and count aggregates, research, and manual review. However, it is important to recognize that the numbers presented in the datasets are estimates and are not a count or building census. At the cell level, they may not be representative. Mapping schemes and replacement costs are representative of typical building infrastructure and replacement costs for the entire country. Regional variations in costs and building distributions (due to cost of materials and labor) will vary however, the final replacement cost values are calculated per development pattern in the country. Validating the distribution of building counts is a multi-step process. The national statistics data is used for spreading population spatially into buildings. Once buildings are distributed, the absolute number of buildings are aggregated and compared with the population. The numbers were not consistent with the expected rates of people per household and households per building for the nation, thus key parameters of the analysis are adjusted, and the process is re-run. For Afghanistan there were too few populated grids and the EO analysis was re-run to capture more areas of settlement.

7. Level 1 Data Access

Level 1 data for all ODA countries can be visualised and downloaded from the METEOR data portal where abstract information associated with the data can be accessed:

- https://maps.meteor-portal.org

ANNEX A: Nepal Building Exposure Metadata Files

NPL_building_exposure_20200805_ISO19110.xml


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                    </gmd:CI_ResponsibleParty>
                  </gmd:citedResponsibleParty>
                </gmd:CI_Citation>
              </gfc:source>
            </gfc:FC_DefinitionSource>
          </gfc:definitionSource>
        </gfc:FC_DefinitionReference>
```

```
            </gfc:definitionReference>
          </gfc:FC_FeatureAttribute>
        </gfc:carrierOfCharacteristics>
      - <gfc:carrierOfCharacteristics>
        - <gfc:FC_FeatureAttribute>
          - <gfc:memberName>
              <gco:LocalName>VAL_USD</gco:LocalName>
            </gfc:memberName>
          - <gfc:definition>
              <gco:CharacterString>Total estimated building replacement cost in 2020 USD per 15-arcsecond grid cell.</gco:CharacterString>
            </gfc:definition>
            <gfc:cardinality gco:nilReason="unknown"/>
          - <gfc:definitionReference>
            - <gfc:FC_DefinitionReference>
              - <gfc:definitionSource>
                - <gfc:FC_DefinitionSource>
                  - <gfc:source>
                    - <gmd:CI_Citation>
                        <gmd:title gco:nilReason="inapplicable"/>
                        <gmd:date gco:nilReason="unknown"/>
                      - <gmd:citedResponsibleParty>
                        - <gmd:CI_ResponsibleParty>
                          - <gmd:organisationName>
                              <gco:CharacterString>ImageCat, Inc.</gco:CharacterString>
                            </gmd:organisationName>
                          - <gmd:role>
                              <gmd:CI_RoleCode codeSpace="001" codeListValue="resourceProvider" codeList="http://www.isotc211.org/2005/resources/Codelist/gmxCodelists.xml#CI_RoleCode"/>
                            </gmd:role>
                          </gmd:CI_ResponsibleParty>
                        </gmd:citedResponsibleParty>
                      </gmd:CI_Citation>
                    </gfc:source>
                  </gfc:FC_DefinitionSource>
                </gfc:definitionSource>
              </gfc:FC_DefinitionReference>
            </gfc:definitionReference>
          </gfc:FC_FeatureAttribute>
        </gfc:carrierOfCharacteristics>
      </gfc:FC_FeatureType>
    </gfc:featureType>
</gfc:FC_FeatureCatalogue>
```

NPL_building_exposure_detail_20200805_19110.xml


```
  <?xml version="1.0"?>
- <gfc:FC_FeatureCatalogue id="FC001" xsi:schemaLocation="http://www.isotc211.org/2005/gfc http://www.ngdc.noaa.gov/metadata/published/xsd/schema/gfc/gfc.xsd" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns="http://www.isotc211.org/2005/gfc" xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:gml="http://www.opengis.net/gml/3.2" xmlns:gts="http://www.isotc211.org/2005/gts" xmlns:gss="http://www.isotc211.org/2005/gss"
  xmlns:gsr="http://www.isotc211.org/2005/gsr" xmlns:gmx="http://www.isotc211.org/2005/gmx" xmlns:gmd="http://www.isotc211.org/2005/gmd" xmlns:gfc="http://www.isotc211.org/2005/gfc"
  xmlns:gco="http://www.isotc211.org/2005/gco">
  - <gmx:name>
      <gco:CharacterString>Feature Catalogue for NPL_building_exposure_detail_20200805.csv</gco:CharacterString>
    </gmx:name>
    <gmx:scope gco:nilReason="unknown"/>
    <gmx:versionNumber gco:nilReason="unknown"/>
    <gmx:versionDate gco:nilReason="unknown"/>
  - <gmx:language>
      <gco:CharacterString>eng; US</gco:CharacterString>
    </gmx:language>
  - <gmx:characterSet>
      <gmd:MD_CharacterSetCode codeSpace="004" codeListValue="utf8" codeList="http://www.isotc211.org/2005/resources/Codelist/gmxCodelists.xml#MD_CharacterSetCode"/>
    </gmx:characterSet>
  - <gfc:producer>
    - <gmd:CI_ResponsibleParty>
      - <gmd:contactInfo>
        - <gmd:CI_Contact>
          - <gmd:phone>
              <gmd:CI_Telephone/>
            </gmd:phone>
          - <gmd:address>
              <gmd:CI_Address/>
            </gmd:address>
          </gmd:CI_Contact>
        </gmd:contactInfo>
      - <gmd:role>
          <gmd:CI_RoleCode codeSpace="001" codeListValue="resourceProvider" codeList="http://www.isotc211.org/2005/resources/Codelist/gmxCodelists.xml#CI_RoleCode"/>
        </gmd:role>
      </gmd:CI_ResponsibleParty>
    </gfc:producer>
  - <gfc:featureType>
    - <gfc:FC_FeatureType>
      - <gfc:typeName>
          <gco:LocalName>NPL_building_exposure_detail_20200805.csv</gco:LocalName>
        </gfc:typeName>
      - <gfc:definition>
          <gco:CharacterString>relational CSV table</gco:CharacterString>
        </gfc:definition>
      - <gfc:isAbstract>
          <gco:Boolean>false</gco:Boolean>
        </gfc:isAbstract>
        <gfc:featureCatalogue uuidref="FC001"/>
      - <gfc:carrierOfCharacteristics>
        - <gfc:FC_FeatureAttribute>
          - <gfc:memberName>
```

```
<gco:LocalName>uid</gco:LocalName>
</gfc:memberName>
- <gfc:definition>
<gco:CharacterString>Unique numerical identification</gco:CharacterString>
</gfc:definition>
<gfc:cardinality gco:nilReason="unknown"/>
- <gfc:definitionReference>
- <gfc:FC_DefinitionReference>
- <gfc:definitionSource>
- <gfc:FC_DefinitionSource>
- <gfc:source>
- <gmd:CI_Citation>
<gmd:title gco:nilReason="inapplicable"/>
<gmd:date gco:nilReason="unknown"/>
- <gmd:citedResponsibleParty>
- <gmd:CI_ResponsibleParty>
- <gmd:organisationName>
<gco:CharacterString>ImageCat, Inc.</gco:CharacterString>
</gmd:organisationName>
- <gmd:role>
<gmd:CI_RoleCode codeSpace="001" codeListValue="resourceProvider" codeList="http://www.isotc211.org/2005/resources/Codelist/gmxCodelists.xml#CI_RoleCode"/>
</gmd:role>
</gmd:CI_ResponsibleParty>
</gmd:citedResponsibleParty>
</gmd:CI_Citation>
</gfc:source>
</gfc:FC_DefinitionSource>
</gfc:definitionSource>
</gfc:FC_DefinitionReference>
</gfc:definitionReference>
</gfc:FC_FeatureAttribute>
</gfc:carrierOfCharacteristics>
- <gfc:carrierOfCharacteristics>
- <gfc:FC_FeatureAttribute>
- <gfc:memberName>
<gco:LocalName>contype</gco:LocalName>
</gfc:memberName>
- <gfc:definition>
<gco:CharacterString>The construction type uses the GEM building taxonomy. The description of each construction type code can be found in the "Structural Distribution" data lineage processing step of the accompanied vector
point shapefile along with the mapping scheme breakdown by development pattern.</gco:CharacterString>
</gfc:definition>
<gfc:cardinality gco:nilReason="unknown"/>
- <gfc:definitionReference>
- <gfc:FC_DefinitionReference>
- <gfc:definitionSource>
- <gfc:FC_DefinitionSource>
- <gfc:source>
- <gmd:CI_Citation>
<gmd:title gco:nilReason="inapplicable"/>
<gmd:date gco:nilReason="unknown"/>
```

```
                              - <gmd:citedResponsibleParty>
                                - <gmd:CI_ResponsibleParty>
                                  - <gmd:organisationName>
                                      <gco:CharacterString>GEM</gco:CharacterString>
                                    </gmd:organisationName>
                                  - <gmd:role>
                                      <gmd:CI_RoleCode codeSpace="001" codeListValue="resourceProvider" codeList="http://www.isotc211.org/2005/resources/Codelist/gmxCodelists.xml#CI_RoleCode"/>
                                    </gmd:role>
                                  </gmd:CI_ResponsibleParty>
                                </gmd:citedResponsibleParty>
                              </gmd:CI_Citation>
                            </gfc:source>
                          </gfc:FC_DefinitionSource>
                        </gfc:definitionSource>
                      </gfc:FC_DefinitionReference>
                    </gfc:definitionReference>
                  </gfc:FC_FeatureAttribute>
                </gfc:carrierOfCharacteristics>
              - <gfc:carrierOfCharacteristics>
                - <gfc:FC_FeatureAttribute>
                  - <gfc:memberName>
                      <gco:LocalName>BLD_CNT</gco:LocalName>
                    </gfc:memberName>
                  - <gfc:definition>
                      <gco:CharacterString>Total estimated count of buildings per 15-arcsecond grid cell.</gco:CharacterString>
                    </gfc:definition>
                    <gfc:cardinality gco:nilReason="unknown"/>
                  - <gfc:definitionReference>
                    - <gfc:FC_DefinitionReference>
                      - <gfc:definitionSource>
                        - <gfc:FC_DefinitionSource>
                          - <gfc:source>
                            - <gmd:CI_Citation>
                                <gmd:title gco:nilReason="inapplicable"/>
                                <gmd:date gco:nilReason="unknown"/>
                              - <gmd:citedResponsibleParty>
                                - <gmd:CI_ResponsibleParty>
                                  - <gmd:organisationName>
                                      <gco:CharacterString>ImageCat, Inc.</gco:CharacterString>
                                    </gmd:organisationName>
                                  - <gmd:role>
                                      <gmd:CI_RoleCode codeSpace="001" codeListValue="resourceProvider" codeList="http://www.isotc211.org/2005/resources/Codelist/gmxCodelists.xml#CI_RoleCode"/>
                                    </gmd:role>
                                  </gmd:CI_ResponsibleParty>
                                </gmd:citedResponsibleParty>
                              </gmd:CI_Citation>
                            </gfc:source>
                          </gfc:FC_DefinitionSource>
                        </gfc:definitionSource>
```

```
            </gfc:FC_DefinitionReference>
          </gfc:definitionReference>
        </gfc:FC_FeatureAttribute>
      </gfc:carrierOfCharacteristics>
    - <gfc:carrierOfCharacteristics>
      - <gfc:FC_FeatureAttribute>
        - <gfc:memberName>
            <gco:LocalName>BLD_SIZE_M</gco:LocalName>
          </gfc:memberName>
        - <gfc:definition>
            <gco:CharacterString>Total estimated building area in meters per 15-arcsecond grid cell.</gco:CharacterString>
          </gfc:definition>
          <gfc:cardinality gco:nilReason="unknown"/>
        - <gfc:definitionReference>
          - <gfc:FC_DefinitionReference>
            - <gfc:definitionSource>
              - <gfc:FC_DefinitionSource>
                - <gfc:source>
                  - <gmd:CI_Citation>
                      <gmd:title gco:nilReason="inapplicable"/>
                      <gmd:date gco:nilReason="unknown"/>
                    - <gmd:citedResponsibleParty>
                      - <gmd:CI_ResponsibleParty>
                        - <gmd:organisationName>
                            <gco:CharacterString>ImageCat, Inc.</gco:CharacterString>
                          </gmd:organisationName>
                        - <gmd:role>
                            <gmd:CI_RoleCode codeSpace="001" codeListValue="resourceProvider" codeList="http://www.isotc211.org/2005/resources/Codelist/gmxCodelists.xml#CI_RoleCode"/>
                          </gmd:role>
                        </gmd:CI_ResponsibleParty>
                      </gmd:citedResponsibleParty>
                    </gmd:CI_Citation>
                  </gfc:source>
                </gfc:FC_DefinitionSource>
              </gfc:definitionSource>
            </gfc:FC_DefinitionReference>
          </gfc:definitionReference>
        </gfc:FC_FeatureAttribute>
      </gfc:carrierOfCharacteristics>
    - <gfc:carrierOfCharacteristics>
      - <gfc:FC_FeatureAttribute>
        - <gfc:memberName>
            <gco:LocalName>VAL_USD</gco:LocalName>
          </gfc:memberName>
        - <gfc:definition>
            <gco:CharacterString>Total estimated building replacement cost in 2020 USD per 15-arcsecond grid cell.</gco:CharacterString>
          </gfc:definition>
          <gfc:cardinality gco:nilReason="unknown"/>
        - <gfc:definitionReference>
          - <gfc:FC_DefinitionReference>
```

```xml
- <gfc:definitionSource>
- <gfc:FC_DefinitionSource>
- <gfc:source>
- <gmd:CI_Citation>
<gmd:title gco:nilReason="inapplicable"/>
<gmd:date gco:nilReason="unknown"/>
- <gmd:citedResponsibleParty>
- <gmd:CI_ResponsibleParty>
- <gmd:organisationName>
<gco:CharacterString>ImageCat, Inc.</gco:CharacterString>
</gmd:organisationName>
- <gmd:role>
<gmd:CI_RoleCode codeSpace="001" codeListValue="resourceProvider" codeList="http://www.isotc211.org/2005/resources/Codelist/gmxCodelists.xml#CI_RoleCode"/>
</gmd:role>
</gmd:CI_ResponsibleParty>
</gmd:citedResponsibleParty>
</gmd:CI_Citation>
</gfc:source>
</gfc:FC_DefinitionSource>
</gfc:definitionSource>
</gfc:FC_DefinitionReference>
</gfc:definitionReference>
</gfc:FC_FeatureAttribute>
</gfc:carrierOfCharacteristics>
</gfc:FC_FeatureType>
</gfc:featureType>
</gfc:FC_FeatureCatalogue>
```

NPL_building_exposure_20200805_ISO19139.xml


```
  <?xml version="1.0"?>
- <MD_Metadata xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns="http://www.isotc211.org/2005/gmd" xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:gml="http://www.opengis.net/gml/3.2"
  xmlns:gts="http://www.isotc211.org/2005/gts" xmlns:gco="http://www.isotc211.org/2005/gco" xmlns:srv="http://www.isotc211.org/2005/srv">
  - <language>
        <LanguageCode codeSpace="ISO639-2" codeListValue="eng" codeList="http://www.loc.gov/standards/iso639-2/php/code_list.php">eng</LanguageCode>
    </language>
  - <characterSet>
        <MD_CharacterSetCode codeSpace="ISOTC211/19115" codeListValue="utf8" codeList="http://www.isotc211.org/2005/resources/Codelist/gmxCodelists.xml#MD_CharacterSetCode">utf8</MD_CharacterSetCode>
    </characterSet>
  - <hierarchyLevel>
        <MD_ScopeCode codeSpace="ISOTC211/19115" codeListValue="dataset" codeList="http://www.isotc211.org/2005/resources/Codelist/gmxCodelists.xml#MD_ScopeCode">dataset</MD_ScopeCode>
    </hierarchyLevel>
  - <hierarchyLevelName>
        <gco:CharacterString>dataset</gco:CharacterString>
    </hierarchyLevelName>
  - <contact>
    - <CI_ResponsibleParty>
      - <individualName>
            <gco:CharacterString>Kay Smith</gco:CharacterString>
        </individualName>
      - <organisationName>
            <gco:CharacterString>British Geological Survey</gco:CharacterString>
        </organisationName>
      - <positionName>
            <gco:CharacterString>METEOR Project Manager</gco:CharacterString>
        </positionName>
      - <contactInfo>
        - <CI_Contact>
          - <phone>
            - <CI_Telephone>
              - <voice>
                    <gco:CharacterString>+44 131 667 1000</gco:CharacterString>
                </voice>
              </CI_Telephone>
            </phone>
          - <address>
            - <CI_Address>
              - <deliveryPoint>
                    <gco:CharacterString>The Lyell Center - Research Avenue South </gco:CharacterString>
                </deliveryPoint>
              - <city>
                    <gco:CharacterString>Edinburgh</gco:CharacterString>
                </city>
              - <postalCode>
                    <gco:CharacterString>EH14 4AP</gco:CharacterString>
                </postalCode>
              - <country>
                    <gco:CharacterString>GB</gco:CharacterString>
                </country>
```

```
        - &lt;electronicMailAddress&gt;
            &lt;gco:CharacterString&gt;kmcm@bgs.ac.uk&lt;/gco:CharacterString&gt;
          &lt;/electronicMailAddress&gt;
        &lt;/CI_Address&gt;
      &lt;/address&gt;
    &lt;/CI_Contact&gt;
  &lt;/contactInfo&gt;
- &lt;role&gt;
    &lt;CI_RoleCode codeSpace="ISOTC211/19115" codeListValue="distributor" codeList="http://www.isotc211.org/2005/resources/Codelist/gmxCodelists.xml#CI_RoleCode"&gt;distributor&lt;/CI_RoleCode&gt;
  &lt;/role&gt;
&lt;/CI_ResponsibleParty&gt;
&lt;/contact&gt;
- &lt;contact&gt;
  - &lt;CI_ResponsibleParty&gt;
    - &lt;individualName&gt;
        &lt;gco:CharacterString&gt;Charles Huyck&lt;/gco:CharacterString&gt;
      &lt;/individualName&gt;
    - &lt;organisationName&gt;
        &lt;gco:CharacterString&gt;ImageCat, Inc.&lt;/gco:CharacterString&gt;
      &lt;/organisationName&gt;
    - &lt;positionName&gt;
        &lt;gco:CharacterString&gt;Executive Vice President&lt;/gco:CharacterString&gt;
      &lt;/positionName&gt;
    - &lt;contactInfo&gt;
      - &lt;CI_Contact&gt;
        - &lt;phone&gt;
          - &lt;CI_Telephone&gt;
            - &lt;voice&gt;
                &lt;gco:CharacterString&gt;5626281675&lt;/gco:CharacterString&gt;
              &lt;/voice&gt;
            &lt;/CI_Telephone&gt;
          &lt;/phone&gt;
        - &lt;address&gt;
          - &lt;CI_Address&gt;
            - &lt;deliveryPoint&gt;
                &lt;gco:CharacterString&gt;400 Oceangate&lt;/gco:CharacterString&gt;
              &lt;/deliveryPoint&gt;
            - &lt;city&gt;
                &lt;gco:CharacterString&gt;Long Beach&lt;/gco:CharacterString&gt;
              &lt;/city&gt;
            - &lt;administrativeArea&gt;
                &lt;gco:CharacterString&gt;Ca&lt;/gco:CharacterString&gt;
              &lt;/administrativeArea&gt;
            - &lt;postalCode&gt;
                &lt;gco:CharacterString&gt;90802&lt;/gco:CharacterString&gt;
              &lt;/postalCode&gt;
            - &lt;country&gt;
                &lt;gco:CharacterString&gt;US&lt;/gco:CharacterString&gt;
              &lt;/country&gt;
            - &lt;electronicMailAddress&gt;
```

```
- <electronicMailAddress>
    <gco:CharacterString>ckh@imagecatinc.com</gco:CharacterString>
  </electronicMailAddress>
  </CI_Address>
  </address>
- <hoursOfService>
    <gco:CharacterString>9am-6pm</gco:CharacterString>
  </hoursOfService>
  </CI_Contact>
  </contactInfo>
- <role>
    <CI_RoleCode codeSpace="ISOTC211/19115" codeListValue="principalInvestigator" codeList="http://www.isotc211.org/2005/resources/Codelist/gmxCodelists.xml#CI_RoleCode">principalInvestigator</CI_RoleCode>
  </role>
  </CI_ResponsibleParty>
  </contact>
- <contact>
- <CI_ResponsibleParty>
- <individualName>
    <gco:CharacterString>Zhenghui Hu</gco:CharacterString>
  </individualName>
- <organisationName>
    <gco:CharacterString>ImageCat, Inc.</gco:CharacterString>
  </organisationName>
- <positionName>
    <gco:CharacterString>Modeler</gco:CharacterString>
  </positionName>
- <contactInfo>
- <CI_Contact>
- <phone>
- <CI_Telephone>
- <voice>
    <gco:CharacterString>5626281675</gco:CharacterString>
  </voice>
  </CI_Telephone>
  </phone>
- <address>
- <CI_Address>
- <deliveryPoint>
    <gco:CharacterString>400 Oceangate</gco:CharacterString>
  </deliveryPoint>
- <city>
    <gco:CharacterString>Long Beach</gco:CharacterString>
  </city>
- <administrativeArea>
    <gco:CharacterString>CA</gco:CharacterString>
  </administrativeArea>
- <postalCode>
    <gco:CharacterString>90802</gco:CharacterString>
  </postalCode>
```

```
                    - <country>
                          <gco:CharacterString>US</gco:CharacterString>
                      </country>
                    - <electronicMailAddress>
                          <gco:CharacterString>zh@imagecatinc.com</gco:CharacterString>
                      </electronicMailAddress>
                  </CI_Address>
              </address>
            - <hoursOfService>
                  <gco:CharacterString>Monday-Friday 9am-6pm</gco:CharacterString>
              </hoursOfService>
          </CI_Contact>
      </contactInfo>
    - <role>
          <CI_RoleCode codeSpace="ISOTC211/19115" codeListValue="processor" codeList="http://www.isotc211.org/2005/resources/Codelist/gmxCodelists.xml#CI_RoleCode">processor</CI_RoleCode>
      </role>
  </CI_ResponsibleParty>
</contact>
- <contact>
  - <CI_ResponsibleParty>
    - <individualName>
          <gco:CharacterString>Georgiana Esquivias</gco:CharacterString>
      </individualName>
    - <organisationName>
          <gco:CharacterString>ImageCat, Inc.</gco:CharacterString>
      </organisationName>
    - <positionName>
          <gco:CharacterString>Project Analyst</gco:CharacterString>
      </positionName>
    + <contactInfo>
    - <role>
          <CI_RoleCode codeSpace="ISOTC211/19115" codeListValue="processor" codeList="http://www.isotc211.org/2005/resources/Codelist/gmxCodelists.xml#CI_RoleCode">processor</CI_RoleCode>
      </role>
  </CI_ResponsibleParty>
</contact>
- <dateStamp>
    <gco:Date>2020-08-07</gco:Date>
</dateStamp>
- <metadataStandardName>
    <gco:CharacterString>ISO 19139 Geographic Information - Metadata - Implementation Specification</gco:CharacterString>
</metadataStandardName>
- <metadataStandardVersion>
    <gco:CharacterString>2007</gco:CharacterString>
</metadataStandardVersion>
- <spatialRepresentationInfo>
  - <MD_VectorSpatialRepresentation>
    - <topologyLevel>
          <MD_TopologyLevelCode codeSpace="ISOTC211/19115" codeListValue="geometryOnly" codeList="http://www.isotc211.org/2005/resources/Codelist/gmxCodelists.xml#MD_TopologyLevelCode">geometryOnly</MD_TopologyLevelCode>
      </topologyLevel>
```

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- <geometricObjects>
  - <MD_GeometricObjects>
    - <geometricObjectType>
        <MD_GeometricObjectTypeCode codeSpace="ISOTC211/19115" codeListValue="point"
          codeList="http://www.isotc211.org/2005/resources/Codelist/gmxCodelists.xml#MD_GeometricObjectTypeCode">point</MD_GeometricObjectTypeCode>
      </geometricObjectType>
    - <geometricObjectCount>
        <gco:Integer>271897</gco:Integer>
      </geometricObjectCount>
    </MD_GeometricObjects>
  </geometricObjects>
</MD_VectorSpatialRepresentation>
</spatialRepresentationInfo>
- <referenceSystemInfo>
  - <MD_ReferenceSystem>
    - <referenceSystemIdentifier>
      - <RS_Identifier>
        - <code>
            <gco:CharacterString>4326</gco:CharacterString>
          </code>
        - <codeSpace>
            <gco:CharacterString>EPSG</gco:CharacterString>
          </codeSpace>
        - <version>
            <gco:CharacterString>6.14(3.0.1)</gco:CharacterString>
          </version>
        </RS_Identifier>
      </referenceSystemIdentifier>
    </MD_ReferenceSystem>
  </referenceSystemInfo>
- <identificationInfo>
  - <MD_DataIdentification>
    - <citation>
      - <CI_Citation>
        - <title>
            <gco:CharacterString>NPL_building_exposure_20200805</gco:CharacterString>
          </title>
        - <date>
          - <CI_Date>
            - <date>
                <gco:Date>2020-08-07</gco:Date>
              </date>
            - <dateType>
                <CI_DateTypeCode codeSpace="ISOTC211/19115" codeListValue="creation" codeList="http://www.isotc211.org/2005/resources/Codelist/gmxCodelists.xml#CI_DateTypeCode">creation</CI_DateTypeCode>
              </dateType>
            </CI_Date>
          </date>
        - <presentationForm>
            <CI_PresentationFormCode codeSpace="ISOTC211/19115" codeListValue="mapDigital"
              codeList="http://www.isotc211.org/2005/resources/Codelist/gmxCodelists.xml#CI_PresentationFormCode">mapDigital</CI_PresentationFormCode>
```

</presentationForm>
</CI_Citation>
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type, construction pattern distributions for various development patterns, the homogeneity of various construction patterns, building densities at the grid level as derived through image processing algorithm, and typical
replacement costs. The methods described above have been carefully tailored through expert opinion, building area and count aggregates, research, and manual review. However, it is important to recognize that the numbers
presented in the datasets are estimates and are not a count or building census. At the cell level, they may not be representative. Mapping schemes and replacement costs are representative of typical building infrastructure
and replacement costs for the entire country. Regional variations in costs and building distributions (due to cost of materials and labor) will vary however, the final replacement cost values are calculated per development
pattern in the country. Validating the distribution of building counts is a multi-step process. The national statistics data is used for spreading population spatially into buildings. Once buildings are distributed, the absolute
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                boundaries that can be used to develop hard ratios to compare with published statistics. However, because buildings are distributed first to settlements, and then distributed to rural areas, there are clear visual cues
                when the distribution between urban and rural areas is inadequate. The follow are examples of the reviews conducted by analysts: 1) If there were too many buildings assigned to urban areas, and there was a void in
                rural areas. Thus, these grids were checked against EO data to confirms whether these areas are populated. 2) If there were too few buildings in urban settlements which caused a “donut” effect, where rural
                populations surrounding urban areas were assigned a greater population than urban areas. This required the adjustment of residential building density for a specific region. 3) Finally, there was a check of reviewing
                the distribution of buildings in rural areas. The parameters used for spreading agricultural buildings may not capture rural development well, and there were limited points with too many buildings in rural areas. In
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European Commission, Joint Research Centre (JRC) doi: 10.2905/jrc-ghsl-10008 PID: Retrieved from http://data.europa.eu/89h/jrc-ghsl-10008 Cortes, C., Vapnik, V. Support-vector networks. Mach Learn 20, 273–297 (1995). DLR Earth Observation Center. (2016). Global Urban Footprint (GUF). Available at https://www.dlr.de/eoc/en/desktopdefault.aspx/tabid-11725/20508_read-47944/ Earle, P. S., Wald, D. J., Jaiswal, K. S., Allen, T. I., Hearne, M. G., Marano, K. D., Hotovec, A.J., & Fee, J. M. (2009). Prompt Assessment of Global Earthquakes for Response (PAGER): A system for rapidly determining the impact of earthquakes worldwide. US Geological Survey Open-File Report, 1131, 15. Earth Observation Group NOAA-NCEI (2015). Version 1 VIIRS Day/Night Band Nighttime Lights- 2015 Nighttime Light Annual Composite [dataset]: https://ngdc.noaa.gov/eog/viirs/download_dnb_composites.html Facebook Connectivity Lab and Center for International Earth Science Information Network - CIESIN - Columbia University. 2016. High Resolution Settlement Layer (HRSL). Source imagery for HRSL © 2016 Digital Globe. GoogleEarth. (n.d.) [map]. Available at https://www.google.com/earth/ Huyck, C.K. and Eguchi, M.T. (2017). GFDRR Africa Disaster Risk Financing-Result Area 5 Exposure Development. Replacement Cost Refinements to the Exposure Data. Prepared for World Bank/GFDRR ImageCat, Inc. (2020). OSM building footprint data aggregation to 15-arcsecond raster grid [dataset]. Unpublished. Jaiswal, K.S. and Wald, D.J. (2011). Rapid estimation of the economic consequences of global earthquakes: U.S. Geological Survey Open-File Report 2011–1116, 47 p. Jaiswal, K. and Wald, D. (2014). PAGER Inventory Database v2.0.xls. 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<gco:CharacterString>Dasymetric Mapping: A machine learning process (CART algorithm (Breiman et al., 1984; Khaled et al., 2014), Random forest (Breiman, 2001), and Support Vector Networks (Cortez et al., 1995)) with a variety of remotely sensed Earth Observation (EO) data products and building footprint aggregates establish the distribution statistics for dispersing buildings by urban density and development pattern type. Each of the EO products, individually or in a combination, act as weights to disperse the known population by structural type to 15-arcsecond grid cells. For determining the weights for distribution several machine learning algorithms were run using the EO to develop a prediction model. For example, in grids designated as a development patterns 1 or 2 (resembling rural or single-family residential communities) an even building distribution of the district is reallocated only to grid cells within the district associated to human settlement. This machine learning exercise informs the estimated building density, replacement cost per meter, and structural characteristics of the building stock, as described in the structural distribution processing step. The following moderate and high-resolution EO data sets used: 1) NOAA night-time light annual composite (VIIRS) 15-arcsecond grid cell (Earth Observation Group NOAA-NCEI (2016)) 2) Oak Ridge National Laboratory Landscan ambient population (LSCAN) resampled from the 30-arcsecond grid cell to 15-arcsecond (Oak Ridge National Laboratory. (2012)) 3) European Commission Joint Research Centre (EC -JRC) Global Human Settlement Layer (GHSL-Landsat) derived from Landsat imagery resampled from the aggregated 250m grid cell to 15-arcsecond (Corbane et al.,(1) 2018) 4) DLR Global Urban Footprint (GUF) resampled from 12-meter grid cells to a 15-arcsecond percentage of human presence raster grid (DLR Earth Observation Center. (2016)) 5) JRC GHSL derived from Sentinel-1 SAR (GHSL-SAR) resampled from 20-meter grid cells to a 15-arcsecond percentage of human presence raster grid (Corbane et al.,(2) 2018) 6) CIESIN-Facebook High Resolution Settlement Layer (HRSL) resampled from 1-arcsecond grid cells to a 15-arcsecond percentage of human presence raster grid (Facebook Connectivity Lab and Center for International Earth Science Information Network - CIESIN - Columbia University. (2016)) 7) JRC mosaiced Sentinel-1 dual polarization bands (SAR B1, B2, B3) resampled from 20-meter resolution to a 15-arcsecond mean raster grid per band and a maximum mean value of the 3 bands (SAR-MaxMean). (Syrris, V., et. al (2018)) 8) National gridded population from WorldPop 2020 resampled from 3-arcsecond grid cells to 15-arcsecond (WorldPop(1)) 9) An indicator of OSM data throughout the country- building count, area, and maximum building height were calculated from building footprint polygons and aggregated up to create 15-arcsecond grids. (ImageCat, Inc. (2020)) 10) Center for International Earth Science Information Network (CIESIN) Water Mask resampled from 30-arcsecond grid cell to 15-arcsecond (CIESIN, 2018) 11) NASA SRTM elevation aggregated and transformed from 90m resolution elevation to 15-arcsecond slope raster grid. (NASA-NGA. 2014) Data Mask: To prevent unpopulated areas from being considered as settlements the CIESIN water layer was used as a mask for populated and non-populated areas. For populated areas, a development pattern is assigned, and population is dispersed by the weight of the combined EO spectral signature. Development Pattern Creation: Development patterns are patterns of construction in the country that typify the building structure development and density as much as possible. They sometimes correspond with land use, but not always. The development patterns are determined by a structural engineer working with GIS analysts to conduct a web reconnaissance survey of available data regarding the structural type and distribution of the country. Various engineering websites and standards (Prompt Assessment of Global Earthquakes for Response [PAGER], Global Earthquake Model [GEM]), IPUMS, and national statistical housing data were used to establish a preliminary structure type distribution. These preliminary distributions are validated through Google Earth Maps. After the web reconnaissance the structural engineer begins to formulate the development pattern. The intensity of urbanity correlates to both the building density and the structural distribution (see Structural Distribution Processing Step for more details). ImageCat engineer characterized 6 development pattern types (see Structural Distribution Processing Step for more details). </gco:CharacterString>
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The data below provides a PAGER description of the structural class from the various data sources and the match to the GEM taxonomy classification: Adobe blocks (unbaked sundried mud block) walls > A > MUR+ADO Nonductile reinforced concrete frame with masonry infill walls high-rise > C3H > CR+CIP/LFINF+DNO/HBET:8,19 Nonductile reinforced concrete frame with masonry infill walls low-rise > C3L > CR+CIP/LFINF+DNO/HBET:1,3 Nonductile reinforced concrete frame with masonry infill walls mid-rise > C3M > CR+CIP/LFINF+DNO/HBET:4,7 Rubble stone (field stone) masonry > RS > MUR+STRU B Unreinforced fired brick masonry > UFB > MUR+CLBRS Informal constructions > INF > MATO Wattle and Daub (Walls with bamboo/light timber log/reed mesh and post) > W5 > W+WWD/LWAL Steel light frame > S3 > S/LFM Wood > W > W Unreinforced brick masonry in mud mortar without timber posts > UFB1 > MUR+CLBRS+MOM/LWAL Steel frame with unreinforced masonry infill walls > S5 > S/LFINF The mapping schemes below provide the distribution of building by structural type per development pattern. The structure type key can be found below. Development Pattern 1: Rural development found outside of city boundaries and is typically associated with agricultural development. The regions typically consist of small, remote villages with single roads in and out. Buildings are typically spaced far apart and are almost exclusively 1 to 2 stories. Local materials and construction practices are generally used and performed in these areas. W - 0.05 | W+WWD/LWAL - 0.171 | MUR+ADO - 0.012 | MUR+STRU B - 0.493 | MUR+CLBRS - 0.204 | MATO - 0.07 Development Pattern 2: This development pattern reflects areas typically dominated by single family residential structures. Commercial properties, such as local markets, are present, however residential structures are the primary occupancy. The built-up area is denser than rural class 1, however open land (yards, vacant lots, etc.) are present and can be observed via satellite imagery. All structures are low-rise, with most in the 1 to 2 story range. W+WWD/LWAL - 0.0099 | S/LFM - 0.0223 | S/LFINF - 0.0223 | CR+CIP/LFINF+DNO/HBET:1,3 - 0.49 | CR+CIP/LFINF+DNO/HBET:4,7 - 0.22 | MUR+ADO - 0.01 | MUR+CLBRS+MOM/LWAL - 0.22 Development Pattern 3: Characterized by structures where the majority of the population lives in multi-family residential housing. The built-up area is typically comprised of long narrow apartment blocks in the 3 to 5 story range. Large open spaces (courtyards or parking lots) are present between buildings, therefore building density is typically not high. Smaller (<300 sq. m.) 1 to 2 story buildings can be observed, but they are typically limited to small offices or commercial structures within the complexes. S/LFM - 0.0117 | S/LFINF - 0.0043 | CR+CIP/LFINF+DNO/HBET:1,3 - 0.3653 | CR+CIP/LFINF+DNO/HBET:4,7 - 0.35 | CR+CIP/LFINF+DNO/HBET:8,19 - 0.01 | MUR+CLBRS - 0.2567 | MATO - 0.0032 Development Pattern 5: Development pattern 5 is characterized by urban areas predominantly occupied by low to mid-rise residential and commercial structures. An occasional high-rise apartment or office building may be present. These developments are typically found near or around major city centers. Buildings are tightly spaced and are fairly regular in shape. S/LFM - 0.0042 | S/LFINF - 0.0021 | CR+CIP/LFINF+DNO/HBET:1,3 - 0.1372 | CR+CIP/LFINF+DNO/HBET:4,7 - 0.56 | CR+CIP/LFINF+DNO/HBET:8,19 - 0.03 | MUR+CLBRS - 0.2641 Development Pattern 6: This development pattern is the central business district of urban areas within the major cities. The region is occupied by low to high-rise apartments and commercial offices. Most structures are under 7-stories, however high-rise (8+ stories) can be found within the region. Building footprints are larger than most non-industrial development patterns. This development pattern will be found only in major cities and along the major, paved roads. S/LFINF - 0.0258 | CR+CIP/LFINF+DNO/HBET:1,3 - 0.1701 | CR+CIP/LFINF+DNO/HBET:4,7 - 0.45 | CR+CIP/LFINF+DNO/HBET:8,19 - 0.08 | MUR+CLBRS - 0.2783 Development Pattern 7: This development pattern is characterized by areas dominated by ports, mining or industrial activities. Structures are typically closely spaced and regular in shape. A majority of buildings within these regions are warehouses, rectangular shape and single story. Smaller low-rise, office and commercial structures can also be found on site. S/LFM - 0.09 | S/LFINF - 0.03 | CR+CIP/LFINF+DNO/HBET:1,3 - 0.28 | CR+CIP/LFINF+DNO/HBET:4,7 - 0.23 | MUR+CLBRS - 0.3527 | MATO - 0.0166 </gco:CharacterString>
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                  residential construction in urban areas was well represented, but that the value of semi-engineered and engineered properties are over predicted by Huizinga et al. when compared to Resettlement Action Plans and
                  local expert opinion. Outer-city areas and smaller settlements are downscaled to 50% of the expected value, and rural construction is 50% of this figure. Urban areas consistent with capital city areas are consistent
                  with the 2019 scaled values from Huizinga et al, 2017, as are industrial areas. These scaling factors are applied in accordance with the development patterns mentioned above. Development Pattern 1 $94.23
                  Development Pattern 2 $188.45 Development Pattern 3 $376.91 Development Pattern 5 $434.21 Development Pattern 6 $1,085.51 Development Pattern 7 $317.49 </gco:CharacterString>
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          construction pattern distributions for various development patterns, the homogeneity of various construction patterns, building densities at the grid level as derived through image processing algorithm, and typical replacement
          costs. The methods described above have been carefully tailored through expert opinion, building area and count aggregates, research, and manual review. However, it is important to recognize that the numbers presented in the
          datasets are estimates and are not a count or building census. At the cell level, they may not be representative. Mapping schemes and replacement costs are representative of typical building infrastructure and replacement costs for
          the entire country. Regional variations in costs and building distributions (due to cost of materials and labor) will vary however, the final replacement cost values are calculated per development pattern in the country. Validating
          the distribution of building counts is a multi-step process. The national statistics data is used for spreading population spatially into buildings. Once buildings are distributed, the absolute number of buildings are aggregated and
          compared with the population. The numbers were not consistent with the expected rates of people per household and households per building for the nation, thus key parameters of the analysis are adjusted, and the process is re-
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NPL_building_exposure_detail_20200805_19139.xml


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          The data is intended for CAT modeling and loss estimation. Repurposing this data for any reason other than assessing risk is not recommended. The data presents the estimated number of buildings, building area, and rebuilding
          value at a 15-arcsecond grid resolution (approximately 500 meters at the equator). This data set is a in point relational table that can be linked using the unique OBJECTID field to the OBJECTID of the
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ANNEX B: PAGER MAPPING

PAGER	PAGER Description	GEM	AIR	OED
W	Wood	W	101	5050
W1	Wood stud-wall frame with plywood/gypsum board sheathing.	W+WLI/LWAL	101	5050
W2	Wood frame, heavy members (with area > 5000 sq. ft.)	W+WHE/LPB	104	5053
W3	Wood light unbraced post and beam frame.	W+WLI/LPB	102	5051
W4	Wood panel or log construction.	W+WS/LWAL	104	5053
W5	Wattle and Daub (Walls with bamboo/light timber log/reed mesh and post).	W+WWD/LWAL	102	5051
W6	Wood unbraced heavy post and beam frame with mud or other infill material.	W+WHE/LWAL	104	5053
W7	Wood braced frame with load-bearing infill wall system.	W+WLI/LWAL	101	5050
S	Steel	S	151	5200
S1	Steel moment frame	S/LFM	156	5205
S1L	Steel moment frame low-rise	S/LFM/HBET:1,3	156	5205
S1M	Steel moment frame mid-rise	S/LFM/HBET:4,7	156	5205
S1H	Steel moment frame high-rise	S/LFM/HBET:8,19	156	5205
S2	Steel braced frame	S/LFBR	153	5202
S2L	Steel braced frame low-rise	S/LFBR/HBET:1,3	153	5202
S2M	Steel braced frame mid-rise	S/LFBR/HBET:4,7	153	5202
S2H	Steel braced frame high-rise	S/LFBR/HBET:8,19	153	5202
S3	Steel light frame	S/LFM	152	5201
S4	Steel frame with cast-in-place concrete shear walls	CR+CIP/LWAL	158	5207
S4L	Steel frame with cast-in-place concrete shear walls low-rise	CR+CIP/LWAL/HBET:1,3	158	5207
S4M	Steel frame with cast-in-place concrete shear walls mid-rise	CR+CIP/LWAL/HBET:4,7	158	5207
S4H	Steel frame with cast-in-place concrete shear walls high-rise	CR+CIP/LWAL/HBET:8,19	158	5207
S5	Steel frame with unreinforced masonry infill walls	S/LFINF	157	5206
S5L	Steel frame with unreinforced masonry infill walls low-rise	S/LFINF/HBET:1,3	157	5206
S5M	Steel frame with unreinforced masonry infill walls mid-rise	S/LFINF/HBET:4,7	157	5206
S5H	Steel frame with unreinforced masonry infill walls high-rise	S/LFINF/HBET:8,19	157	5206

C	Reinforced concrete	CR	131	5150
C1	Ductile reinforced concrete moment frame with or without infill	CR+CIP/LFINF+DUC	134	5153
C1L	Ductile reinforced concrete moment frame with or without infill low-rise	CR+CIP/LFINF+DUC/HBET:1,3	134	5153
C1M	Ductile reinforced concrete moment frame with or without infill mid-rise	CR+CIP/LFINF+DUC/HBET:4,7	134	5153
C1H	Ductile reinforced concrete moment frame with or without infill high-rise	CR+CIP/LFINF+DUC/HBET:8,19	134	5153
C2	Reinforced concrete shear walls	CR+CIP/LWAL	133	5152
C2L	Reinforced concrete shear walls low-rise	CR+CIP/LWAL/HBET:1,3	133	5152
C2M	Reinforced concrete shear walls mid-rise	CR+CIP/LWAL/HBET:4,7	133	5152
C2H	Reinforced concrete shear walls high-rise	CR+CIP/LWAL/HBET:8,19	133	5152
C3	Nonductile reinforced concrete frame with masonry infill walls	CR+CIP/LFINF+DNO	140	5159
C3L	Nonductile reinforced concrete frame with masonry infill walls low-rise	CR+CIP/LFINF+DNO/HBET:1,3	140	5159
C3M	Nonductile reinforced concrete frame with masonry infill walls mid-rise	CR+CIP/LFINF+DNO/HBET:4,7	140	5159
C3H	Nonductile reinforced concrete frame with masonry infill walls high-rise	CR+CIP/LFINF+DNO/HBET:8,19	140	5159
C4	Nonductile reinforced concrete frame without masonry infill walls	CR+CIP/LFM+DNO	135	5154
C4L	Nonductile reinforced concrete frame without masonry infill walls low-rise	CR+CIP/LFM+DNO/HBET:1,3	135	5154
C4M	Nonductile reinforced concrete frame without masonry infill walls mid-rise	CR+CIP/LFM+DNO/HBET:4,7	135	5154
C4H	Nonductile reinforced concrete frame without masonry infill walls high-rise	CR+CIP/LFM+DNO/HBET:8,19	135	5154
C5	Steel reinforced concrete (Steel members encased in reinforced concrete)	SRC+CIP	159	5208
C5L	Steel reinforced concrete (Steel members encased in reinforced concrete) low-rise	SRC+CIP/HBET:1,3	159	5208
C5M	Steel reinforced concrete (Steel members encased in reinforced concrete) mid-rise	SRC+CIP/HBET:4,7	159	5208
C5H	Steel reinforced concrete (Steel members encased in reinforced concrete) high-rise	SRC+CIP/HBET:8,19	159	5208
C6	Concrete moment resisting frame with shear wall - dual system	CR+CIP/LDUAL	132	5151
C6L	Concrete moment resisting frame with shear wall - dual system low-rise	CR+CIP/LDUAL/HBET:1,3	132	5151
C6M	Concrete moment resisting frame with shear wall - dual system mid-rise	CR+CIP/LDUAL/HBET:4,7	132	5151
C6H	Concrete moment resisting frame with shear wall - dual system high-rise	CR+CIP/LDUAL/HBET:8,19	132	5151
C7	Flat slab structure	CR+CIP/LFLS	131	5150
PC1	Precast concrete tilt-up walls	CR+PC/LWAL	136	5155
PC2	Precast concrete frames with concrete shear walls	CR+PC/LDUAL	138	5157
PC2L	Precast concrete frames with concrete shear walls low-rise	CR+PC/LDUAL/HBET:1,3	138	5157
PC2M	Precast concrete frames with concrete shear walls mid-rise	CR+PC/LDUAL/HBET:4,7	138	5157

PC2H	Precast concrete frames with concrete shear walls high-rise	CR+PC/LDUAL/HBET:8,19	138	5157
PC3	Precast reinforced concrete moment resisting frame with masonry infill walls	CR+PC/LFINF	140	5159
PC3L	Precast reinforced concrete moment resisting frame with masonry infill walls low-rise	CR+PC/LFINF/HBET:1,3	140	5159
PC3M	Precast reinforced concrete moment resisting frame with masonry infill walls mid-rise	CR+PC/LFINF/HBET:4,7	140	5159
PC3H	Precast reinforced concrete moment resisting frame with masonry infill walls high-rise	CR+PC/LFINF/HBET:8,19	140	5159
PC4	Precast panels (wall made of number of horizontal precast panels, construction from former Soviet Union countries)	CR+PC/LWAL	137	5156
RM	Reinforced masonry	MR	116	5105
RM1	Reinforced masonry bearing walls with wood or metal deck diaphragms	MR/RWO	116	5105
RM1L	Reinforced masonry bearing walls with wood or metal deck diaphragms low-rise	MR/HBET:1,3/RWO	116	5105
RM1M	Reinforced masonry bearing walls with wood or metal deck diaphragms mid-rise (4+ stories)	MR/HBET:3,7/RWO	116	5105
RM2	Reinforced masonry bearing walls with concrete diaphragms	MR/RC/FC	116	5105
RM2L	Reinforced masonry bearing walls with concrete diaphragms low-rise	MR/HBET:1,3/RC/FC	116	5105
RM2M	Reinforced masonry bearing walls with concrete diaphragms mid-rise	MR/HBET:4,7/RC/FC	116	5105
RM2H	Reinforced masonry bearing walls with concrete diaphragms high-rise	MR/HBET:8,19/RC/FC	116	5105
CM	Confined masonry	MCF/LWAL	120	5109
CML	Confined masonry low-rise	MCF/LWAL/HBET:1,3	120	5109
CMM	Confined masonry mid-rise	MCF/LWAL/HBET:4,7	120	5109
CMH	Confined masonry high-rise	MCF/LWAL/HBET:8,19	120	5109
MH	Mobile homes	W+WLI/LWAL	191	5350
M	Mud walls	E99+ET99/LWAL	112	5101
M1	Mud walls without horizontal wood elements	EU+ETC/LWAL	112	5101
M2	Mud walls with horizontal wood elements	ER+ETC+RW/LWAL	112	5101
A	Adobe blocks (unbaked sundried mud block) walls	MUR+ADO	112	5101
A1	Adobe block, mud mortar, wood roof and floors	MUR+ADO+MOM/LWAL	112	5101
A2	Adobe block, mud mortar, bamboo, straw, and thatch roof	MR+ADO+RB+MOM/LWAL	112	5101
A3	Adobe block, straw, and thatch roof cement-sand mortar	MUR+ADO+MOC/LWAL	112	5101
A4	Adobe block, mud mortar, reinforced concrete bond beam, cane and mud roof	MR+ADO+RCB+MOM/LWAL	112	5101
A5	Adobe block, mud mortar, with bamboo or rope reinforcement	MR+ADO+RB+MOM/LWAL	112	5101
RE	Rammed Earth/Pneumatically impacted stabilized earth	EU+ETR/LWAL	112	5101

RS	Rubble stone (field stone) masonry	MUR+STRU B	113	5102
RS1	Local field stones dry stacked (no mortar) with timber floors, earth, or metal roof.	MUR+STRUB+MON/LWAL	113	5102
RS2	Local field stones with mud mortar.	MUR+STRUB+MOM/LWAL	113	5102
RS3	Local field stones with lime mortar.	MUR+STRUB+MOL/LWAL	113	5102
RS4	Local field stones with cement mortar, vaulted brick roof and floors	MUR+STRUB+MOC/LWAL	114	5102
RS5	Local field stones with cement mortar and reinforced concrete bond beam.	MR+STRU B+RCB+MOC/LWAL	120	5109
DS	Rectangular cut-stone masonry block	MUR+STDRE	114	5103
DS1	Rectangular cut stone masonry block with mud mortar, timber roof and floors	MUR+STDRE+MOM/LWAL	114	5103
DS2	Rectangular cut stone masonry block with lime mortar	MUR+STDRE+MOL/LWAL	114	5103
DS3	Rectangular cut stone masonry block with cement mortar	MUR+STDRE+MOC/LWAL	114	5103
DS4	Rectangular cut stone masonry block with reinforced concrete floors and roof	MUR+STDRE+MOC/LWAL	120	5109
UFB	Unreinforced fired brick masonry	MUR+CLBRS	114	5103
UFB1	Unreinforced brick masonry in mud mortar without timber posts	MUR+CLBRS+MOM/LWAL	114	5103
UFB2	Unreinforced brick masonry in mud mortar with timber posts	MUR+CLBRS+MOM/LWAL	114	5103
UFB3	Unreinforced brick masonry in lime mortar	MUR+CLBRS+MOL/LWAL	114	5103
UFB4	Unreinforced fired brick masonry, cement mortar.	MUR+CLBRS+MOC/LWAL	114	5103
UFB5	Unreinforced fired brick masonry, cement mortar, but with reinforced concrete floor and roof slabs	MUR+CLBRS+MOC/LWAL	120	5109
UCB	Concrete block unreinforced masonry with lime or cement mortar	MUR+CB99+MOC/LWAL	114	5103
MS	Massive stone masonry in lime or cement mortar	MUR+STDRE+MOL/LWAL	111	5100
INF	Informal constructions.	MATO	113	5102
UNK	Not specified (unknown/default)	-	100	5000

AIR-OED Codes for PAGER Mapping

OED Code	AIR code	Name	Description
5000	100	Unknown	The construction class is not known.
5050	101	Wood, Wood frame	Wood frame (modern) structures tend to be mostly low rise (one to three stories, occasionally four). Stud walls are typically constructed of 2x4 or 2x6 inch wood members vertically set 16 or 24 inches apart. These walls are braced by plywood or by diagonals made of wood or steel. Many detached single and low-rise multiple family residences in the United States are of stud wall wood frame construction.
5051	102	Wood, Light wood frame	Light wood frame structures are typically not built in the United States but would be found in other countries, such as Japan. In Hawaii, this classification would include single wall (studless) construction framed with light timber trusses.
5052	103	Wood, Masonry veneer	A wood-framed structure faced with a single width of non-load-bearing concrete, stone, or clay brick attached to the stud wall.
5053	104	Wood, Heavy timber	Heavy Timber structures typically have masonry walls with heavy wood column supports, and floor and roof decks are 2-3 inch tongue-and-groove planks.
5054	105	Wood, Okabe	
5055	106	Wood, Shinkabe	
5056	107	Wood, Lightweight Cladding	Non-structural cladding and linings (e.g., fibre cement, plywood) used in lightweight construction that uses timber or light gauge steel framing as the structural support system.
5057	108	Wood, Hawaii indigenous material	Indigenous Hawaiian construction.
5100	111	Masonry, Masonry	Use this option when the exterior walls are constructed of masonry materials, but detailed construction information is unavailable or unknown.
5101	112	Masonry, Adobe	Adobe construction uses adobe (clay) blocks with cement or cement-clay mixture as mortar. The roof consists of a timber frame with clay tiles or, in some cases, metal roofing.
5102	113	Masonry, Rubble stone masonry	Rubble stone masonry consists of low-rise perimeter load bearing walls composed of irregular stones laid as coursed or uncoursed rubble in a cement mortar bed, with floor and roof joists constructed with wood framing.
5103	114	Masonry, Unreinforced masonry bearing wall	Unreinforced masonry buildings consist of structures in which there is no steel reinforcing within a load bearing masonry wall. Floors, roofs, and internal partitions in these bearing wall buildings are usually of wood.
5104	115	Masonry, Unreinforced masonry bearing frame	Unreinforced masonry is used for infill walls of buildings with a bearing frame. In this structure type, the masonry is intended to be used not to support gravity loads, but to assist with lateral loads.
5105	116	Masonry, Reinforced masonry	Reinforced masonry construction consists of load bearing walls of reinforced brick or concrete-block masonry. Floor and roof joists constructed with wood framing are common.
5106	117	Masonry, Reinforced masonry shear wall with MRF	Reinforced masonry construction consists of load bearing walls of reinforced brick or concrete-block masonry. Reinforced masonry buildings with "Moment Resisting Frames" carry lateral loads by bending. "Shear Walls" are continuous reinforced brick or reinforced hollow concrete block walls extending from the foundation to the roof and can be exterior walls or interior walls.
5107	118	Masonry, Reinforced masonry shear wall w/o MRF	Reinforced masonry construction consists of load bearing walls of reinforced brick or concrete-block masonry. "Shear Walls" are continuous reinforced brick or reinforced hollow concrete block walls extending from the foundation to the roof and can be exterior walls or interior walls.
5108	119	Masonry, Joisted masonry	Masonry exterior walls with roof of combustible materials on non-combustible supports.
5109	120	Masonry, Confined Masonry	Confined masonry is a construction system in which plain masonry walls are confined on all four sides by reinforced concrete or reinforced masonry members. The walls themselves, however, carry all of the gravity and lateral loads.
5110	121	Masonry, Cavity Double Brick	An unreinforced masonry construction type composed of two layers of bricks, common in many cities in Australia.

5150	131	Concrete, Reinforced concrete	Reinforced concrete buildings consist of reinforced concrete columns and beams. Use this if the other technical characteristics of the building are unknown.
5151	132	Concrete, Reinforced concrete shear wall w/ MRF	Building constructed with reinforced concrete columns and beams, as well as reinforced concrete floor and roof. "Moment Resisting Frames" carry lateral loads by bending. "Shear Walls" are continuous reinforced concrete extending from the foundation to the roof and can be exterior walls or interior walls.
5152	133	Concrete, Reinforced concrete shear wall w/o MRF	Building constructed with reinforced concrete columns and beams, as well as reinforced concrete floor and roof. Reinforced concrete Shear Walls are continuous reinforced concrete, extending from the foundation to the roof and can be exterior walls or interior walls. This category typically consists of buildings with a concrete box structural system with shear walls. The entire structure, along with the usual concrete diaphragm, is typically cast in place.
5153	134	Concrete, Reinforced concrete MRF ductile	Buildings constructed with reinforced concrete columns, beams, and slabs. Moment Resisting Frames carry lateral loads due to earthquakes by bending. This kind of structural system can sustain large deformations and absorb energy without brittle failure.
5154	135	Concrete, Reinforced concrete MRF non-ductile	Buildings constructed with reinforced concrete columns, beams, and slabs. Moment Resisting Frames carry lateral loads due to earthquakes by bending. These structures have insufficient reinforcing steel embedded in the concrete and thus display low ductility.
5155	136	Concrete, Tilt-up	Tilt-up buildings are constructed with reinforced concrete wall panels that are cast on the ground and then tilted upward into their final positions. These wall units are then anchored to the foundation and attached to each other. The roof and floor decks are typically wood. More recently, the wall panels are fabricated off-site and trucked in. These buildings tend to be one or two stories in height.
5156	137	Concrete, Pre-cast concrete	The pre-cast frame is essentially a post and beam system in concrete in which columns, beams, and slabs are prefabricated and assembled on site.
5157	138	Concrete, Pre-cast concrete w/ shear wall	The pre-cast frame is essentially a post and beam system in concrete in which columns, beams, and slabs are prefabricated and assembled on site. Lateral loads due to earthquakes are carried by cast-in-place concrete "shear" walls.
5158	139	Concrete, Reinforced concrete MRF	A building constructed with reinforced concrete columns, beams, and slabs. "Moment-resisting frames" carry lateral loads due to earthquakes by bending. Information on the reinforcing steels is not sufficient to determine the building level of ductility.
5159	140	Concrete, Reinforced concrete MRF with URM	Reinforced concrete columns and beams form "moment-resisting frames" to carry lateral loads due to earthquakes. Unreinforced masonry walls are used as infills between the columns to add lateral load resistance but are not intended to serve as gravity load-bearing elements.
5200	151	Steel, Steel	Steel frame buildings consist of steel columns and beams. Use this if the other technical characteristics of the building are unknown.
5201	152	Steel, Light metal	Light metal buildings are made of light gauge steel frame and are usually clad with lightweight metal or asbestos siding and roof, often corrugated. They typically are low-rise structures.
5202	153	Steel, Braced steel frame	Buildings constructed with steel columns and beams that are braced with diagonal steel members to resist lateral forces.
5203	154	Steel, Steel MRF perimeter	Buildings constructed with steel columns and beams that are braced with diagonal steel members to resist lateral forces.
5204	155	Steel, Steel MRF distributed	Buildings constructed with steel columns and beams to carry lateral loads distributed throughout the building. The diaphragms are usually concrete, sometimes over steel decking. This structural type is seldom used for low-rise buildings.
5205	156	Steel, Steel MRF	Steel MRF buildings consist of structural steel columns and beams. Lateral loads due to earthquakes are carried by the "moment-resisting frames," but the locations of the moment-resisting frames in the building are unknown.
5206	157	Steel, Steel frame w/ URM	Structural steel columns and beams form "moment-resisting frames" to carry lateral loads due to earthquakes. Unreinforced masonry walls are used as infills between the columns to add lateral load resistance but are not intended to serve as vertical load-bearing elements. Sometimes the steel frames are completely hidden in the masonry walls.
5207	158	Steel, Steel frame w/ concrete shear wall	Structural steel columns and beams form exterior frames, but the joints are not designed for moment resistance. Lateral loads due to earthquakes are carried by reinforced concrete "shear" walls. The concrete walls are continuous from the foundation to the roof.

5208	159	Steel, Steel reinforced concrete	Structural steel sections (beams and columns) are encased in reinforced concrete. The encased structural steel columns are sometimes discontinued in the upper portions of the buildings, making the columns in the upper floor regular reinforced concrete columns.
5209	160	Steel, Steel long span	Steel long-span buildings create unobstructed, column-free spaces greater than 100 feet for a variety of activities or functions. These include activities where visibility is important for large audiences (e.g., auditoriums and covered stadiums), where flexibility is important (e.g., exhibition halls and certain types of manufacturing facilities), and where large movable objects are housed. Two-hinge (made of a single member hinged at each end) and three-hinge (made of two members hinged at each end and at the meeting point at the crown) trussed arches are widely used.

ANNEX C: NEPAL OED Building Exposure Metadata File

NPL_oed_exposure_20200811.xml


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          The data is intended for CAT modeling and loss estimation. Repurposing this data for any reason other than assessing risk is not recommended. The data presents the estimated number of buildings, building area, and rebuilding
          value at a 15-arcsecond grid resolution (approximately 500 meters at the equator). This data set is in point shapefile format where the points represent the centroids of the 15-arcsecond grid. The results were created through a
          process of spreading the number of buildings from the 2016 Nepal Demographic And Health Survey to the 15-arcsecond level by a statistical assessment of moderate resolution EO data, which is described in more detail in the
          dasymetric mapping lineage processing step. The estimated building count at any given area is a result of statistical processes and should not be mistaken as a building count. The structural classes of buildings used for risk
          assessment are estimated given the building wall, floor, and roof material classes surveyed through 2015-2016 Annual Household Survey. Additionally, the data is provided in Open Exposure Data (OED) import format, as a pair of
          CSV files. One CSV file contains the location details, and the other is an "account" file that is filled with default information to satisfy OED format requirements. The OED input files are set to use "All perils" (i.e. "AA1"). All required
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                    replacement costs. The methods described above have been carefully tailored through expert opinion, building area and count aggregates, research, and manual review. However, it is important to recognize that the numbers
                    presented in the datasets are estimates and are not a count or building census. At the cell level, they may not be representative. Mapping schemes and replacement costs are representative of typical building infrastructure
                    and replacement costs for the entire country. Regional variations in costs and building distributions (due to cost of materials and labor) will vary however, the final replacement cost values are calculated per development
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                  when the distribution between urban and rural areas is inadequate. The follow are examples of the reviews conducted by analysts: 1) If there were too many buildings assigned to urban areas, and there was a void in
                  rural areas. Thus, these grids were checked against EO data to confirms whether these areas are populated. 2) If there were too few buildings in urban settlements which caused a “donut” effect, where rural
                  populations surrounding urban areas were assigned a greater population than urban areas. This required the adjustment of residential building density for a specific region. 3) Finally, there was a check of reviewing
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<gco:CharacterString>Dasymetric Mapping: A machine learning process (CART algorithm (Breiman et al., 1984; Khaled et al., 2014), Random forest (Breiman, 2001), and Support Vector Networks (Cortez et al., 1995)) with a variety of remotely sensed Earth Observation (EO) data products and building footprint aggregates establish the distribution statistics for dispersing buildings by urban density and development pattern type. Each of the EO products, individually or in a combination, act as weights to disperse the known population by structural type to 15-arcsecond grid cells. For determining the weights for distribution several machine learning algorithms were run using the EO to develop a prediction model. For example, in grids designated as a development patterns 1 or 2 (resembling rural or single-family residential communities) an even building distribution of the district is reallocated only to grid cells within the district associated to human settlement. This machine learning exercise informs the estimated building density, replacement cost per meter, and structural characteristics of the building stock, as described in the structural distribution processing step. The following moderate and high-resolution EO data sets used: 1) NOAA night-time light annual composite (VIIRS) 15-arcsecond grid cell (Earth Observation Group NOAA-NCEI (2016)) 2) Oak Ridge National Laboratory Landscan ambient population (LSCAN) resampled from the 30-arcsecond grid cell to 15-arcsecond (Oak Ridge National Laboratory. (2012)) 3) European Commission Joint Research Centre (EC -JRC) Global Human Settlement Layer (GHSL-Landsat) derived from Landsat imagery resampled from the aggregated 250m grid cell to 15-arcsecond (Corbane et al.,(1) 2018) 4) DLR Global Urban Footprint (GUF) resampled from 12-meter grid cells to a 15-arcsecond percentage of human presence raster grid (DLR Earth Observation Center. (2016)) 5) JRC GHSL derived from Sentinel-1 SAR (GHSL-SAR) resampled from 20-meter grid cells to a 15-arcsecond percentage of human presence raster grid (Corbane et al.,(2) 2018) 6) CIESIN-Facebook High Resolution Settlement Layer (HRSL) resampled from 1-arcsecond grid cells to a 15-arcsecond percentage of human presence raster grid (Facebook Connectivity Lab and Center for International Earth Science Information Network - CIESIN - Columbia University. (2016)) 7) JRC mosaiced Sentinel-1 dual polarization bands (SAR B1, B2, B3) resampled from 20-meter resolution to a 15-arcsecond mean raster grid per band and a maximum mean value of the 3 bands (SAR-MaxMean). (Syrris, V., et. al (2018)) 8) National gridded population from WorldPop 2020 resampled from 3-arcsecond grid cells to 15-arcsecond (WorldPop(1)) 9) An indicator of OSM data throughout the country- building count, area, and maximum building height were calculated from building footprint polygons and aggregated up to create 15-arcsecond grids. (ImageCat, Inc. (2020)) 10) Center for International Earth Science Information Network (CIESIN) Water Mask resampled from 30-arcsecond grid cell to 15-arcsecond (CIESIN, 2018) 11) NASA SRTM elevation aggregated and transformed from 90m resolution elevation to 15-arcsecond slope raster grid. (NASA-NGA. 2014) Data Mask: To prevent unpopulated areas from being considered as settlements the CIESIN water layer was used as a mask for populated and non-populated areas. For populated areas, a development pattern is assigned, and population is dispersed by the weight of the combined EO spectral signature. Development Pattern Creation: Development patterns are patterns of construction in the country that typify the building structure development and density as much as possible. They sometimes correspond with land use, but not always. The development patterns are determined by a structural engineer working with GIS analysts to conduct a web reconnaissance survey of available data regarding the structural type and distribution of the country. Various engineering websites and standards (Prompt Assessment of Global Earthquakes for Response [PAGER], Global Earthquake Model [GEM]), IPUMS, and national statistical housing data were used to establish a preliminary structure type distribution. These preliminary distributions are validated through Google Earth Maps. After the web reconnaissance the structural engineer begins to formulate the development pattern. The intensity of urbanity correlates to both the building density and the structural distribution (see Structural Distribution Processing Step for more details). ImageCat engineer characterized 6 development pattern types (see Structural Distribution Processing Step for more details). </gco:CharacterString>
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<gco:CharacterString>Number of Buildings: The total number of buildings per structural class per grid cell was inferred using a combination of 1:1 number household to buildings based on the national population and housing statistics, EO machine learning, and aggregated OSM building count raster. </gco:CharacterString>
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<gco:CharacterString>Structural Distribution: Using the national population and housing census data mapping schemes were developed using a combination of the building wall, roof, and floor material type. Each combination of wall, roof, and floor material type are mapped to PAGER standard structural types and GEM construction type. The number of households is used to develop a structural distribution. The NSET national census data and 2015-16 Annual Household Survey data was used to create the mapping schemes. A final round of sanity checking is conducted by ImageCat engineers. The data below provides a PAGER description of the structural class from the various data sources and the match to the GEM taxonomy classification: Adobe blocks (unbaked sundried mud block) walls > A > MUR+ADO Nonductile reinforced concrete frame with masonry infill walls high-rise > C3H > CR+CIP/LFINF+DNO/HBET:8,19 Nonductile reinforced concrete frame with masonry infill walls low-rise > C3L > CR+CIP/LFINF+DNO/HBET:1,3 Nonductile reinforced concrete frame with masonry infill walls mid-rise > C3M > CR+CIP/LFINF+DNO/HBET:4,7 Rubble stone (field stone) masonry > RS > MUR+STRU B Unreinforced fired brick masonry > UFB > MUR+CLBRS Informal constructions > INF > MATO Wattle and Daub (Walls with bamboo/light timber log/reed mesh and post) > W5 > W+WWD/LWAL Steel light frame > S3 > S/LFM Wood > W > W Unreinforced brick masonry in mud mortar without timber posts > UFB1 > MUR+CLBRS+MOM/LWAL Steel frame with unreinforced masonry infill walls > S5 > S/LFINF The mapping schemes below provide the distribution of building by structural type per development pattern. The structure type key can be found below. Development Pattern 1: Rural development found outside of city boundaries and is typically associated with agricultural development. The regions typically consist of small, remote villages with single roads in and out. Buildings are typically spaced far apart and are almost exclusively 1 to 2 stories. Local materials and construction practices are generally used and performed in these areas. W - 0.05 | W+WWD/LWAL - 0.171 | MUR+ADO - 0.012 | MUR+STRU B - 0.493 | MUR+CLBRS - 0.204 | MATO - 0.07 Development Pattern 2: This development pattern reflects areas typically dominated by single family residential structures. Commercial properties, such as local markets, are present, however residential structures are the primary occupancy. The built-up area is denser than rural class 1, however open land (yards, vacant lots, etc.) are present and can be observed via satellite imagery. All structures are low-rise, with most in the 1 to 2 story range. W+WWD/LWAL - 0.0099 | S/LFM - 0.0223 | S/LFINF - 0.0223 | CR+CIP/LFINF+DNO/HBET:1,3 - 0.49 | CR+CIP/LFINF+DNO/HBET:4,7 - 0.22 | MUR+ADO - 0.01 | MUR+CLBRS+MOM/LWAL - 0.22 Development Pattern 3: Characterized by structures where the majority of the population lives in multi-family residential housing. The built-up area is typically comprised of long narrow apartment blocks in the 3 to 5 story range. Large open spaces (courtyards or parking lots) are present between buildings, therefore building density is typically not high. Smaller (<300 sq. m.) 1 to 2 story buildings can be observed, but they are typically limited to small offices or commercial structures within the complexes. S/LFM - 0.0117 | S/LFINF - 0.0043 | CR+CIP/LFINF+DNO/HBET:1,3 - 0.3653 | CR+CIP/LFINF+DNO/HBET:4,7 - 0.35 | CR+CIP/LFINF+DNO/HBET:8,19 - 0.01 | MUR+CLBRS - 0.2567 | MATO - 0.0032 Development Pattern 5: Development pattern 5 is characterized by urban areas predominantly occupied by low to mid-rise residential and commercial structures. An occasional high-rise apartment or office building may be present. These developments are typically found near or around major city centers. Buildings are tightly spaced and are fairly regular in shape. S/LFM - 0.0042 | S/LFINF - 0.0021 | CR+CIP/LFINF+DNO/HBET:1,3 - 0.1372 | CR+CIP/LFINF+DNO/HBET:4,7 - 0.56 | CR+CIP/LFINF+DNO/HBET:8,19 - 0.03 | MUR+CLBRS - 0.2641 Development Pattern 6: This development pattern is the central business district of urban areas within the major cities. The region is occupied by low to high-rise apartments and commercial offices. Most structures are under 7-stories, however high-rise (8+ stories) can be found within the region. Building footprints are larger than most non-industrial development patterns. This development pattern will be found only in major cities and along the major, paved roads. S/LFINF - 0.0258 | CR+CIP/LFINF+DNO/HBET:1,3 - 0.1701 | CR+CIP/LFINF+DNO/HBET:4,7 - 0.45 | CR+CIP/LFINF+DNO/HBET:8,19 - 0.08 | MUR+CLBRS - 0.2783 Development Pattern 7: This development pattern is characterized by areas dominated by ports, mining or industrial activities. Structures are typically closely spaced and regular in shape. A majority of buildings within these regions are warehouses, rectangular shape and single story. Smaller low-rise, office and commercial structures can also be found on site. S/LFM - 0.09 | S/LFINF - 0.03 | CR+CIP/LFINF+DNO/HBET:1,3 - 0.28 | CR+CIP/LFINF+DNO/HBET:4,7 - 0.23 | MUR+CLBRS - 0.3527 | MATO - 0.0166 </gco:CharacterString>
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<gco:CharacterString>Total Building Area: The total building area was calculated using 15-arcsecond aggregated OSM building raster data sets. The area per household was estimated based on an extensive assessment of OSM building footprint data and screening based on likely size for buildings. The average size of single-family households was often found to be reasonable, and an average was used for development patterns that are primarily residential. </gco:CharacterString>
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        <gco:CharacterString>Replacement Cost was determined based on Huyck & Eguchi, 2017 and Huizinga et al., 2017. From Huizinga et al., the replacement cost of residential, commercial, and industrial structures is estimated as a function of GDP. These were updated to 2019 USD ( x 1.08) per meter squared and then adjusted based on development pattern based on Huyck & Eguchi, which found that in developing countries residential construction in urban areas was well represented, but that the value of semi-engineered and engineered properties are over predicted by Huizinga et al. when compared to Resettlement Action Plans and local expert opinion. Outer-city areas and smaller settlements are downscaled to 50% of the expected value, and rural construction is 50% of this figure. Urban areas consistent with capital city areas are consistent with the 2019 scaled values from Huizinga et al, 2017, as are industrial areas. These scaling factors are applied in accordance with the development patterns mentioned above. Development Pattern 1 $94.23 Development Pattern 2 $188.45 Development Pattern 3 $376.91 Development Pattern 5 $434.21 Development Pattern 6 $1,085.51 Development Pattern 7 $317.49 </gco:CharacterString>
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        <gco:CharacterString>The building stock estimates developed in this project spread an estimate of the number of buildings derived from national population statistics including persons per household, households per building type, construction pattern distributions for various development patterns, the homogeneity of various construction patterns, building densities at the grid level as derived through image processing algorithm, and typical replacement costs. The methods described above have been carefully tailored through expert opinion, building area and count aggregates, research, and manual review. However, it is important to recognize that the numbers presented in the datasets are estimates and are not a count or building census. At the cell level, they may not be representative. Mapping schemes and replacement costs are representative of typical building infrastructure and replacement costs for the entire country. Regional variations in costs and building distributions (due to cost of materials and labor) will vary however, the final replacement cost values are calculated per development pattern in the country. Validating the distribution of building counts is a multi-step process. The national statistics data is used for spreading population spatially into buildings. Once buildings are distributed, the absolute number of buildings are aggregated and compared with the population. The numbers were not consistent with the expected rates of people per household and households per building for the nation, thus key parameters of the analysis are adjusted, and the process is re-run. For Afghanistan there were too few populated grids and the EO analysis was re-run to capture more areas of settlement. </gco:CharacterString>
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