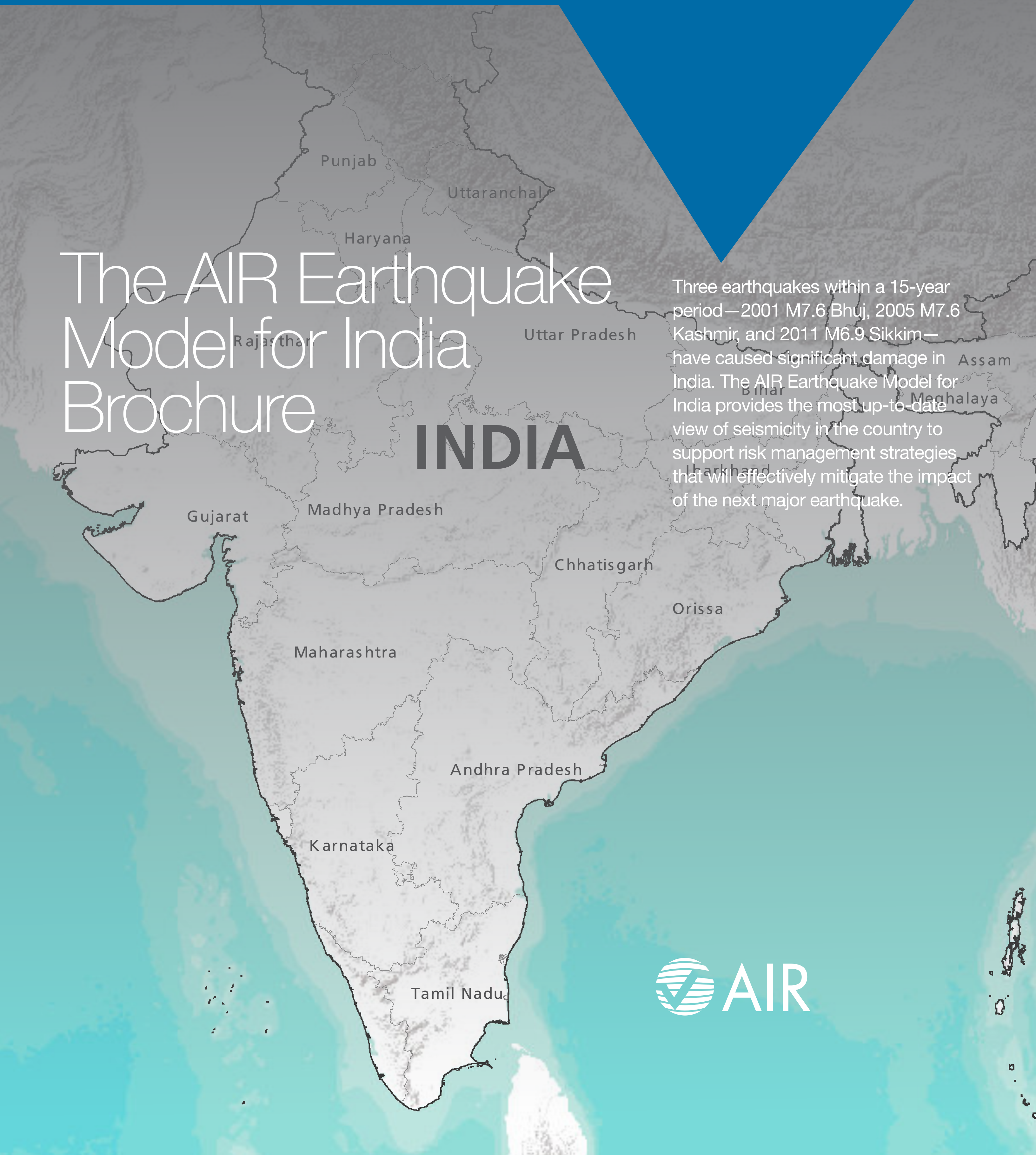
The AIR Earthquake Model for India Brochure

Three earthquakes within a 15-year period—2001 M7.6 Bhuj, 2005 M7.6 Kashmir, and 2011 M6.9 Sikkim—have caused significant damage in India. The AIR Earthquake Model for India provides the most up-to-date view of seismicity in the country to support risk management strategies that will effectively mitigate the impact of the next major earthquake.

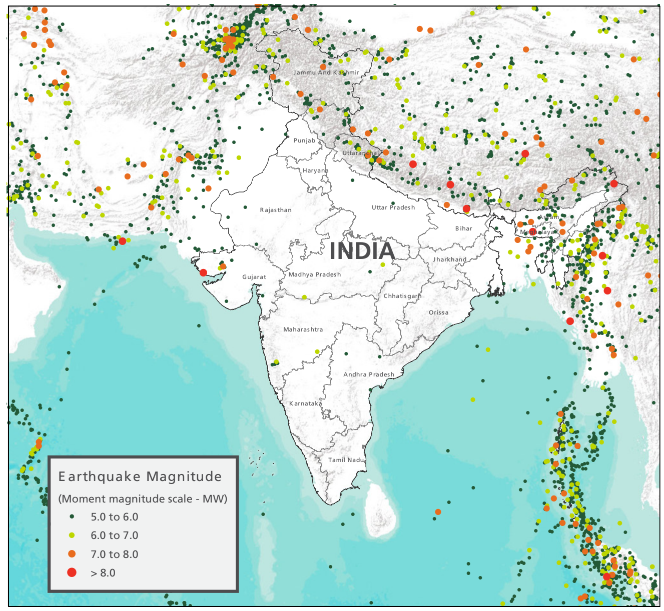


AIR

India's economy is among the fastest growing in the world. Metropolitan areas such as Ahmedabad, Bengaluru, Chennai, Delhi, Gandhinagar, Hyderabad, Jamnagar, Kolkata, Mumbai, and Pune continue to grow not only in population but also in geographic size—in many cases, in areas of high seismic risk.

As India continues to develop into an open market economy, the opportunities for stakeholders in the country's insurance industry are vast. The AIR Earthquake Model for India will play a critical role in helping stakeholders better understand and manage exposure to earthquake risk and demonstrate regulatory compliance.

> "The AIR team has excellently captured the regional seismicity and structural vulnerability of building portfolios in the India Earthquake Model. A comprehensive tracking of seismic code evolution and subsequent vulnerability evaluation procedure will render confidence to the user in predicting seismic losses."
>
> Professor Jayadipta Ghosh,
> Indian Institute of Technology Bombay



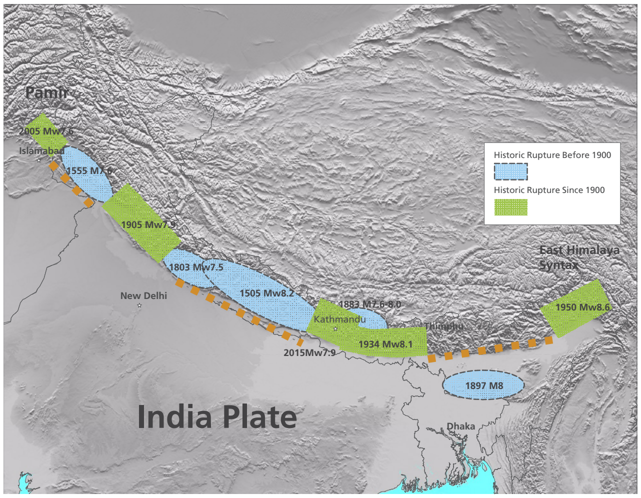
Caption: Earthquakes of M5.0 and greater in and around India. (Source: AIR)

The Most Comprehensive View of Seismic Hazard in India

The Himalayas, where the Indian and Eurasian plates collide, are the source of many of India's most damaging earthquakes, including the 1934 M8.0 Bihar-Nepal, 1950 M8.6 Assam, 2005 M7.6 Kashmir, and 2011 M6.9 Sikkim earthquakes. The 2015 M7.8 Gorkha-Nepal earthquake in the Himalayan region may have increased the seismic risk in an adjacent fault segment. The Andaman and Nicobar Islands are at risk from the subduction of the southeastern part of the Indian plate along the Sumatra-Andaman Trench (e.g., the 2004 M9.3 Indian Ocean earthquake). Rare intraplate earthquakes, such as the 2001 M7.6 Bhuj earthquake, have also caused extensive damage.

Using the most recent historical earthquake data from the ISC-GEM Global Instrumental Earthquake Catalogue, GEM Global Historical Catalogue, Global Centroid Moment Tensor Catalogue, U.S. Geological Survey, the India Meteorological Department, and the National Disaster Management Authority of India, along with fault slip rates and paleoseismological data on active faults, and GPS data, AIR scientists have created the most comprehensive model of India's seismic hazard.

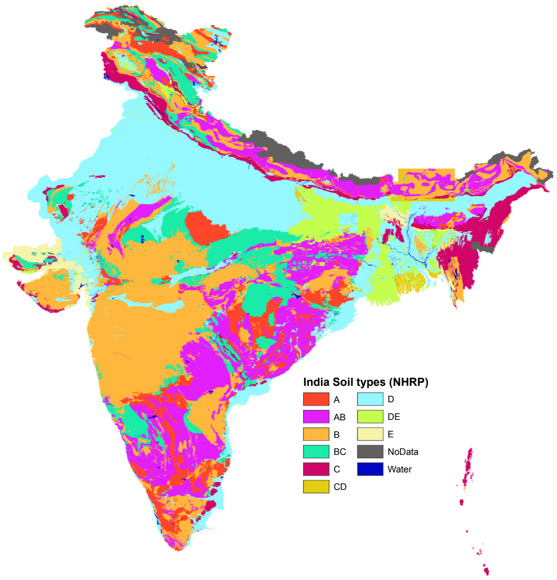
AIR also uses GPS data, along with the kinematic continuum model from the GEM Global Strain Rate Model, to constrain the seismic moment rate of each earthquake source zone. Kinematic continuum models capture the plate deformation patterns in terms of strain rate field and provide supplementary constraints on the rate of seismicity. The result is a more complete view of seismic hazard across the region.



On the map, the green areas indicate the fault segments that have ruptured after 1900. The blue areas indicate segments where earthquakes occurred before 1900. The orange lines mark the fault segments that have not ruptured for perhaps more than 400–500 years. Based on the historical record of large ruptures in the past 500 years, AIR divided the Main Himalaya fault zone into nine segments and calculated the time-dependent probability for each segment. The time-dependent rate is much higher for segments that have not ruptured in the last 400–500 years, whereas for segments ruptured in recent years, the time-dependent rate is much lower than the time-independent rate.

Optimized Stochastic Catalog Reflects Time-Dependent and Time-Independent Earthquake Rupture Probabilities to Provide the Most Robust View of Risk

According to a time-dependent view of earthquake risk, the annual probability of an earthquake occurring on a given fault is dependent on when the last earthquake occurred on that fault and how quickly that fault is accumulating elastic strain (or slip deficit). The AIR Earthquake Model for India incorporates both time-dependent and time-independent earthquake rupture probabilities—the former, for seismic source zones in India with well-known rupture histories, such as the Himalayas, Gujarat, and the Andaman subduction zones, and the latter for source zones where rupture histories are not well documented.

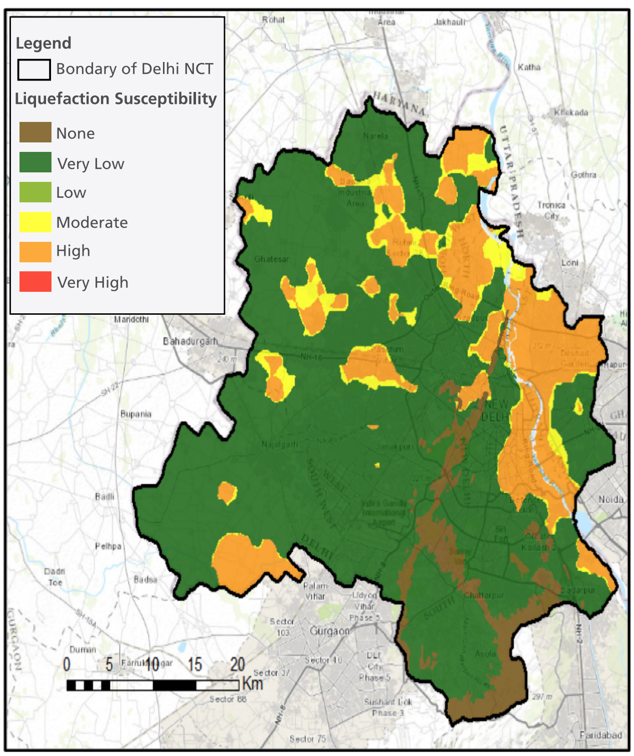


Soil maps for India are at resolutions as fine as 90 meters in metropolitan locations. (Source: AIR)

High Resolution Soil Maps Capture Shaking Intensity

Using geological data obtained from the Geological Survey of India (GSI), together with geotechnical data from published studies, the AIR model accounts for variations in soil type that can dramatically alter the intensity and nature of ground shaking. The resolution of the soil maps countrywide is 1 km, and is as high as 90 meters for Bengaluru, Chennai, Kolkata, and Mumbai, and National Capital Territory of Delhi (Delhi).

The most up-to-date ground motion prediction equations (GMPEs) appropriate to each of the region's seismic settings—which include active crustal fault, stable continental, interface subduction, and deep zones—are used in a logic-tree approach to model the ground shaking at each affected site.



Liquefaction risk in the National Capital Territory of Delhi, with high liquefaction susceptibility areas mainly along the Yamuna River. (Source: AIR)

Explicit Modeling of Liquefaction

When violent ground shaking causes water-saturated soils to lose their strength, buildings can suddenly tilt or even topple. Buried utility lines, pipelines, and ducts can rupture.

Recent temblors around the world, including the 2011 Christchurch earthquake, have shown that damage due to liquefaction can increase total losses significantly. Because liquefaction is strongly correlated with soil type and water depth, detailed geological and geotechnical soil data, and groundwater data are required to produce a comprehensive picture of liquefaction risk. The AIR model explicitly captures liquefaction risk in the larger and seismically vulnerable cities of India, such as Kolkata, Mumbai, and Delhi, which are home to nearly half of India's population.

Damage Functions Provide Robust View of Vulnerability

In developing the model's damage functions, AIR conducted a comprehensive evaluation of the evolution of India's building code and consulted with scientists and engineers from India to gain further insight into local construction practices and their impact on vulnerability.

The model features unique damage functions for shake and liquefaction for 61 construction classes and 115 occupancy classes. These damage functions fully capture the relationship between the intensity of the hazard and the vulnerability of affected structures.

Further highlights of the vulnerability module of the AIR Earthquake Model for India include:

— Damage functions generated using nonlinear dynamic analysis, together with component-level fragilities, to establish relationships between building damage and intensity

— Detailed age bands that are fully consistent with the evolution of building codes in India and that incorporate knowledge from local experts

— Height bands that include a "tall" building designation for buildings of 25+ stories

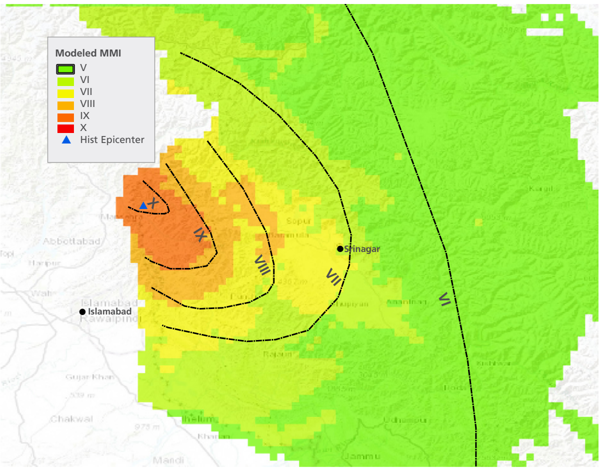
— For buildings with unknown attributes—including construction type, building height, and year built—damage ratios are calculated as a weighted average of the damage ratio for buildings of known attributes

— Damage functions for buildings, contents, business interruption, industrial facilities, builder's risk, and automobiles are included for both the shake and liquefaction perils

Leveraging AIR's Detailed Industry Exposure Database for India

The greatest concentrations of exposure are found in the densely populated and industrialized cities of India. AIR's industry exposure database (IED) for India consists of information on risk counts, building characteristics, and construction costs, at a 1-km spatial resolution.

The benefits and uses of AIR's IEDs are numerous: They provide a foundation for all modeled industry loss estimates and risk transfer solutions, such as industry loss warranties that pay out based on industry losses rely on the IED; and aggregate CRESTA or District exposures are automatically disaggregated to a 1-km grid during analysis based on the industry exposure weights by line of business.

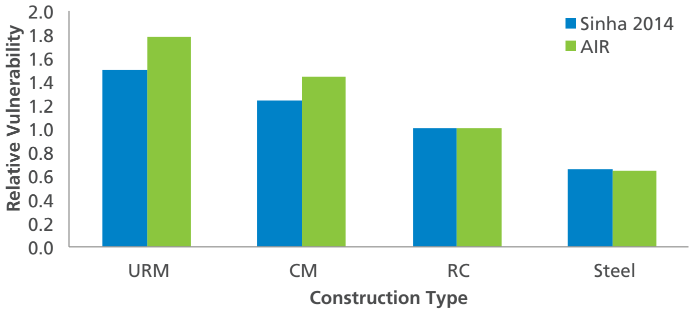


Modeled ground motion intensity footprints for the 2005 Kashmir earthquake agree well with observed ground motion footprints. (Source: AIR)

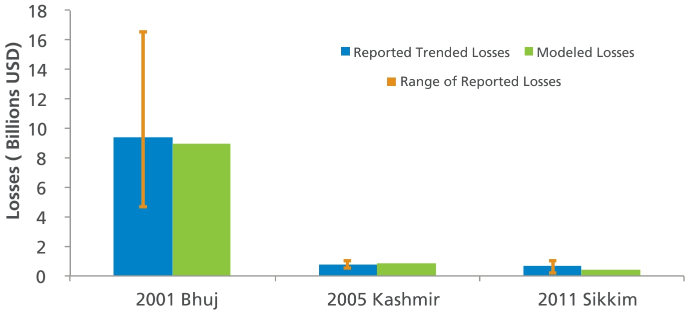
A Comprehensive Approach to Model Validation

To ensure the most robust and scientifically rigorous results possible, the AIR Earthquake Model for India was built from the ground up, with each model component independently validated against multiple sources and data from historical events in India and around the world. For example, the magnitude-frequency distribution of events in the stochastic catalog has been validated against historical earthquake rates and published kinematic modeling results. In addition, modeled ground motion agrees well with recorded ground motion fields for earthquakes, and geological and geotechnical data were validated using remote sensing images and published studies.

Similarly, modeled damage ratios have been validated against available observations and published reports for earthquakes in India.



AIR's modeled relative vulnerabilities compare well with observed relative vulnerabilities of different construction types.



AIR's India earthquake modeled ground-up losses show good agreement with trended reported ground-up losses for historical events.

Model at a Glance

Modeled Perils	Ground shaking and liquefaction
Supported Geographic Resolution	CRESTA zone, district, postcode and latitude/longitude. AIR software solutions can disaggregate CRESTA and district level exposure to 1-km resolution for more accurate results.
Stochastic Catalogs	Optimized 10,000-year catalog contains 44,638 loss-causing simulated events. The model has 34 historical events available for loss analysis and one Extreme Disaster Scenario (EDS).
Supported Construction Classes, Occupancies, and Specialized Risks	— 62 construction classes and 115 occupancy classes are supported for shake and liquefaction — Large industrial facilities, which are represented by 62 occupancy classes, are supported for shake and liquefaction — “Unknown” damage functions are available for instances when risk characteristics (e.g., construction type, occupancy, or height) are unavailable
Industry Exposure Database	— Contains risk counts, building characteristics, and construction costs, at a 1-km spatial resolution — Provides a foundation for all modeled industry loss estimates
Supported Policy Conditions	Supports a wide variety of location, policy, and reinsurance conditions that are specific to India

Model Highlights

- Explicitly models ground shaking and liquefaction
- Includes a 10,000-year catalog optimized from a 100,000-year catalog
- Incorporates the most up-to-date view of seismicity based on the latest local, regional, and global historical earthquake catalogs
- Employs kinematic continuum modeling, active faults, and historical earthquake data to produce a comprehensive view of seismic hazard that includes time-dependent modeling and time-independent modeling
- Uses high-resolution soil maps to capture site amplification and liquefaction potential
- Features peril-specific damage functions for shake and liquefaction that have been validated using data from earthquakes around the world and industry claims data
- Benefits from AIR’s consultation with local experts during model development, and from a thorough peer review of the model’s vulnerability component

ABOUT AIR WORLDWIDE

AIR Worldwide (AIR) provides risk modeling solutions that make individuals, businesses, and society more resilient to extreme events. In 1987, AIR Worldwide founded the catastrophe modeling industry and today models the risk from natural catastrophes, terrorism, pandemics, casualty catastrophes, and cyber attacks, globally. Insurance, reinsurance, financial, corporate, and government clients rely on AIR’s advanced science, software, and consulting services for catastrophe risk management, insurance-linked securities, site-specific engineering analyses, and agricultural risk management. AIR Worldwide, a Verisk (Nasdaq:VRSK) business, is headquartered in Boston with additional offices in North America, Europe, and Asia. For more information, please visit www.air-worldwide.com.

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