Update to Touchstone Loss Estimates

Version 2021 Technical Update

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Revision History

Date	Description
June 15, 2021	Original release
July 16, 2021	Japan Typhoon: Removed references to damage distribution updates (the previous and current versions both use inflated transformed beta distribution).
March 10, 2022	Japan Typhoon: Corrected the number of loss-causing events in the stochastic catalog.

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1 Executive Summary

AIR Terrorism Model

The AIR Terrorism Model has major enhancements to intensity and vulnerability analytics in the 2021 release. AIR introduced an improved method for calculating the local intensity of a conventional-weapon blast in the United States and for estimating the resulting property damage and injuries. Model resolution is upgraded from building-level to 14-ft cubic cells for conventional buildings and to 31-ft cubic cells for large industrial facilities. Infrastructure is explicitly supported; cell size varies between 14 and 20-ft cubic cells, depending on the infrastructure type. Damage in the updated model is estimated by an on-the-fly cell-by-cell calculation. The updated model has an enhanced overpressure and impulse calculation method across the surface of and inside buildings. It has improved intensity attenuation curves, a new medium truck (10-ton TNT) weapon type, support for floor of interest as a secondary risk characteristic, finer geographic resolution, updated urban density classification, updated damage functions, enhanced treatment of unknown primary risk characteristics, and vulnerability differentiation by the actual number of stories instead of by height class. The latest United States Industry Exposure Database is incorporated into the model.

AIR Earthquake Model for Japan

The AIR Earthquake Model for Japan incorporates learnings and findings from the 2019 National Seismic Hazard Maps for Japan (HERP 2019) from Headquarters for Earthquake Research Promotion in the model's 2021 release. The historical catalog, stochastic catalog, and historical event set are all updated, and a new Extreme Disaster Scenarios (EDS) were introduced. Local intensity calculation module enhancements include updates to the site amplification model, subperil modeles, as well as incorporation of the post-Tohoku ground motion prediction equations (GMPEs). Damage estimation module improved efficiency, transparency, and flexibility through intensity-based damage functions, support for unknown primary building characteristics, and improvements to personal accident and workers compensation loss estimates.

AIR Typhoon Model for Japan

The AIR Typhoon Model for Japan includes four new historical events, an expanded stochastic catalog, new wind damage functions, and updated damage distributions.

2 The AIR Terrorism Model

2.1 Overview of Model Updates and Changes

The AIR Terrorism Model is updated in the 2021 release to include:

- Improved method for calculating the local intensity of a conventional-weapon blast and estimating the resulting property damage and injuries in the United States
- Model resolution upgraded from building-level to 14 to 31-ft cubic cells, depending on the risk type:
    - Conventional building - 14 ft cubic cells
    - Large industrial facilities - 31 ft cubic cells
    - Infrastructure cell size varies between 14 ft cubic cells and 20 ft cubic cells, depending upon the type
- Damage estimated by an on-the-fly cell-by-cell calculation
- Enhanced overpressure and impulse calculation across the surface of and inside buildings
- Improved intensity attenuation curves. Developed 270 attenuations (2 intensities, 5 urban settings, 3 exterior functions differentiated by the front, side and rear of a structure, and 9 interior attenuations accounting for the difference in intensity drop and rates of decay) using 3-dimensional computational fluid dynamics analyses
- New **Medium Truck (10-ton TNT)** weapon type. The **Delivery Truck (6-ton TNT)** weapon type is renamed to **Small Truck (6-ton TNT)** .
- Vulnerability differentiation by the actual number of stories instead of by height class for conventional blasts in the United States
- Support for floor of interest as a secondary risk characteristic
- Finer geographic resolution: urban density resolution upgraded to 1-km resolution across the entire United States. Several large metropolitan areas maintain ZIP code resolution where ZIP codes are smaller than the 1-km grid.
- Updated urban density classification
- Updated damage functions for buildings, contents, business interruption, and injuries due to blasts from conventional-weapons in the United States
- Enhanced treatment in damage calculations of unknown construction class and of unknown height
- Latest United States Industry Exposure Database is incorporated

Note

It is important to note that all of these updates apply only to terrorist attacks in the United States that use conventional weapons. These updates apply to both stochastic and deterministic analyses.

2.2 Local Intensity Calculation

The updated AIR Terrorism Model calculates two types of blast intensities for use in estimating property damage and injuries:

- Overpressure - the initial significant change in pressure that is experienced by the structure or person in the vicinity of the blast
- Pressure impulse - the integral (i.e., area under the curve) with respect to local pressure and duration of that pressure

Each intensity type has several intensity attenuation functions, for use in calculating local intensity at the front, side, rear, or interior of a structure. The front intensity is calculated from the blast size, distance, and urban density. The intensities impacting the side and rear of the building are lower than the intensity impacting the front due to the assumed orientation of the building. The interior intensity is a function of front intensity with further attenuation and decay to account for the blast penetrating the building envelope and being impacted by interior contents and partitions. For each cell, one of these functions is used to calculate the intensity of the conventional weapon-blast as the blast wave propagates through the building.

The intensity calculation has been validated extensively against the literature as well as internal three-dimensional computational fluid dynamics analyses, as shown in the following figure.

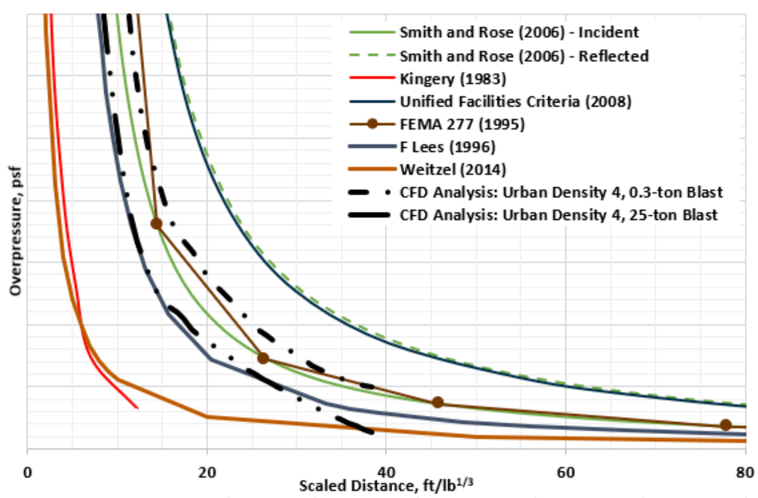

Figure 1. Validation of Local Intensity Attenuation Calculations

Impact of the Local Intensity Calculation Update

The new local intensity calculation methodology using three-dimensional computation fluid dynamics results in improved intensity attenuation and results closer to historical observation and a multitude of publications. The modeled overpressure closely matches observations, as shown in the following figure.

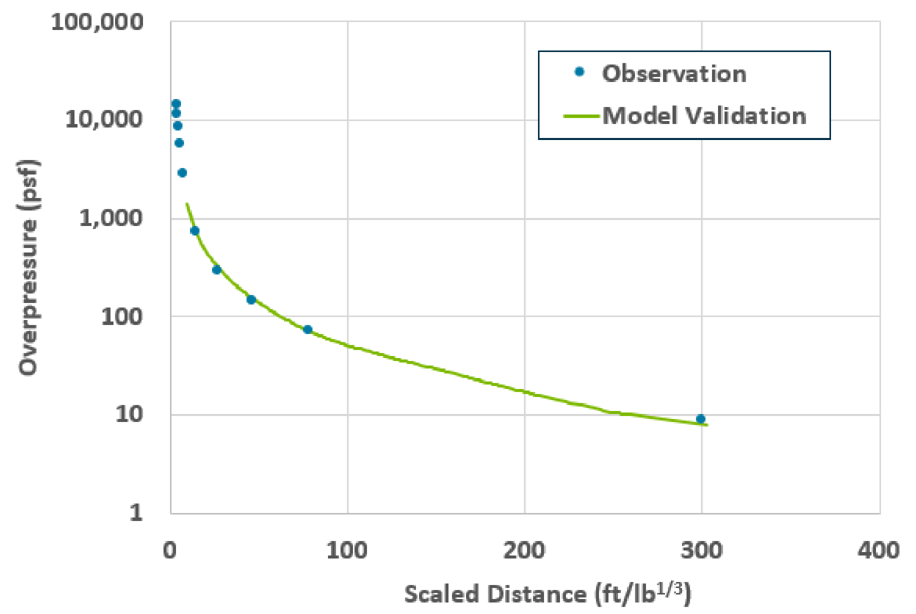

Figure 2. Validation of modeled overpressure

2.3 Damage Estimation

Damage estimation updates to the AIR Terrorism Model in 2021 include:

- Updated damage functions for buildings, contents, business interruption, and injuries due to blasts
- Enhanced treatment in damage calculations of unknown construction class and of unknown height
- Support for damage differentiation by the actual number of stories instead of by height class
- Support for floor of interest as a secondary risk characteristic (SRC)
- Explicit support of infrastructure and other non-conventional risks

Updated Damage Functions

Damage due to a conventional-weapon blast is now modeled as a function of overpressure and pressure impulse. There is no specific damage function for a structure. Instead, damage is estimated by an on-the-fly cell-by-cell calculation, where the vulnerability of each cell is determined based on the building material. Damage to the structure is the result of aggregating the damage to each cell across the entire structure. For a given construction class, occupancy class, and number of stories, a rectangular building with a specific width, depth, and height is created within the model and its floor plan centroid is placed at the input latitude/longitude with its width side facing the blast. The width and depth directions are discretized into 14-ft cells and the height is discretized by the number of stories. The estimated damage is aggregated cell-by-cell progressively from the front cells to the rear cells, and from the lower layers to the upper layers based on the level of intensity that is impacting each cell within the building.

Once a building is discretized into cells, the distance from the blast to a front cell surface centroid is calculated. For a given urban class, blast size, and distance, overpressure and impulse are calculated as the incident intensities for the front cell. Based on wall strength, the blast wave breaks through the wall and travels to the opposite end of the cell, where exit intensities are calculated as a function of incident intensities, intensity drop, distance, and occupancy. The occupancy determines the rate of intensity decay inside a building, which depends on the amount of open space within the building as well as building layout. This process repeats until the damage to all cells is calculated. The damage to the entire building is a weighted sum of the damage to each cell. When calculating the damage to a rear or side cell, the shielding effect of the building is considered.

For a large industrial facility, the cell size is 31 ft instead of 14 ft in order to improve computational efficiency. Open spaces such as parking lots are not included in dimension estimations. For infrastructure such as a road, railway, runway, or underground pipeline, the dimensions are defined such that the blast is detonated above it. Cell size varies between 14 ft and 20 ft, depending on the size and type of infrastructure.

Enhanced Treatment of Unknown Primary Risk Characteristics

In client portfolios, primary building attributes, such as construction, occupancy, number of stories and year built are often unknown or unavailable. When this kind of risk is input into a models, a common practice is to do a weighted damage average of the known risks on-the-fly. In the AIR Terrorism Model, calculating cellular damage with this type of average would lead to prohibitively long computation time. Therefore, a different approach is adopted based on cell damageability and risk dimension. A cell’s damageability is determined by the risk materials, and the risk dimension is estimated based on occupancy class and number of stories.

When the construction class is unknown, a pre-calculated weighted cell damageability is used in the damage calculation. When the occupancy class is unknown and the number of stories is known, or when the occupancy is known and the number of stories is unknown, or when all of these are unknown, a pre-calculated weighted dimension is input into the model for damage estimation.

Support for Damage Differentiation by Number of Stories

For terrorist attacks in the United States using conventional weapons, the updated model supports vulnerability variation explicitly by the number of stories, not by height bands. (International terrorist attacks, as well as CBRN attacks, continue to determine vulnerability by height bands.)

Support for Floor of Interest SRC

The updated model supports the floor of interest as a secondary risk characteristic (SRC) for all residential and commercial buildings, with the exception of mobile homes.

If the entire building is not covered under the insurance policy, the floor of interest (which could be a basement) is entered with a numerical input. When the number of stories is coded as N (> 0), the floor of interest (-1, 0, 1, 2, …, N) is interpreted as damage to the basement (which is assumed to be equal to the damage to the first floor), to the entire building, and to the first, second, …, N^{th} floor, respectively. If the floor of interest is mistakenly input as larger than N, the model outputs the damage to the N^{th} floor. If the number of stories is coded as 0 (unknown), the input for floor of interest is ignored. Replacement values for the building, contents, and time element and all policy terms are applied only to the floor of interest. However, the number of days out of use is always calculated for the entire building, independent of the floor of interest.

Explicit Support for Infrastructure and Other Non-conventional Risks

The updated model explicitly supports loss estimation for many types of infrastructure and other non-conventional risks, including:

Roads	Automobiles
Bridges	Trucks
Railways	Pleasure boats
Runways	Airplanes
Towers	Trains
Marine hulls	Tunnels
Tanks	Earth-filled dams
Pipelines	Concrete dams
Transit warehouses	Offshore platforms
Cargo	Retaining structures

Impact of the Damage Estimation Update

The updated model provides a more accurate estimate of the damage to structures and contents affected by a conventional weapon blast, as validated by comparisons to historic events. Greater risk differentiation by building height as well as damage estimation for a specific floor of interest is now possible.

The following figure compares the loss, in millions of U.S. dollars, calculated by the previous model (green bars), and the updated model (blue bars) with the observed historical loss (orange bars) for three terrorist attacks in the United States. The updated model results are clearly closer to the actual historical losses.

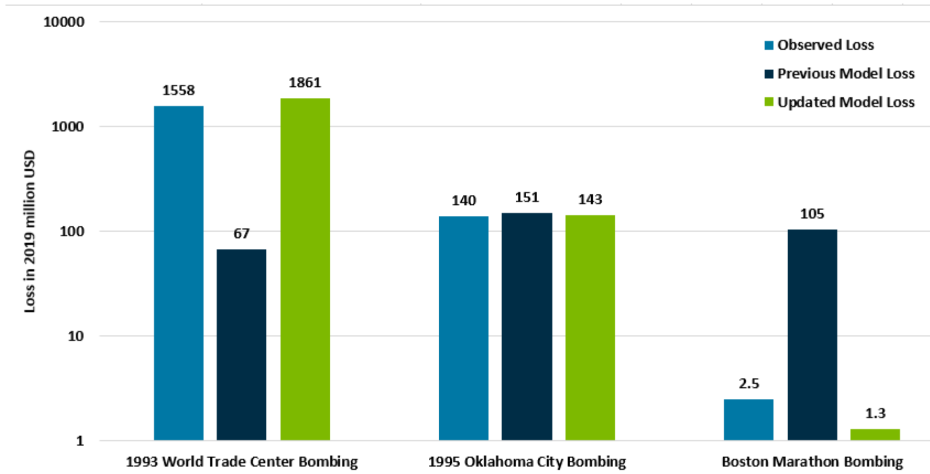

Figure 3. Comparison of historical losses calculated by the previous and updated AIR Terrorism Model to the historical loss observations

The following figure compares the number of casualties estimated by the previous model (green bars) and the updated model (blue bars) with the actual number of casualties (orange bars) caused by the Oklahoma City bombing of 1995.

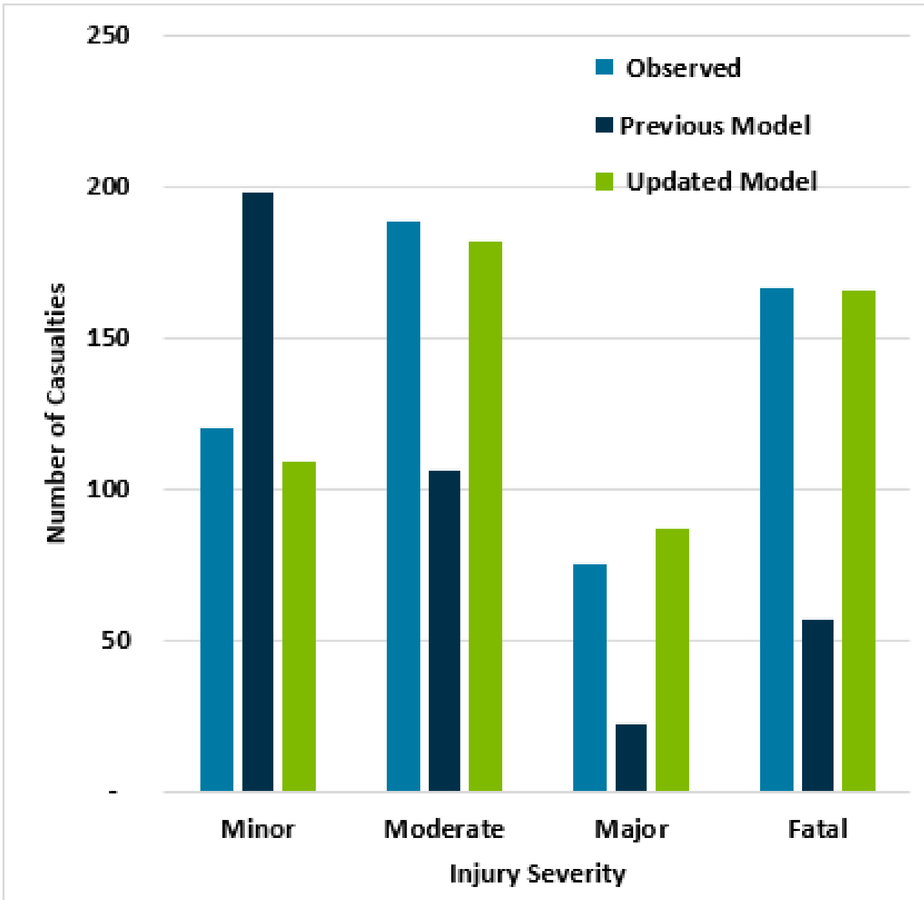

Figure 4. Comparison of personal injuries due to the 1995 Oklahoma City bombing with the estimates by the previous and updated AIR Terrorism Model

2.4 Industry Exposure Database

The updated model uses the latest version of the AIR Industry Exposure Database for the United States, which is fully updated and current as of end-of-year 2019. The database is constructed with a 90-m grid.

The database contains risk counts and their respective replacement values, along with information about the occupancy and physical characteristics of the structures, such as construction types and height classifications. It can aid in the development of AIR's damage functions for buildings with unknown characteristics, as well as in disaggregation of the exposure data in client portfolios to a highly-detailed level.

Detailed information about the AIR Industry Exposure Database for the United States is available on the AIR Client Portal at www.air-worldwide.com .

2.5 General Impact of the Model Updates on Loss Estimates - Touchstone

The overall impact of the updates to the AIR Terrorism Model on the gross insurable occurrence and aggregate losses to property as well as worker's compensation losses can be found in a separate publication, available in HTML format at the following links:

- Gross Insurable Aggregate
- Gross Insurable Occurrence
- Workers' Compensation Insurable Aggregate and Occurrence
- Analysis Settings

These losses are due to a combination of domestic and international conventional and CBRN-weapon attacks. Demand surge is not applicable to the AIR Terrorism Model. Loss changes represent the percentage change in loss estimates calculated by Touchstone 2021 as compared with those calculated by Touchstone 2020 for the 10 states with the highest stochastic event frequencies, using the 500,000-year AIR U.S. Terrorism Standard catalog. The changes represent overall change, including the effects of model updates as well as the updated industry exposures.

The longer return periods are dominated by CBRN attacks, and the shorter return periods are influenced mainly by conventional blast attacks. Therefore, this update has a greater effect on the losses for the shorter return periods. The impact of this update also varies for different states. For states such as New York and California, where the attacks occur mostly in urban canyons such as downtown Manhattan or San Francisco, a noticeable increase in loss is seen due to the increased intensity footprint. For states such as Florida and Colorado, where the high-risk areas are a mixture of mid- and high-rise buildings, the losses have minimal change or decrease because the use of interior intensity for contents damage estimation results in reduced estimated contents damage.

Note that caution should be exercised before relating the industry changes shown here to a particular portfolio. The changes to individual books of business may deviate from the losses represented here to the extent that their spatial distribution and construction/occupancy mix deviate from industry averages.

3 The AIR Earthquake Model for Japan

3.1 Overview of Model Updates and Changes

The AIR Earthquake Model for Japan captures the effects of ground shaking and earthquake triggered perils (liquefaction, fire, and tsunami) on properties in Japan. This is a stochastic, event-based model. The summer 2021 update of the model is the result of several years of research and development by many professionals at AIR and represents a major advancement in the scientific understanding of earthquakes and how assets respond to them.

The 2021 release of the model includes a significant update to the hazard component as it incorporates the findings and learnings from the 2019 National Seismic Hazard Maps for Japan, developed by the Headquarters for Earthquake Research Promotion (HERP 2019[1]). The 2019 release of the National Seismic Hazard Maps has caused the re-evaluation of AIR's views of seismic risk in Japan. In particular, the view includes newly-gained insights into seismic hazard sources; multi-fault ruptures; the impact on short-, medium-, and long-term seismicity in areas that have experienced recent earthquakes.

The AIR Earthquake Model for Japan in the 2021 release of Touchstone includes the explicit modeling of the liquefaction, tsunami, and fire following earthquake (FFE) sub-perils.

3.2 Catalogs and Event Sets

The 2021 model includes updates to the stochastic event set as well as the historical, realistic, government, and extreme event scenarios, as described below.

Stochastic Catalog

The offering of catalogs in the 2021 model release has been updated to better represent HERP's view of seismicity for Japan (2019). The model provides the time-dependent (TD, default) and time-independent (TID) views of seismicity in two catalogs of 10,000 simulated years of events. Note that all event IDs are new.

Historical Event Set

The updated model features a Historical Event Set consisting of 66 (as compared to 63 in the previous model version) historical events for loss analysis. The model features two

[1] Existing model was based on the HERP 2010 model. Updated model incorporates HERP's findings over the past 10 years, since HERP 2010. For the sake of simplification, this document refers to all of the HERP updates as HERP 2019.

additions to the historical event set: Kumamoto, 2016 and Osaka, 2018 (new events are listed in Historical Events available in Touchstone in **bold** typeface). One historical event for Hoei (1707) has been removed, and a second Tohoku (2011) event has been included with this update.

Table 1. Historical events available in Touchstone

ID	Earthquake	Magnitude (M_W)	Year	ID[2]	Earthquake	Magnitude (M_W)	Year
1	Hoei*	8.75	1707	34	Ebino	6.3	1968
2	Yaeyama	8.0	1771	35	Tokachi-oki	8.2	1968
3	Ansei-Tokai	8.4	1854	36	Nemuro-hanto-oki	7.8	1973
4	Ansei-Nankai	8.4	1854	37	Izu-hanto-oki	6.5	1974
5	Ansei-Edo	7.1	1855	38	Izuoshima	6.6	1978
6	Noubi	8.0	1891	39	Miyagi-ken-oki	7.6	1978
7	Meiji-Tokyo	7.0	1894	40	Chiba-ken-Chubu	6.0	1980
8	Shonai	6.6	1894	41	Urakawa-oki	6.9	1982
9	Meiji-Sanriku	8.0	1896	42	Nihonkai-Chubu	7.58	1983
10	Rikuu	7.2	1896	43	Nagano-ken-seibu	6.2	1984
11	Kikaijima	8.1	1911	44	Chiba-ken-toho-oki	6.5	1987
12	Sakurajima	7.1	1914	45	Kushiro-oki	7.6	1993
13	Tachibana-wan	6.9	1922	46	Hokkaido-nansei-oki	7.8	1993
14	Taisho-Kanto	7.9	1923	47	Hokkaido-toho-oki	8.3	1994
15	Tanzawa	7.3	1924	48	Sanriku-haruka-oki	7.7	1994
16	Kita-Tajima	6.8	1925	49	Kobe	6.9	1995
17	Kita-Tango	7.1	1927	50	Tottori-ken-seibu	6.75	2000
18	Kita-Izu	7.0	1930	51	Geiyo	6.8	2001
19	Nishi-Saitama	6.9	1931	52	Miyagi-ken-oki	7.05	2003
20	Showa-Sanriku	8.4	1933	53	Miyagi-ken-hokubu	6.2	2003
21	Kussharoko	6.1	1938	54	Tokachi-oki	8.1	2003
22	Tottori	7.0	1943	55	Niigata-Chuetsu	6.6	2004
23	Tonankai	8.1	1944	56	Fukuoka-seiho-oki	6.6	2005
24	Mikawa	6.6	1945	57	Miyagi-ken-oki	7.2	2005
25	Nankai	8.4	1946	58	Noto-Hanto	6.7	2007
26	Fukui	6.9	1948	59	Niigata-ken-Chuetsu-oki	6.6	2007
27	Imaichi	6.4	1949	60	Iwate-Miyagi-Nairiku	6.9	2008
28	Tokachi-oki	8.1	1952	61	Iwate-ken-engan-hokubu	6.8	2008

[2] New events are in **bold** typeface.

ID	Earthquake	Magnitude (M_W)	Year	ID[2]	Earthquake	Magnitude (M_W)	Year
29	Yoshino	6.9	1952	62	Surugawan	6.5	2009
30	Nagaoka	5.2	1961	63	Tohoku-oki**	9.0	2011
31	Hyuganada	7.0	1961	64	**Tohoku-oki**	**9.0**	**2011**
32	Miyagi-ken-hokubu	6.5	1962	65	**Kumamoto**	**7.0**	**2016**
33	Niigata	7.5	1964	66	**Osaka**	**5.7**	**2018**

World Scenarios Event Set

The 2021 update to the AIR Earthquake Model for Japan also features the World Scenario event set that includes four Extreme Disaster Scenario (EDS) events, one Lloyd's Realistic Disaster Scenario (RDS), and 15 government event scenarios. The events represent scenarios that have been studied and discussed in various sources relevant to extreme disaster modeling for Japan. The event set includes a new 9.2 magnitude EDS scenario for the Japan Trench and one updated Tokachi-oki Kushiro-oki scenario, which is a standard stress-test scenario developed by the Japanese government. Other world scenario events are low-probability, high-impact events for various metropolitan areas of Japan.

3.3 Event Generation

The updated AIR Earthquake Model for Japan offers the TD and TID versions of 10,000-year stochastic catalog. These catalogs contain simulated events along with their epicenters, moment magnitudes, rupture geometries, and split mechanisms.

In the following sections, changes in hazard due to the updated stochastic catalog are discussed. Note that the change in losses reflects only the update to the stochastic catalog, with ground motion, vulnerability, and the AIR view of industry exposure held constant.

Model Domain

The size and shape of the stochastic catalog domain for the AIR Earthquake Model for Japan (shown in Figure 5) have changed slightly, relative to the previous version of the model. Stochastic events in the earthquake catalog are generated both on-land and off-shore Japan, including islands, as indicated by the boundary in Figure 5.

[2] New events are in **bold** typeface.

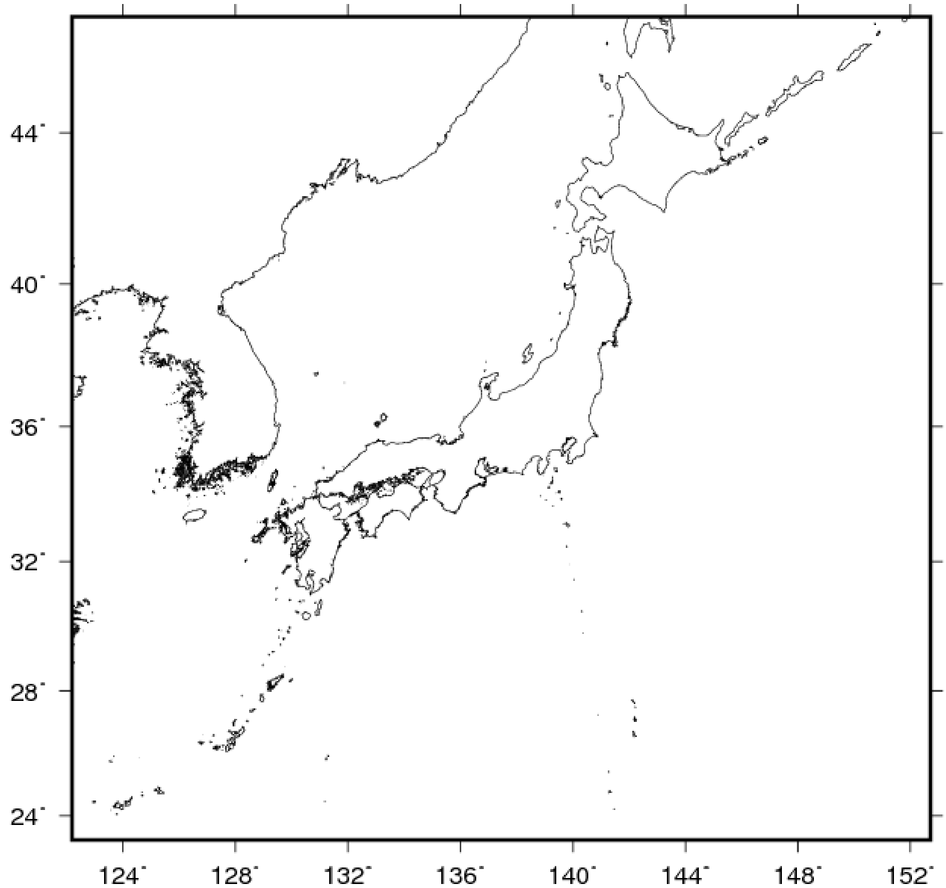

Figure 5. Domain of the AIR Earthquake Model for Japan

Generating the Stochastic Catalog

The AIR earthquake model captures the complex seismicity of Japan by generating events along known active crustal faults, large subduction zone interfaces, and background source zones. Through the use of smoothed background seismicity, the model captures the potential for earthquakes to occur where there has been little or no recorded historical seismic activity. The stochastic event generation process includes determination of the magnitude, location, rupture geometry and slip mechanism. The processes used to generate the stochastic event catalog have been significantly updated and enhanced.

The offering of catalogs in the AIR Earthquake Model for Japan has been updated to better represent AIR's view of seismicity for Japan. The 2021 release of the model includes findings from the 2019 HERP model, which has been used to develop the National Seismic Hazard maps.

- AIR generated the model's 10,000-year stochastic TD catalog using HERP's rates, scenarios and geometries, including their time-dependent rupture probabilities for all major subduction zones and active crustal faults.

Some notable features of the new stochastic event set(s) are as follows:

- Larger rupture interface areas for all major subduction zones which extend deeper and landward
- Larger magnitude (greater than M_W 9.0) scenarios for subduction interface earthquakes along Kuril Trench and Nankai Trough
- Special TD analysis for characteristic earthquakes associated with subduction along Nankai Trough since it poses significant risk. AIR adapts the HERP TD model for other sources.
- Higher rates for moderate to relatively large inter- and intra-slab earthquakes associated with subduction of Pacific and Philippine Sea plates (HERP Type 4 sources)
- Improved fault geometries and scenarios for active crustal sources, including multi-fault rupture scenarios along major faults (Itoigawa-Shizuoka-Kozosen fault zone)

Impact of the Event Generation Update

As part of the latest update to the National Seismic Hazard maps for Japan, Headquarters for Earthquake Research Promotion revised geometries and rates for a number of seismic sources. Increased hazard in coastal areas is related to broader zones of inter and intra-slab earthquakes as well as increased seismogenic depths for large subduction interface events.

The revision led to a large increase in industry losses. The impact of catalog update on loss is significant across all regions beyond the 100-year return period. The most significant increase occurs in Hokkaido, Tohoku, Kanto, and Kyushu regions. At shorter return periods, the stochastic catalog update decreases industry losses in some prefectures within Kansai, Chubu, and Chugoku regions.This is because of relatively lower rates for smaller Nankai interface scenarios, particularly the single Tokai.

For more information about the hazard component of the model, refer to the AIR Earthquake Model for Japan publication available on AIR Client Portal.

See Also
Generating the Stochastic Catalog

3.4 Local Intensity Calculation

The calculation of local shake intensity requires the following distinct components: ground motion prediction equations (GMPEs), site amplification equations, and soil maps. The calculation of liquefaction, tsunami, and fire-following earthquake intensities requires the utilization of the latest advancements in the respective peril modeling.

Modeling Ground Shaking

The model update includes the following changes to the local intensity calculation module.

Incorporation of the post-2011 Tohoku GMPEs

The updated suite of GMPEs implemented in the 2021 version of the AIR Earthquake Model for Japan is intended to represent the ground motion attenuation for a wide variety of tectonic settings found in the country. AIR scientists have incorporated the post-2011 Tohoku GMPEs (Zhao et al., 2016 and Abrahamson et al., 2015) for Japan and a corresponding logic tree weighting for calculating spectral accelerations at each site based on historic data analysis. This new approach to modeling the local intensity (magnitude-scaling relationship) is better suited for mega-thrust interface earthquakes (M_W>8).

While the pre-Tohoku attenuation relationships are still valid and incorporated in the model for earthquakes up to M_W 8, the post-Tohoku attenuation equations are better suited for a magnitude-scaling relationship for mega-earthquakes (M_W>8). To account for regional complexity unique to Japan, the GMPEs also include volcanic path and back arc effects.

Minor updates to the site amplification model

The updated AIR model for Japan uses a unique site amplification model. The methodology of site-amplification in the AIR Earthquake Model for Japan remains the same as in the previous release, with a major update to the set of new local and global GMPE relations as discussed previously. Site amplification factors for high and low frequencies have been conducted using the most recent attenuation relations for Japan (Kanno et al. (2006), Zhao et al. (2016), and Takahashi et al. (2004). Since the Japanese relations did not include non-linearity site response, the latest research results on the Next Generation of Attenuation, NGA2 models are included in the final site amplification calculation for Japan.

Table 2 presents the AIR list of attenuation equations and weighting factors for each earthquake type.

Table 2. Attenuation equations and weighting factors for Japan

GMPEs in **bold** typeface denote equations that are new to the model, developed post-Tohoku (2011).

Earthquake Type	Attenuation Equation	Weighting Factor	
Active Crustal Events	Takahashi et al. (2004)	0.15	100
	Kanno et al. (2006)	0.15	
	Cauzzi at al. (2014)	**0.2**	
	Zhao at al. (2016)	**0.5**	
Interface Subduction Zone Events	**Abrahamson at al. (2015)**	**0.3**	100
	Takahashi at al. (2004)	0.15	
	Kanno at al. (2006)	0.15	
	Zhao at al. (2016)	**0.4**	
Intra-Slab Subduction Zone Events	**Abrahamson at al. (2015)**	**0.2**	100
	Takahashi at al. (2004)	0.15	
	Kanno at al. (2006)	0.15	

Earthquake Type	Attenuation Equation	Weighting Factor	
	Zhao at al. (2016)	**0.5**	

Minor update to soil maps

Underlying the local intensity calculations are the highest-quality geological soil maps (see Soil and shear-wave velocity maps for Japan). For the 2021 release, AIR changed projection of maps in the AIR Earthquake Model for Japan from Tokyo Datum to JGD2000.

Table 3. Soil and shear-wave velocity maps for Japan

Region	Map's Origin	Resolution (m)
Entire Japan **Note**	Vs30 Map (7.5-arc-second) by Wakamatsu and Matsuoka (2014) The map is also used in the HERP model.	250
Tokyo, Yokohama, Kawasaki, Osaka, Kobe, Nagoya, Kyoto, Hiroshima, Sendai	High-resolution geologic maps by Japan Geological Survey (Quadrangle Map Series, scale 1:50,000)	50

Impact of the Local Intensity Calculation Update

The updated ground motion model incorporates the newer attenuation relationships (published post-Tohoku) which collectively are given a higher weighting in the updated model. The remaining weighting is divided among the pre-Tohoku attenuation relationships. The updated ground motion model matches the observed ground motions from the Tohoku earthquake better than the older model, especially at longer periods, i.e., greater or equal to Sa1.0 second.

In general, for the same catalog, the updated ground motion model leads to a reduction in hazard and subsequently losses across the entire model domain for all return periods. Although, the extent of hazard change is different for different intensities, e.g., for Sa0.3 second vs Sa3.0 seconds. Regions that experience the most significant reduction in hazard and, therefore, industry losses include Hokkaido, Northern Kansai, Chugoku, and Kyushu.

Losses are not affected by the changed projection of soil maps in the AIR Earthquake Model for Japan.

For more information, refer to the Local Intensity Calculation chapter of the model description, available on the AIR Client Portal.

See Also

Generating the Stochastic Catalog

3.5 Damage Estimation

The improvements to the AIR Earthquake Model for Japan include a substantial update to the vulnerability component. The most notable features are as follows.

Introduction of the intensity-based damage functions

At its core, the vulnerability framework has been updated from a Capacity Spectrum Method (CSM) based approach to an Intensity-Based Damage Function (IBDF) approach. While the Capacity Spectrum Method is a suitable framework for assessing the performance of a specific building at a single location, the performance of the CSM and IBDF approaches has been observed to be similar for the purposes of catastrophe risk modeling. This is due to the fact that the accuracy of the CSM approach applied to a known building can be overshadowed by the variability and uncertainty associated with a portfolio of spatially distributed buildings.

Review of the application of uniform vulnerability assessments

In addition to the shift in methodology, AIR engineers reviewed the application of uniform vulnerability assessment framework for deriving vulnerability classes from the chronology of historical building codes. The framework uses stringency of design codes (code levels) to represent the expected seismic behavior for each construction class. The assignment of vulnerability class to regions across Japan is based on different versions of the seismic design loading standards. Figure 6 shows the variation of code levels for all age bands implemented in the model for engineered buildings.

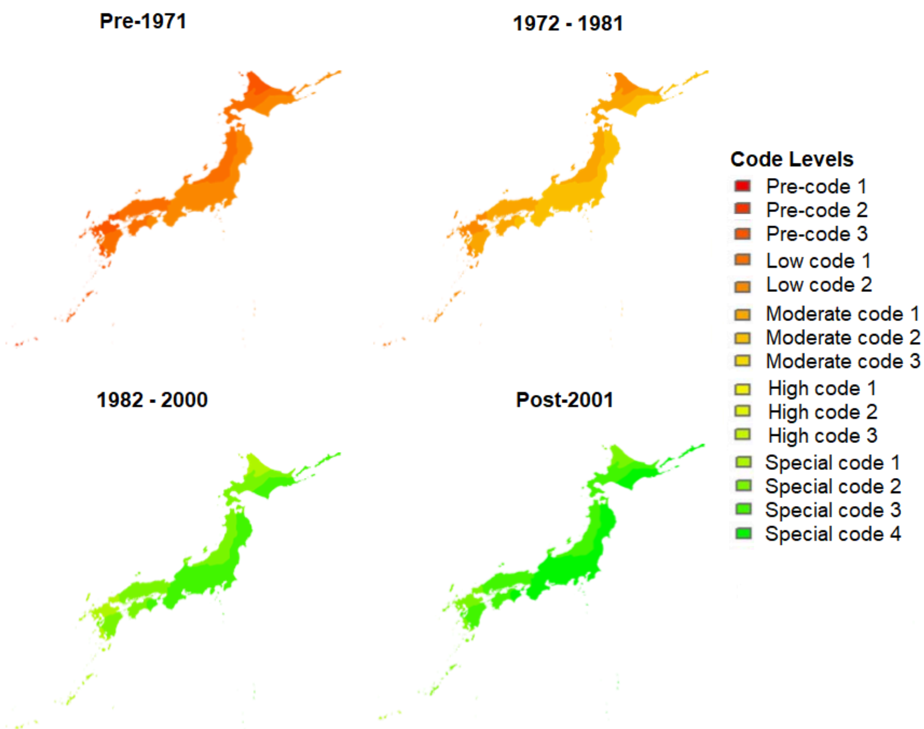

Figure 6. Spatial and temporal variation of vulnerability for engineered buildings in Japan, represented by code levels

In the maps, the cooler green colors denote areas of higher hazard and, therefore, more stringent design standards, resulting in buildings with lower vulnerability. Conversely, the locations in yellow and orange represent areas of moderate-to-low hazard, where the design requirements are less strict, resulting in buildings with higher vulnerability. Figure 6 shows that the seismic loading standards vary in the earliest age band, confirming AIR earthquake engineers' good understanding of regional variation of seismic hazard. The design requirements gradually became more and more stringent with the evolution of seismic design standard.

Accommodation of unknown primary building characteristics

When primary features, such as construction, occupancy, height, and age are unknown, the AIR earthquake models provide the vulnerability as a weighted average of known construction types. This weighted average for unknown vulnerability is calculated based on the distribution of building characteristics within a given geographical area. Furthermore, as more information is provided about a specific risk, the unknown vulnerability becomes more refined and conditioned on whatever known information is provided. The support of damage functions with unknown primary characteristics has been substantially improved and now is uniquely supported for all 47 prefectures of Japan.

Updates to vulnerability functions

To ensure reasonability and avoid overfitting to a single-event's data, AIR engineers validated and calibrated damage functions using various sources of data, including damage observations from historical events, claims data, and publications based on analytical and data-driven studies. Building damage functions were also compared with those developed by other researchers and organizations, such as GEM (global earthquake model) and PEER (Pacific Earthquake Engineering Research center).

Vulnerability improvements to other recently-updated AIR earthquake models were also applied to the earthquake model for Japan, especially as related to content damage (based on the analysis of claims from the 2010/2011 New Zealand earthquakes) and business interruption (BI).

Shake vulnerability of large industrial facilities (IFM) were re-evaluated in light of new data from recent Japan earthquakes. Damage data indicates that facilities in Japan performs better than peers in other high seismic countries or regions, such as New Zealand, California, Italy, and Turkey.

Updates to the Personal Accident (PA) module

Personal accident modeling in the AIR Earthquake Model for Japan includes these new features:

- Shake casualty is modeled as a function of building damage, considering the likelihood of structural collapse with enhanced injury rate functions that are consistent with published literature.
- Tsunami casualty is modeled through enhanced injury rate functions in conjunction with the consideration of uncertainty in evacuation processes and wave arrival times.
- Personal accident module is validated and calibrated against historical data and client feedback.

Supported Risk Types

The 2021 version of the AIR Earthquake Model for Japan can estimate earthquake damage to various types of specialized risks, including builder's risk (buildings under construction), marine hull, and marine cargo as well as aviation risk and railways.

Builder's risk is calculated by varying replacement value and vulnerability of the building under construction over the lifespan of the construction project. Most construction projects can be divided into four phases. The builder's risk ("construction all risks/erection all risks"; CAR/EAR) line of business determines potential losses resulting from earthquake damage to buildings while they are still under construction. It provides an estimate of average loss for the entire duration of construction using occupancies 381-384. Builder's risk can be applied to all supported 100-series construction classes, for all height bands. It supports all conventional residential, commercial, and industrial occupancy classes but does not apply to large complex industrial facilities (400-series occupancy classes).

In the model, the marine hull risk type includes the hull and machinery of a vessel. This risk can be modeled at a specific port location and for a particular status of port risk, builder's risk, or repair risk. The status that is used depends on whether the vessel is at port (loading, unloading cargo, or undergoing regular maintenance) or if it is under construction. In the model, damage to marine hulls can be caused by ground shaking, liquefaction, and tsunami. In estimating earthquake-related damage, three different conditions are considered for marine hulls; namely, "at port", "at repair", and "under construction" (i.e., builder's risk). These three conditions for marine hull are represented by occupancy types 354, 314 and 381, respectively. Marine hull damage functions are developed using worldwide resources (mainly from Japan), but are applicable to other regions, including Japan.

Marine cargo covered in the model includes general containers, heavy cargo, refrigerated containers, dry bulk cargo, liquid bulk cargo, and carpool. In the model, damage to these risks is estimated for the ground shaking, tsunami and liquefaction perils. Note that marine cargo is modeled as an independent risk type using construction types 270-276, and the total value is entered under Coverage A. Furthermore, the model supports cargo at inland transit warehouses using construction code 259. These risks are modeled as contents inside warehouses and several occupancy codes are used to differentiate the type of cargo.

The model also extended support for specialized marine risks (4-digit occupancy types) in Touchstone.

Impact of the Damage Estimation Update

The most significant update to the vulnerability component of the AIR Earthquake Model for Japan is a shift in the damage assessment framework from the Capacity Spectrum Method to Intensity-Based Damage Functions (IBDF). In the CSM framework, roof drifts are estimated from a capacity curve, and then drift-based damage functions are used to calculate a mean damage ratio. In the updated framework, damage ratios are calculated as a function of ground shaking intensity. The IBDF framework brings the vulnerability component of the AIR Earthquake Model for Japan into consistency with other recently released AIR earthquake models, namely, for the United States, New Zealand, and Australia.

The vulnerability updates in the earthquake model for Japan generally result in the following trends of loss change (hazard and exposure held constant).

- Building loss reduction in low-to-moderate level of ground motion and increase in moderate-to-high level of ground motions
- Content loss reduction
- BI loss increase
- LIF loss decrease

Because of the vulnerability module update, Japan industry loss results in a reduction of around 20% at AAL (average annual loss). Industry AALs for most of prefectures are reduced,while AALs for a few prefectures are increased. At the 100-year return period, some prefectures’ losses increased while some decreased, resulting in almost no change at the country level. At the 250-year return period, Japan industry loss increased by about 10%. Majority prefectures' losses increased, while some prefectures' losses decreased.

The impacts of vulnerability updates are quantified using AIR's Industry Exposure Database for Japan. While the vulnerability module switches from old to new, other components are held constant. Only building and contents values are included in the Industry Exposure Database. Therefore, the impact of the BI damage function updates cannot be quantified in this study. The impact of the vulnerability module update on a portfolio can be different from above, depending on its risk profile.

For more information, refer to the Damage Estimation chapter of the model description, available on the AIR Client Portal.

See Also
Generating the Stochastic Catalog

3.6 Treatment of Uncertainty in the Model

Accounting for uncertainties in earthquake loss analysis plays a critical role in catastrophe risk modeling in general, and in AIR models in particular. In the AIR Earthquake Model for Japan, robust and comprehensive approaches are used to account for uncertainty in hazard, vulnerability, and loss estimates. Highlights include:

- Robust treatment of uncertainties in underlying data used for calculating rupture probabilities as well as earthquake scenarios for active faults, subduction, and background seismic sources
- Explicit and enhanced treatment of intra-event and inter-event ground motion uncertainty
- Updated secondary distributions using millions of claims (local and global)

For more information, refer to the Accounting for Uncertainty chapter of the model description, available on the AIR Client Portal.

3.7 Sub-Peril Updates and Additions

The updated AIR Earthquake Model for Japan in the 2021 release of Touchstone includes the explicit modeling of the liquefaction, tsunami, and fire following earthquake sub-perils.

Liquefaction

The liquefaction module of the AIR Earthquake Model for Japan incorporates detailed geological and ground water data to inform an assessment of liquefaction susceptibility. Using a given earthquake's physical parameters and considering the behavior of characteristic soil profiles, the updated liquefaction likelihood functions vary by geological zones. These advancements are leveraged from the recently released AIR Earthquake Model for New Zealand (2019).

The performance of the model's liquefaction module is validated against observed liquefaction features and damage from historical earthquakes in Japan. The updated AIR Earthquake Model for Japan captures the liquefaction severity and extent of damage closer to reality. When validated, the updated liquefaction module compares very well in terms of liquefaction coverage and loss.

Tsunami

AIR uses fully numerical models to simulate the generation, propagation and run-up of tsunami waves for all tsunamigenic earthquakes in the stochastic catalog, along the entire Japanese coastline, including all of its islands. The model has been extensively validated using observations from historic events, such as the 2011 Tohoku earthquake. The model incorporates up-to-date subduction interface and fault geometries and uses the latest high-resolution bathymetric and digital elevation data-sets that include coastal levees, dikes and sea-walls, including those built in the aftermath of the Tohoku earthquake to estimate coastal inundation depth and flow velocities. The contribution of astronomical tides and surface roughness is also considered in the calculations. By identifying nearby ports and coastal industrial centers/facilities, the potential likelihood for the presence of large, damaging debris is also estimated. These variables (inundation depth, flow velocity, and debris factor) are accounted for in calculating local tsunami intensity, which are then used to carry out damage estimation.

Fire Following Earthquakes

AIR's FFE framework consists of modeling the built environment, modeling ground shake induced fire ignitions, modeling fire spreading at city block level and regional level, as well as modeling the fire suppression at regional level. In the updated FFE module, AIR engineers updated the fire ignition rate by incorporating the latest research and Japan specific data.

Impact of sub-peril updates on modeled loss estimates

Sub-peril contributions to ground-up AAL, by prefecture, show the percentages of modeled average annual ground-up losses contributed by tsunami and fire following earthquake, respectively.

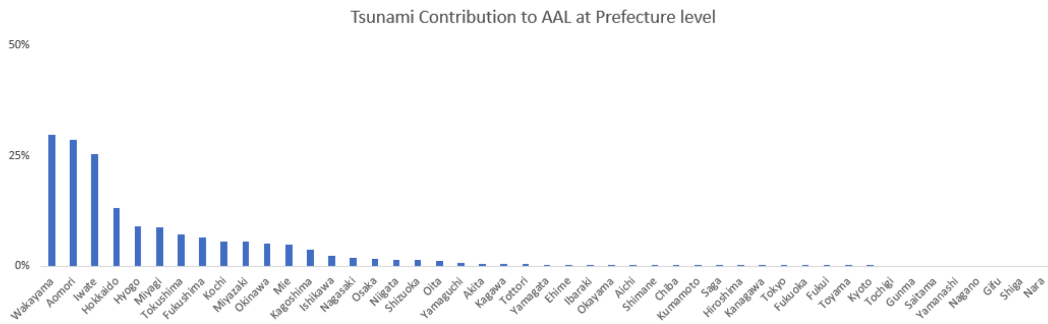

Figure 7. Tsunami contribution to Prefecture AAL

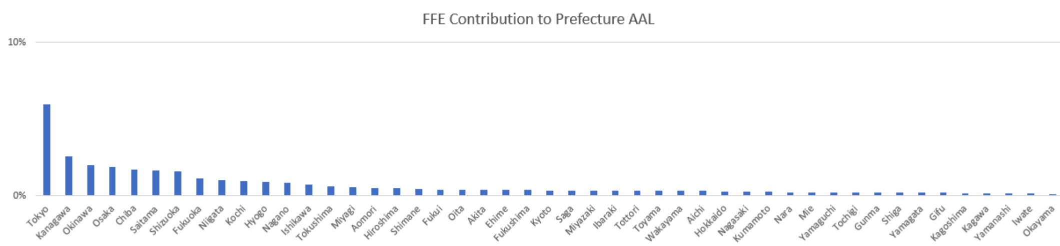

Figure 8. FFE contribution to Prefecture AAL

3.8 General Impact of Model Updates on Loss Estimates

Both hazard and vulnerability components have been modified with the summer 2021 release of the AIR Earthquake Model for Japan. The hazard component—including the seismicity and ground motion models—is updated in response to a significant change in the underlying data for the seismicity model and updated view of the ground motion model in the National Seismic Hazard maps published by HERP in 2019. For additional information regarding seismic hazard, refer to the model description and these white papers, available on AIR AIR Client Portal:

- *Tohoku, the Great East Japan Earthquake, 10 Years on*
- *A Great Earthquake's Aftershocks Can Occur Years Afterwards*
- *How the View of Megathrust Earthquake Hazard in Japan Changed after Tohoku*

On the country level, Japan's industry AAL in Touchstone 2021 is almost the same as in 2020 (Touchstone 8.0), but loss changes show different trends at different return periods. Losses decrease at short return periods, up to 20-year. This is primarily driven by vulnerability module update. Losses significantly increase between the 50- and 250-year return periods, which is driven by the catalog update. The loss changes again reverse at the tail, which is primarily dictated by the ground motion model updates. The overall patterns of loss change of individual lines of business (LOB) are alike. However, the magnitudes of changes vary significantly across LOBs. Such a variation is caused by the construction and occupancy mix differences across LOBs.

Considering the fact that earthquake hazard in Japan depends on a region, the industry loss changes at prefecture level can deviate greatly from those at the country level. Take Aichi and Chiba prefectures as an example. Aichi prefecture is part of the Chubu region, where the ground motion model updates result in a greater reduction than other regions. Chiba prefecture is part of the Kanto region, where the loss reduction caused by the ground motion model update is less significant, but the catalog update impacted and significantly elevated the earthquake risk.

The overall impact of the model updates on loss estimates from the previous version of Touchstone (2020) to the current version, Touchstone 2021 can be found in a separate publication, available in HTML format at the following links:

- Gross Insurable Aggregate: Shake
- Gross Insurable Occurrence: Shake
- Gross Insurable Aggregate: All Perils
- Gross Insurable Occurrence: All Perils
- Analysis Settings

The tables in the document show the percentage changes in gross insurable occurrence and aggregate loss estimates for ground-shaking (including liquefaction) and all perils (i.e., ground shaking, liquefaction, tsunami, and fires following earthquakes) combined, by line of business, for Japan as a whole and 47 prefectures. The loss changes do not include demand surge.

To create the exhibits, AIR ran its 10,000-year time-dependent catalogs in the previous and updated versions of the AIR Earthquake Model for Japan. The changes are calculated as Touchstone 9.0 Loss / Touchstone 8.0 Loss - 1. The changes indicate the combined effects of all changes, including updates to the catalog, ground motion model, and vulnerability module. The exposure is held constant in these analyses. The Touchstone analysis options can be found in "Analysis Settings", following the above link.

Note that caution should be exercised before relating the industry loss changes shown here to a particular portfolio. The changes to individual books may deviate from those presented in this document to the extent that their spatial distribution and construction/occupancy mix deviate from industry averages.

4 The AIR Typhoon Model for Japan

4.1 Overview of Model Updates and Changes

The AIR Typhoon Model for Japan includes updates to the historical event set and vulnerability module. These improvements are listed below, and details are presented in the following sections.

- Four new events added to the historical event set
- Updated wind damage functions, including unknown
- Updated regional variation for wind vulnerability

4.2 Catalogs and Event Sets

Stochastic Catalog

While the number of events in stochastic catalog for the AIR Northwest Pacific basinwide typhoon model remains unchanged (more than 293,000 events), enhancements to the AIR Typhoon Model for Japan's vulnerability module have increased the number of events that produce losses in Japan. The updated model includes over 83,000 loss-causing[3] events, while the previous version included approximately 79,000 events.

Event IDs have not changed.

Historical Event Set

The updated historical event set includes 21 typhoon events. Four events are new:

- 2018 Typhoon Jebi (wind and storm surge)
- 2018 Typhoon Trami (wind and storm surge)
- 2019 Typhoon Faxai (wind and storm surge)
- 2019 Typhoon Hagibis (wind, precipitation flood and storm surge)

Table 4. Historical events available in the AIR Typhoon Model for Japan

Year	Event Name
1947	Kathleen

[3] Loss-causing events are defined as events that cause at least USD 40,000 or JPY 4.35 million in losses from a ground-up insurable perspective. The catalog includes >90,000 events that cause **any** loss (no threshold).

Year	Event Name
1958	Ida
1959	Vera
1961	Nancy
1982	Bess
1991	Mireille
1993	Yancy
1998	Vicki
1999	Bart
2004	Chaba
2004	Songda
2004	Meari
2004	Tokage
2005	Nabi
2006	Shanshan
2011	Talas
2015	Etau
2018	Jebi
2018	Trami
2019	Faxai
2019	Hagibis

4.3 Vulnerability

Enhancements to the vulnerability component of the AIR Typhoon Model for Japan include updated wind damage functions and updated regional variability for wind vulnerability.

Wind Damage Functions

AIR has developed new wind damage functions (buildings and contents), including both old and new fire codes, for the traditional lines of business. These updates incorporate the findings of an AIR study of claims data from 2018 and 2019 typhoons, as well as client feedback.

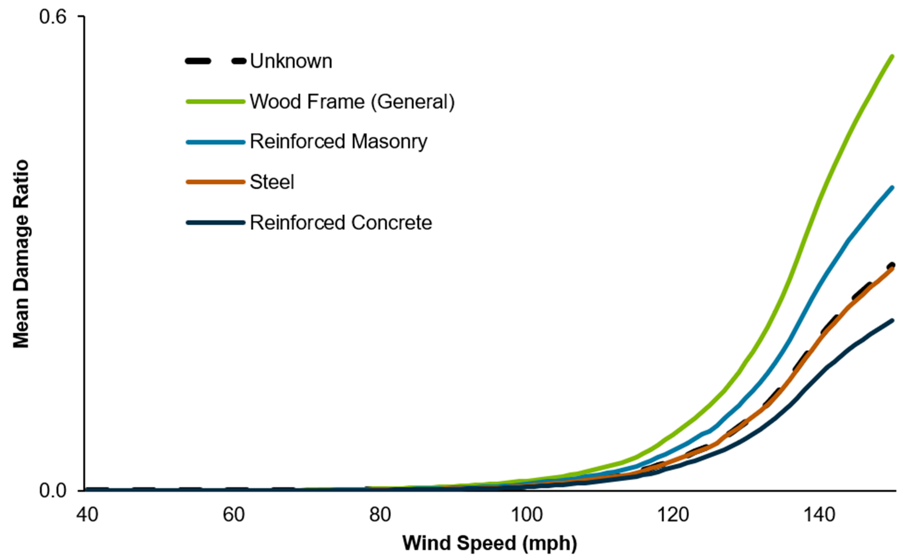

Figure 9. Example of updated wind damage functions for different construction classes
Apartment building, unknown height

Secondary Risk Characteristics

The model supports five secondary risk characteristics (SRCs) for flood and storm surge associated with typhoons:

Custom elevation	The elevation of the local ground surface can be entered for this feature, which will override the underlying modeled digital terrain elevation. A higher surface elevation can significantly reduce flood damage and loss.
Custom standard of protection	For buildings that are protected by a custom flood protection system such as a levee or flood wall, this feature provides the height of the custom flood protection system, above the ground surface.
First floor height	The height of the first floor, above the ground surface, can be entered for all residential, commercial, and small industrial buildings. A raised first floor significantly reduces a building's vulnerability to flood damage.
Floor of interest	In cases where the entire building is not covered under the insurance policy, the floor of interest (including a basement) can be entered with a numerical input. Replacement values (building, contents, and business interruption) and policy terms will be

applied for the floor of interest only. This is supported for all residential and commercial buildings.

Foundation type The type of building foundation has a significant impact on its flood vulnerability. Basements can greatly increase the susceptibility to flood/surge damage at low water depths. While concrete slab foundations usually suffer the less damage, the structure sitting on top of a slab may suffer considerable damage. The foundation type SRC is available for all residential and commercial buildings.

Details regarding secondary risk characteristics for flood and surge associated with typhoons are presented in the publication *Secondary Risk Characteristics for AIR Flood Perils*, which is available on the AIR Client Portal.

4.4 General Impact of Model Updates on Loss Estimates

The general impact of model updates on gross insurable occurrence and aggregate losses is presented in tables available through the links below. These loss changes represent the percentage change in loss estimates calculated by the previous version of Touchstone [2020 (8.0)] as compared with those calculated by the current version of Touchstone [2021 (9.0)] for the model domain (Japan) and each prefecture. These losses do not include demand surge.

For 2021 AIR has completed a major overhaul of the AIR Industry Exposure Database for Japan. To obtain the loss changes, AIR typically runs the model with the full industry exposure database. However, given the 125-m resolution of the database, coupled with the high model resolution and the number of events, using the entire industry exposure database was not feasible. Instead, AIR ran a subset of the industry exposure database consisting of a random sample of 10% of the exposure database, without any prefecture or line of business bias.

As illustrated in the data tables, for the wind peril, there is a general increase in losses for all lines of business, with the exception of auto. This increase is due to the vulnerability updates as well as the inclusion of additional loss-causing events. For flood and storm surge, there is a small increase in losses due to the additional loss-causing events. Users may also see a change in wind, precipitation flood and storm surge losses due to Touchstone updates to administrative areas and disaggregation (if aggregated exposure is used).

The following loss change tables are available:

- Gross Insurable Occurrence Loss Changes
  - Wind
  - Flood and storm surge
  - All perils (wind, flood, and storm surge combined)
- Gross Insurable Aggregate Loss Changes
  - Wind
  - Flood and storm surge
  - All perils (wind, flood, and storm surge combined)
- Analysis Settings

Caution should be exercised before relating the industry changes shown here to a particular portfolio. The changes to individual books of business may deviate from the losses represented here to the extent that their exposure spatial distribution and construction/occupancy mix deviate from industry averages.

5 Event ID Updates

The following table indicates changed event IDs in the updated models for Touchstone in 2020.

Table 5. Stochastic Event ID Updates

AIR Model	Stochastic Event IDs
AIR Typhoon Model for Japan	No change[4]
AIR Terrorism Model	No change
AIR Earthquake Model for Japan	All events IDs are new.

[4] Additional events have been added, however previously existing event IDs have not changed.

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 incidents. Insurance, reinsurance, financial, corporate, and government clients rely on AIR's advanced science, software, and consulting services for catastrophe risk management, insurance-linked securities, longevity modeling, 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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