Data Interchange Formats for Generic Earthquake Models

Originally prepared for

Global Earthquake Model

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Current version offered for use with any generic earthquake model

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1 Dec 2014

SPA Project 10013-01-09-05

Revision history

Ver.	Date	Comments
1.0	2 Mar 2009	Initial draft for Canberra meeting
2.0	4 May 2009	Revisions following review and commentary by OpenSHA, PAGER, and EUCENTRE staff. Revises HAZ01C. Adds EXP02, HAZ03, HAZ04, DMG01, DMG02, LOS01, LOS02, LOS03, LOS04, FRA02. Adds structure type & damage standards.
2.2	22 May 2011	Add VUL07 draft DIF for encoding casualty rates as a function of asset type and damage state.
3	1 Dec 2014	Add RSP01 draft DIF for encoded a matrix of structural response vectors for an asset subjected to 2D or 3D nonlinear dynamic structural analysis. Repurposed report for use with any generic earthquake model, (denoted by GEM*).

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Porter, K.A. and C.R. Scawthorn, 2014. *Data Interchange Formats for Generic Earthquake Models*, *ver 3.* SPA Risk LLC, Denver CO.

EXECUTIVE SUMMARY

This document was initially produced at the request of the executive director of the Global Earthquake Model (GEM) to document data interchanges formats and labeling standards for use in GEM1, the initial software platform of GEM. The executive director who requested it departed around the time of delivery of the 1st version. We recommended that the document be implemented as a living document, subject to enhancement over time. GEM ultimately took no action to adopt that recommendation, instead developing an XML-like standard. The present document offers standards that are adapted more for the convenience of the engineer who uses spreadsheets, database tables, and text files. While we gratefully acknowledge the support of GEM in sponsoring the initial version of this document, we continue to find communication value outside of GEM in these standards and in new, similar ones that we have added since the initial version. We have therefore undertaken to continue revising and publishing this document for general use, and have renamed the post-GEM version from *Data Interchange Formats for the Global Earthquake Model* to *Data Interchange Formats for Generic Earthquake Models*. We use the acronym GEM* to refer to generic earthquake models, the asterisk intended to call the reader's attention to the fact that we don't mean the Global Earthquake Model (GEM).

Approximately two dozen data interchange formats and 10 terminology and labeling standards are proposed and listed in Tables E1 and E2. DIFs for exposure (i.e., values at risk), hazard output, structural response, fragility, vulnerability, damage and loss are provided, covering single assets and portfolios of assets, for both deterministic and probabilistic risk analysis. Figure E1 provides a schematic overview of seismic risk modeling and lists the DIFs related to each stage. The figure is read from left to right: risk modeling begins by defining the assets at risks, referred to here as the exposure. DIFs related to exposure are labeled EXP01 and EXP02, and are summarized in Table E1. The exposure information is combined with a hazard model to produce hazard output (e.g., shaking intensity by asset in an event set). DIFs related to hazard output are labeled HAZ01 through HAZ04, whose meaning is summarized in Figure E1 and Table E1.

Site hazard and asset information can be input to a damage model that includes fragility functions to estimate damage. (As used here, damage refers to degradation of valuable attributes such as cracks in walls). The structural response DIF is labeled RSP01. Fragility-related DIFs are labeled FRA01 and FRA02, while DIFs for damage outputs are labeled DMG01 and DMG02. Site hazard and asset information can also be input to a loss model that includes vulnerability functions to estimate loss. (As used here, loss refers to financial cost to reverse degradation, e.g., repair cost, or non-monetary human or operational losses such as casualties and loss of use, i.e., "dollars, deaths, and downtime.") Vulnerability DIFs are labeled VUL01 through VUL07, and loss-output DIFs are labeled LOS01 through LOS04, again summarized in the figure and Table E1, and detailed in the report.

Examples are provided of each DIF, and in each case, each parameter is defined and explained, assigned a variable type (e.g., integer, text string, double-precision floating point, etc.) and specified as to constraints (e.g., probabilities between 0 and 1). The proposed data standards draw on OpenSHA, OpenRisk, EMS-98, PAGER, HAZUS-MH, the World Housing Encyclopedia, other common risk methodologies and resources, and our own professional and academic experience in risk modeling. The DIFs are human-readable, plain-text flat files (commas-and-quotes). The emphasis in these DIFs is on simplicity and universality over storage efficiency and elegance. It is not intended that these DIFs represent a complete or exhaustive set of what a global earthquake model will require. We therefore outline a suggested wiki-based system to disseminate, maintain, update, and supplement the DIFs and other standards proposed here and by others.

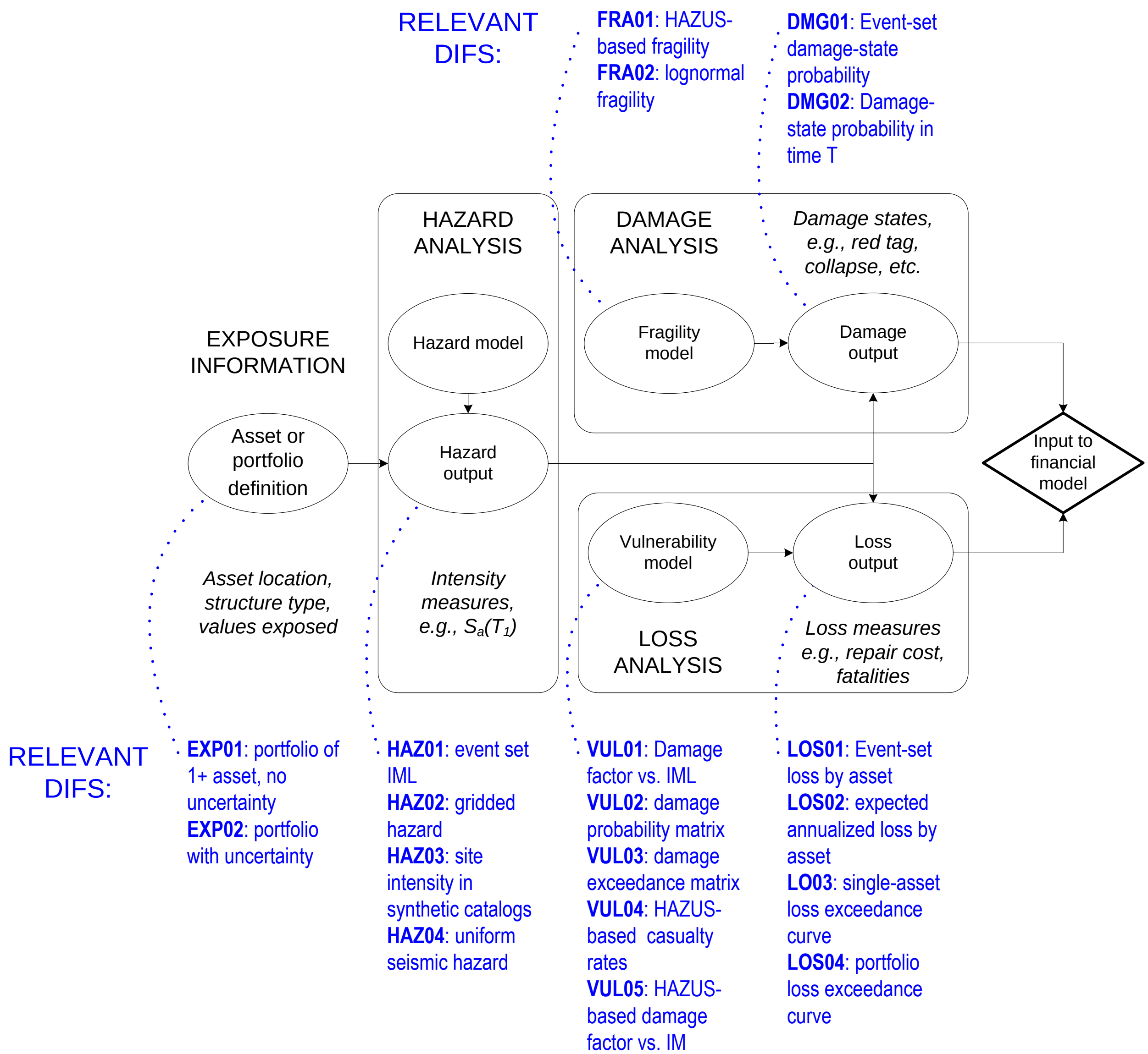

Figure E1: The risk-modeling process and DIFs related to each stage

Table E1. Summary list of risk-related DIFs

DIF	Description	Site (S) or Portfolio (P)?	Deterministic (D) or probabilistic (P)?
Exposure DIFs (Section 4)			
EXP01	Portfolio of point assets	Either	D
EXP02	Portfolio of point assets with uncertainty	Either	P
Hazard-output DIFs (Section 5)			
HAZ01A	Event set: probabilistic ground motion by earthquake rupture forecast, ground-motion prediction equation, IMT, source, rupture, site	Either	Either
HAZ01B	Source & rupture rate and magnitude for HAZ01A	Either	Either
HAZ01C	Logic tree weights for HAZ01A	Either	Either
HAZ02	Gridded hazard	Mostly S	Mostly P
HAZ03	Site intensity for Monte Carlo simulation	Either	P
HAZ04	Uniform seismic hazard	Mostly S	D
Structural response DIFs (Section 6)			
RSP01	Structural response for 1 building and 1 IML	S	D
Damage-analysis DIFs (Section 7)			
FRA01	HAZUS-based fragility functions	Either	Either
FRA02	Generic lognormal fragility functions	Either	D
DMG01	Event-set damage-state probabilities by asset	Either	Either
DMG02	Damage probability to point assets in time T	Either	P
Loss-analysis DIFs (Section 8)			
VUL01A	Mean damage factor versus intensity measure	Either	D
VUL01B	Coefficient of variation of damage factor vs. intensity for VUL01A	Either	P
VUL02	Damage probability matrix	Either	P
VUL03	Damage exceedance matrix	Either	P
VUL04	HAZUS-based casualty rate vs intensity	Either	D
VUL05	HAZUS-based mean damage factor vs intensity	Either	D
VUL06	HAZUS-based mean & COV damage factor	Either	D
VUL07	Casualty rate vs damage state and building type	Either	D
LOS01	Event-set loss estimate by asset	Either	Either
LOS02	Expected annualized loss estimate by asset	Either	P
LOS03	Single-asset loss-exceedance curve	S	P
LOS04	Portfolio loss-exceedance curve	P	P

Table E2. Summary of proposed taxonomies and labeling standards

Standard	**Description**
STD01	Earthquake rupture forecasts
STD02	Excitation types a.k.a. intensity measure types
STD03	Ground-motion prediction equations
STD04	ATC-13 facility class taxonomy
STD05	FEMA 154 structure types
STD06	EMS-98 structure types
STD07	PAGER structure type taxonomy ver 1.1 (FEMA + EMS98 + WHE + extras)
STD08	HAZUS-MH structure type taxonomy
STD09	Loss measures
STD10	Damage states

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1 INTRODUCTION

1.1 BACKGROUND

The Global Earthquake Model (GEM) was intended to be an open-source system of authoritative analytical models, software, and data for researchers and professionals to perform earthquake hazard and risk analysis for single assets, portfolios of assets, or societal-level risk located virtually anywhere in the world. Current software and other tools (GSHAP, HAZUS, EXTREMUM, OpenSHA, OpenRisk, PAGER, EQRM, Selena, etc.,) offer many of these features. GEM software attempted to integrate them into proof-of-concept or prototype software. As used henceforth however, GEM* refers to any generic earthquake model. An issue for successful GEM* development is to create a set of data interchange formats (DIFs), which are standards to facilitate interaction with existing and developing hazard and risk software.

1.2 SCOPE OF WORK

To address the above issue, this report presents DIFs that are intended to facilitate interchange between GEM* software packages, especially for interaction between components related to risk, as opposed to hazard. A parallel project by the US Geological Survey was intended to compile hazard-related DIFs. The DIFs presented here take the form of human-readable text files.

The development of such DIFs is a significant task, and will evolve as a GEM* develops, but it is necessary to develop standards for use with GEM* tools and procedures for their further development. DIFs developed here will address exposure and risk-related information, i.e., standards for defining the assets exposed to risk and the results of risk calculations: assets locations, values exposed, characteristics related to seismic vulnerability, fragility, earthquake damage, and loss. We have collaborated with developers of hazard-related DIFs, especially Ned Field and Dave Wald of the US Geological Survey, primarily to address outputs of a seismic hazard calculation that can be used as inputs to loss calculations.

Not included are intermediate hazard-related DIFs, e.g., fault locations, seismicity information, earthquake rupture forecasts, and ground-motion prediction equations (we believe these were to be addressed separately by the USGS for GEM). It is expected that the companion DIF proposal by the USGS will either detail or include by reference a number of hazard-related DIFs associated with HAZUS-MH (NIBS and FEMA 2003), OpenSHA (www.opensha.org) and the USGS's ShakeMap, ShakeCast, and PAGER products.

Considering GEM*'s need for DIFs early in its development, we have surveyed current practices and capacity for new technology in regard to three classes of DIFs: (1) exposure information: the location, quantity, and other attributes of social and built assets exposed to seismic risk; (2) hazard information: primarily output information such as the probabilistic or deterministic shaking or other seismic effects at a single asset or a portfolio of asset (we understand however that others will be developing hazard-related DIFs); and (3) risk information: either input information such as data about the vulnerability of assets at risk, or output information such as the deterministic or probabilistic loss to a single asset or a portfolio of assets.

Our findings have been assessed within a unifying DIF format. We identified those current DIFs that most relevant, acceptable, and adaptable for GEM*'s purposes. In some cases we proposed modifications to the original developer of the DIF, in consultation with the developer. To the extent that GEM*-required DIFs do not exist or are unsuitable, we have proposed new DIFs to meet GEM's needs.

The DIFs discussed here are not exhaustive, but should provide a useful foundation for data interchange for GEM* developers and users. We focus on DIFs related to exposure, property damage, and ground-up repair cost in buildings, plus selected socioeconomic issues, e.g., human casualties and repair duration ("dollars, deaths, and downtime"). We do not address financial structure of risk such as insurance limits, deductibles, pro-rate shares, reinstatement, parametric catastrophe triggers, etc.

It should be noted that the DIFs ultimately required for GEM* depend on the GEM* software architecture and vice versa. Writing DIFs is an iterative process, and only limited iteration is possible here. We proposed draft DIFs, delivered them for discussion at the March 2009 GEM meeting and Canberra, and revised them following discussions with various GEM contributors. In addition, we have proposed in outline form a wiki-based system to enhance and supplement GEM DIFs and other standards. The proposal was not adopted by GEM, so to accommodate our own communication needs, we have repurposed this report for use by any generic earthquake model, denoted here by GEM*, and not to be confused with the Global Earthquake Model, although of course the latter is welcome to the use of this document.

1.3 ORGANIZATION OF REPORT

This section has introduced the problem to be addressed and presented the scope of work. Section 2 contains a brief plan for disseminating, revising and supplementing these and other GEM* standards and data interchange formats. Section 3 presents a number of standard taxonomies (of structure types, damage measures, loss measures, etc.) referred to by the DIFs. DIFs with samples are then presented in the subsequent sections: Section 4 presents those related to exposure, Section 5 to hazard output, Section 6 to damage analysis (fragility and damage output), and Section 7 to loss analysis (vulnerability and loss output). Conclusions are presented in Section 8. References are presented in Section 9. An appendix contains brief notes of review commentary and resulting revisions.

2 A SYSTEM FOR REVISING AND SUPPLEMENTING DIFS

It is understood that the current DIFs and other standards are not exhaustive or final. We recommended that GEM institute a system for disseminating, revising and supplementing these DIFs and other hazard-related DIFs currently under development by others. We refer to this as a curatorial system, which would include the following attributes:

- DIF and standards to be served on a wiki to GEM users and developers.
- People who access the wiki classified in 3 groups: (1) read-only by non-registered visitors, (2) read and edit with proposed modifications by registered GEM users and developers who have already participated in GEM activities or register by email or a web form; and (3) post approved standards by GEM employees or other GEM curator.
- Curators could be GEM employees or outside co-developer appointed by GEM leadership. We offer no recommendation of how the curator for each DIF or group of DIFs should be selected, other than that for each DIF or group of DIFs, it might be wise to assign 2 curators: a domain expert and an IT expert, both personally involved in using or programming to the DIF.
- Wiki organized similar to this report, e.g., sections and subsections related to (1) objectives and use; (2) taxonomy and definitions; (3) exposure; (4) earthquake rupture forecasts; (5) ground-motion prediction equations; (6) hazard output to risk models; (7) fragility, site and portfolio damage; (8) vulnerability, site and portfolio loss; (9) references; (10) appendices
- Within each DIF section, one subsection for each DIF. Each subsection to contain brief explanatory text on the purpose and content of the DIF, the generic layout of the DIF, and an example. It might be wise to include a section for additional discussion of the DIF and listing registered GEM users and developers who use or program to the DIF or standard, and for identifying the DIF curator(s).
- Each DIF labeled for convenience with some short name such as those proposed here, e.g., AAAnn, where AAA is a 3-letter code to suggest the general domain of the DIF,

and nn is a 2-digit number to distinguish between DIFs in the same domain. For example, AAA could be limited to “EXP” for information about people or property exposed to seismic risk; “ERF” for a DIF related to earthquake rupture forecasts, “GMP” for a ground-motion prediction equation, “HAZ” for deterministic or probabilistic shaking maps and related information; “FRA” for fragility functions (relating excitation to probability of exceeding a limit state); “DMG” for damage results; “VUL” for vulnerability functions (related excitation to degree of loss); and “LOS” for loss results. Taxonomies and labeling conventions could use the prefix “STD” as used here.

- Revisions of the same DIF or standard could be identified with a version number, perhaps in the format X.Y, where X.0 is an “official” release version authorized by a responsible GEM curator, and X.1, X.2, etc. indicating a proposed revision not yet “official,” a higher value of Y indicates a later proposed revision, and a higher value of X indicates a later official version. Decisions about when and how to accept new “official” versions could initially be made on an ad-hoc basis, perhaps through correspondence between the GEM curator and one or more GEM users or developers who commonly use or program code involving the relevant DIF. No formal procedure is proposed here.

3 STANDARD TAXONOMIES AND DEFINITIONS

This chapter contains a set of proposed standard definitions, labels, and taxonomies collected from various existing loss models. They address labels for:

- Earthquake rupture forecasts (Table 1)
- Intensity measures (Table 2)
- Ground-motion prediction equations (Table 3)
- Structure types: ATC-13 (Table 4), FEMA 154 (Table 5), EMS-98 (Table 6), PAGER (Table 7) and HAZUS-MH (Table 8)
- Loss measures (Table 9)
- Damage measures (Table 10)

Table 1. STD01: initial list of earthquake rupture forecasts

Label	Meaning
FLOAT1	Floating Poisson Fault earthquake rupture forecast
POINT	Point Source earthquake rupture forecast
POINT2	Point 2 Mult Vertical SS Fault earthquake rupture forecast
POISS1	Poisson Fault earthquake rupture forecast
UCERF1	WGCEP UCERF 1.0 (2005)
UCERF2	WGCEP UCERF 2.0 (2008)
USGS/CGS1996	USGS/CGS 1996 Adj. Cal earthquake rupture forecast
USGS/CGS2002	USGS/CGS 2002 Adj. Cal earthquake rupture forecast
USGS2002	NSHMP, Frankel et al. (2002)

Table 2. STD02: initial list of intensity measure types (IMTs) and units

Label	Meaning
EMS98	European Macroseismic Scale 1998
JMA	Japan Meteorological Agency intensity
MMI	Modified Mercalli Intensity
PGA	geometric-mean horizontal peak ground acceleration, g
PGAMD	max-direction horizontal peak ground acceleration, g
PGD	geometric-mean horizontal peak ground displacement, cm
PGDMD	ditto, maximum-direction
PGV	geometric-mean horizontal peak ground velocity, cm/sec
PGVMD	ditto, maximum-direction
SAxy	geometric-mean 5%-damped spectral acceleration response at x.y sec period, g (eg., SA02, SA03, SA10, SA30)
SAxymd	ditto, maximum-direction
SDxy	geometric-mean 5%-damped spectral displacement response at x.y sec period, cm
SDxymd	ditto, maximum-direction

Table 3. STD03: initial list of ground-motion prediction equation identifiers

Label	Meaning
A2000	Abrahamson (2000)
AS1997	Abrahamson and Silva (1997)
BA2006	Boore and Atkinson (2006)
BA2008	Boore and Atkinson (2008)
BC2004	Bazzurro and Cornell (2004)
BJF1997	Boore, Joyner, and Fumal (2007)
BS2003	Baturay and Stewart (2003)
CB2003	Campbell and Bozorgnia (2003)
CB2006	Campbell and Bozorgnia (2006)
CB2008	Campbell and Bozorgnia (2008)
CS2005	Choi and Stewart (2005)
CY2006	Chiou and Youngs (2006)
F2000	Field (2000)
GEA2006	Goulet et al. (2006)
SEA1997	Sadigh et al. (1997)
SHK2003	ShakeMap 2003 (Field NDa)
USGS2002	USGS Combined (Frankel et al. 2002)
USGS2004	USGS Combined 2004 (Field NDb)

Table 4. STD04: ATC-13 facility classes (Applied Technology Council 1985)

Abbrev	Description
W/F/LR	Wood Frame (Low Rise)
M/F/LR	Light Metal (Low Rise)
RC/SW-MRF/LR	Reinforced Concrete Shear Wall (with Moment-Resisting Frame) Low Rise
RC/SW-MRF/MR	Reinforced Concrete Shear Wall (with Moment-Resisting Frame) Medium Rise
RC/SW-MRF/HR	Reinforced Concrete Shear Wall (with Moment-Resisting Frame) High Rise
RC/SW-0/LR	Reinforced Concrete Shear Wall (without Moment-Resisting Frame) Low Rise
RC/SW-0/MR	Reinforced Concrete Shear Wall (without Moment-Resisting Frame) Medium Rise
RC/SW-0/HR	Reinforced Concrete Shear Wall (without Moment-Resisting Frame) High Rise
RM/SW-0/LR	Reinforced Masonry Shear Wall (without Moment-Resisting Frame) Low Rise
RM/SW-0/MR	Reinforced Masonry Shear Wall (without Moment-Resisting Frame) Medium Rise
RM/SW-0/HR	Reinforced Masonry Shear Wall (without Moment-Resisting Frame) High Rise
S/BR/LR	Braced Steel Frame Low Rise
S/BR/MR	Braced Steel Frame Medium Rise
S/BR/HR	Braced Steel Frame High Rise
S/MRF-P/LR	Moment-Resisting Steel Frame (Perimeter Frame) Low Rise
S/MRF-P/MR	Moment-Resisting Steel Frame (Perimeter Frame) Medium Rise
S/MRF-P/HR	Moment-Resisting Steel Frame (Perimeter Frame) High Rise
RC/DMRF-D/LR	Moment-Resisting Ductile Concrete Frame (Distributed Frame) Low Rise
RC/DMRF-D/MR	Moment-Resisting Ductile Concrete Frame (Distributed Frame) Medium Rise
RC/DMRF-D/HR	Moment-Resisting Ductile Concrete Frame (Distributed Frame) High Rise
TU	Tilt-up Low Rise
MH	Mobile Home
SIMPLE-BRIDGE	Conventional Bridge (<500-ft spans) Multiple Simple Spans
CONT.-BRIDGE	Conventional Bridge (<500-ft spans) Continuous or Single or Monolithic Spans
MAJOR-BRIDGE	Major Bridge (greater than 500-ft span)
PIPE-UG	Underground Pipeline
PIPE-AG	At-grade Pipeline
RC-DAM	Concrete Dam
EARTH-DAM	Earthfill and Rockfill Dam
AL-TUNNEL	Tunnel through Alluvium
RK-TUNNEL	Tunnel through Rock
CC-TUNNEL	Cut-and-cover Tunnel
UG-LIQUID-TANK	Underground Liquid Storage Tank
UG-SOLID-TANK	Underground Solid Storage Tank
AG-LIQUID-TANK	On-ground Liquid Storage Tank
AG-SOLID-TANK	On-ground Solid Storage Tank
EL-LIQUID-TANK	Elevated Liquid Storage Tank
EL-SOLID-TANK	Elevated Solid Storage Tank
RAILROAD	Railroad
HIGHWAY	Highway
RUNWAY	Runway
URM/CHIMNEY	High Industrial Masonry Chimney
RC/CHIMNEY	High Industrial Concrete Chimney
S/CHIMNEY	High Industrial Steel Chimney
CRANE	Crane
CONVEYOR	Conveyor System
STD.-ELEC.-TOWER	Conventional Electric Transmission Line Tower (less than 100 ft high)
MAJOR-ELEC.-TOWER	Major Electric Transmission Line Tower (more than 100 ft high)
BROADCASTING-TOWER	Broadcast Tower
OBSERVATION-TOWER	Observation Tower
OFFSHORE-TOWER	Offshore Tower
CANAL	Canal

Abbrev	Description
EARTH-RET.-STRUCTURE	Earth Retaining Structure over 20 ft High
WATERFRONT-STRUCTURE	Waterfront Structure
RESIDENTIAL-EQUIP.	Residential Equipment
OFFICE-EQUIP.	Office Equipment (Furniture, Computers, etc.)
ELECTRICAL-EQUIP.	Electrical Equipment
MECHANICAL-EQUIP.	Mechanical Equipment
HIGH-TECH-EQUIP.	High Technology and Laboratory Equipment
S/MRF-D/LR	Moment-Resisting Steel Frame (Distributed Frame) Low Rise
S/MRF-D/MR	Moment-Resisting Steel Frame (Distributed Frame) Medium Rise
S/MRF-D/HR	Moment-Resisting Steel Frame (Distributed Frame) High Rise
URM/BRG-WALL/LR	Unreinforced Masonry Bearing Wall Low Rise
URM/BRG-WALL/MR	Unreinforced Masonry Bearing Wall Medium Rise
URM/FR/LR	Unreinforced Masonry with Load-Bearing Frame Low Rise
URM/FR/MR	Unreinforced Masonry with Load-Bearing Frame Medium Rise
URM/FR/HR	Unreinforced Masonry with Load-Bearing Frame High Rise
PCC/LR	Precast Concrete other than Tilt-Up Low Rise
PCC/MR	Precast Concrete other than Tilt-Up Medium Rise
PCC/HR	Precast Concrete other than Tilt-Up High Rise
RM/SW/LR	Reinforced Masonry Shear Wall (with Moment-Resisting Frame) Low Rise
RM/SW/MR	Reinforced Masonry Shear Wall (with Moment-Resisting Frame) Medium Rise
RM/SW/HR	Reinforced Masonry Shear Wall (with Moment-Resisting Frame) High Rise
RC/ND-FR-D/LR	Moment-Resisting Non-Ductile Concrete Frame (Distributed Frame) Low Rise
RC/ND-FR-D/MR	Moment-Resisting Non-Ductile Concrete Frame (Distributed Frame) Medium Rise
RC/ND-FR-D/HR	Moment-Resisting Non-Ductile Concrete Frame (Distributed Frame) High Rise
VEHICLES	Trains, Trucks, Airplanes, & other Vehicles
LS/LR	Long Span Low Rise

Table 5. STD05: FEMA 154 structure types (FEMA 1988)

Abbrev	Description
W1	Light wood-frame residential and commercial buildings ≤ 5,000 square feet
W2	Light wood-frame buildings > 5,000 square feet
S1	Steel moment-resisting frame buildings
S2	Braced steel frame buildings
S3	Light metal buildings
S4	Steel frame buildings with cast-in-place concrete shear walls
S5	Steel frame buildings with unreinforced masonry infill walls
C1	Concrete moment-resisting frame buildings
C2	Concrete shear-wall buildings
C3	Concrete frame buildings with unreinforced masonry infill walls
PC1	Tilt-up buildings
PC2	Precast concrete frame buildings
RM1	Reinforced masonry buildings with flexible floor and roof diaphragms
RM2	Reinforced masonry buildings with rigid floor and roof diaphragms
URM	Unreinforced masonry bearing-wall buildings

Table 6. STD06: EMS-98 structure types (EMS, 1998)

Group	Structure type
Masonry	1. Rubble stone, field stone
	2. Adobe (earth brick)
	3. Simple stone
	4. Massive stone
	5. Unreinforced masonry with manufactured stone units
	6. Unreinforced masonry with reinforced concrete floors
	7. Reinforced or confined masonry
Reinforced concrete	8. Reinforced concrete frame without earthquake resistant design
	9. Reinforced concrete frame with moderate level of earthquake resistant design
	10. Reinforced concrete frame with high level of earthquake resistant design
	11. Reinforced concrete walls without earthquake resistant design
	12. Reinforced concrete walls with moderate level of earthquake resistant design
	13. Reinforced concrete walls with high level of earthquake resistant design
Steel	14. Steel structures
Wood	15. Timber structures

Table 7. STD07: PAGER structure types (PAGER-STR ver 1.1)

	Abbrev	Description
Wood	W	WOOD
	W1	Woodframe, Wood Stud, with Wood, Stucco, or Brick Veneer < 5000 sf (500 m^2)
	W2	Woodframe, Heavy Members, > 5000 sf (500 m^2), No Infill
	W3	Woodframe, Light Post and Beam Wood Frame
	W4	Log building
	W5	Wattle and Daub
	W6	Unbraced Heavy Post and Beam Woodframe with Heavy Infill
	W7	Braced Wood Frame with Load-Bearing Infill Walls
Steel	S	STEEL
	S1	Steel Moment Frame
	S1L	Steel Moment Frame 1-3 Story
	S1M	Steel Moment Frame 4-7 Story
	S1H	Steel Moment Frame 8+ Story
	S2	Steel Braced Frame
	S2L	Steel Braced Frame 1-3 Story
	S2M	Steel Braced Frame 4-7 Story
	S2H	Steel Braced Frame 8+ Story
	S3	Steel Light Frame
	S4	Steel Frame with Cast-in-Place Concrete Shearwalls
	S4L	Steel Frame with Cast-in-Place Concrete Shearwalls 1-3 Story
	S4M	Steel Frame with Cast-in-Place Concrete Shearwalls 4-7 Story
	S4H	Steel Frame with Cast-in-Place Concrete Shearwalls 8+ Story
	S5	Steel Frame with Unreinforced Masonry Infill Walls
	S5L	Steel Frame with Unreinforced Masonry Infill Walls 1-3 Story
	S5M	Steel Frame with Unreinforced Masonry Infill Walls 4-7 Story
	S5H	Steel Frame with Unreinforced Masonry Infill Walls 8+ Story
Concrete	C	REINFORCED CONCRETE
	C1	Ductile Reinforced Concrete Moment Frame
	C1L	Ductile Reinforced Concrete Moment Frame 1-3 Story
	C1M	Ductile Reinforced Concrete Moment Frame 4-7 Story
	C1H	Ductile Reinforced Concrete Moment Frame 8+ Story
	C2	Reinforced Concrete Shearwall
	C2L	Reinforced Concrete Shearwall 1-3 Story
	C2M	Reinforced Concrete Shearwall 4-7 Story
	C2H	Reinforced Concrete Shearwall 8+ Story
	C3	Nonductile Reinforced Concrete Moment Frame with Masonry Infill Walls
	C3L	Nonductile Reinforced Concrete Moment Frame with Masonry Infill Walls 1-3 Story
	C3M	Nonductile Reinforced Concrete Moment Frame with Masonry Infill Walls 4-7 Story
	C3H	Nonductile Reinforced Concrete Moment Frame with Masonry Infill Walls 8+ Story
	C4	Nonductile Reinforced Concrete Frame without Masonry Infill Walls
	C4L	Nonductile Reinforced Concrete Frame without Masonry Infill Walls 1-3 Story
	C4M	Nonductile Reinforced Concrete Frame without Masonry Infill Walls 4-7 Story
	C4H	Nonductile Reinforced Concrete Frame without Masonry Infill Walls 8+ Story
	C5	Steel Reinforced Concrete
	C5L	Steel Reinforced Concrete 1-3 Story
	C5M	Steel Reinforced Concrete 4-7 Story
	C5H	Steel Reinforced Concrete 8+ Story
	C6	Concrete Moment Resisting Frame with Shearwalls
	C6L	Concrete Moment Resisting Frame with Shearwalls 1-3 Story
	C6M	Concrete Moment Resisting Frame with Shearwalls 4-7 Story

	Abbrev	Description
	C6H	Concrete Moment Resisting Frame with Shearwalls 8+ Story
	C7	Concrete Flat Slab System (No Beams or Shearwalls)
Precast concrete	PC1	Tiltup
	PC2	Precast Concrete Frames with Concrete Shearwalls
	PC2L	Precast Concrete Frames with Concrete Shearwalls 1-3 Story
	PC2M	Precast Concrete Frames with Concrete Shearwalls 4-7 Story
	PC2H	Precast Concrete Frames with Concrete Shearwalls 8+ Story
	PC3	Precast Concrete Frames with Masonry Infill Walls
	PC3L	Precast Concrete Frames with Masonry Infill Walls 1-3 Story
	PC3M	Precast Concrete Frames with Masonry Infill Walls 4-7 Story
	PC3H	Precast Concrete Frames with Masonry Infill Walls 8+ Story
	PC4	Precast Wall Panel System
Reinforced masonry	RM	REINFORCED MASONRY
	RM1	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms
	RM1L	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms 1-3 Story
	RM1M	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms 4-7 Story
	RM2	Reinforced Masonry Bearing Walls with Concrete Diaphragms
	RM2L	Reinforced Masonry Bearing Walls with Concrete Diaphragms 1-3 Story
	RM2M	Reinforced Masonry Bearing Walls with Concrete Diaphragms 4-7 Story
	RM2H	Reinforced Masonry Bearing Walls with Concrete Diaphragms 8+ Story
	RM3	Confined Masonry
Earthen	M	MUD WALLS
	M1	Mud Walls without Horizontal Wood Elements
	M2	Mud Walls with Horizontal Wood Elements
	A	ADOBE BLOCK (UNBAKED DRIED MUD BLOCK) WALLS
	A1	Adobe Block, Mud Mortar, Wood Roof and Floors
	A2	Adobe Block, Mud Mortar, Wood Roof and Floors, Bamboo, Straw, and Thatch Roof
	A3	Adobe Block, Mud Mortar, Wood Roof and Floors, Cement-sand Mortar
	A4	Adobe Block, Mud Mortar, Wood Roof and Floors, Reinforced Concrete Bond Beam, Cane and Mud Roof
	A5	Adobe Block, Mud Mortar, Wood Roof and Floors, with Bamboo or Rope Reinforcement
	RE	RAMMED EARTH/PNEUMATICALLY IMPACTED STABILIZED EARTH
Stone	RS	RUBBLE STONE (FIELD STONE) MASONRY
	RS1	Field Stones Dry Stacked (No Mortar), Timber Floors, Timber, Earth, or Metal Roof
	RS2	Field Stones, Mud Mortar, Timber Floors, Timber, Earth, or Metal Roof
	RS3	Field Stones, Lime Mortar, Timber Floors, Timber, Earth, or Metal Roof
	RS4	Field Stones, Cement Mortar, Vaulted Brick Roof and Floors
	RS5	Field Stones, Cement Mortar, Timber Floors, Timber, Earth, or Metal Roof, Reinforced Concrete Bond Beam
	DS	RECTANGULAR CUT STONE MASONRY BLOCK
	DS1	Rectangular Cut Stone Masonry, Mud Mortar, Timber Roof and Floors
	DS2	Rectangular Cut Stone Masonry, Lime Mortar, Timber Roof and Floors
	DS3	Rectangular Cut Stone Masonry, Cement Mortar, Timber Roof and Floors
	DS4	Rectangular Cut Stone Masonry, Lime Mortar, Concrete Roof and Floors
Unreinforced brick, block	UFB	UNREINFORCED FIRED BRICK MASONRY
	UFB1	Unreinforced Brick Masonry, Mud Mortar, no Timber Posts
	UFB2	Unreinforced Brick Masonry, Mud Mortar, with Timber Posts
	UFB3	Unreinforced Brick Masonry, Lime Mortar
	UFB4	Unreinforced Fired Brick Masonry, Cement Mortar, Timber Floors, Timber or Steel Beams and Columns, Tie Courses
	UFB5	Unreinforced Fired Brick Masonry, Cement Mortar, Concrete Diaphragms, Timber or Steel Beams and Columns, Tie Courses
	UCB	UNREINFORCED CONCRETE BLOCK MASONRY, LIME/CEMENT MORTAR

	Abbrev	Description
	MS	MASSIVE STONE MASONRY IN LIME/CEMENT MORTAR
Other	INF	INFORMAL CONSTRUCTION. Exterior closure of wood, plastic, light metal, or composite sheets; informal framing.
	MH	Mobile Home
	UNK	Unknown Category (Not specified)

Table 8. STD08: HAZUS-MH structure types (NIBS and FEMA 2003) with code suffix

Abbrev	Description
W1h	Wood frame < 5000 sf high code
W1m	Wood frame < 5000 sf moderate code
W1l	Wood frame < 5000 sf low code
W1p	Wood frame < 5000 sf pre-code
W2h	Wood frame ≥ 5000 sf high code
W2m	Wood frame ≥ 5000 sf moderate code
W2l	Wood frame ≥ 5000 sf low code
W2p	Wood frame ≥ 5000 sf pre-code
S1Lh	Steel moment frame lowrise high code
S1Lm	Steel moment frame lowrise moderate code
S1Ll	Steel moment frame lowrise low code
S1Lp	Steel moment frame lowrise pre-code
S1Mh	Steel moment frame midrise high code
S1Mm	Steel moment frame midrise moderate code
S1Ml	Steel moment frame midrise low code
S1Mp	Steel moment frame midrise pre-code
S1Hh	Steel moment frame highrise high code
S1Hm	Steel moment frame highrise moderate code
S1Hl	Steel moment frame highrise low code
S1Hp	Steel moment frame highrise pre-code
S2Lh	Steel braced frame lowrise high code
S2Lm	Steel braced frame lowrise moderate code
S2Ll	Steel braced frame lowrise low code
S2Lp	Steel braced frame lowrise pre-code
S2Mh	Steel braced frame midrise high code
S2Mm	Steel braced frame midrise moderate code
S2Ml	Steel braced frame midrise low code
S2Mp	Steel braced frame midrise pre-code
S2Hh	Steel braced frame highrise high code
S2Hm	Steel braced frame highrise moderate code
S2Hl	Steel braced frame highrise low code
S2Hp	Steel braced frame highrise pre-code
S3h	Steel light frame high code
S3m	Steel light frame moderate code
S3l	Steel light frame low code
S3p	Steel light frame pre-code
S4Lh	Steel frame with cast-in-place shearwalls lowrise high code
S4Lm	Steel frame with cast-in-place shearwalls lowrise moderate code
S4Ll	Steel frame with cast-in-place shearwalls lowrise low code
S4Lp	Steel frame with cast-in-place shearwalls lowrise pre-code
S4Mh	Steel frame with cast-in-place shearwalls midrise high code
S4Mm	Steel frame with cast-in-place shearwalls midrise moderate code
S4Ml	Steel frame with cast-in-place shearwalls midrise low code
S4Mp	Steel frame with cast-in-place shearwalls midrise pre-code
S4Hh	Steel frame with cast-in-place shearwalls highrise high code
S4Hm	Steel frame with cast-in-place shearwalls highrise moderate code
S4Hl	Steel frame with cast-in-place shearwalls highrise low code
S4Hp	Steel frame with cast-in-place shearwalls highrise pre-code
S5Ll	Steel frame with unreinforced masonry infill lowrise low code
S5Lp	Steel frame with unreinforced masonry infill lowrise pre-code

Abbrev	Description
S5Ml	Steel frame with unreinforced masonry infill midrise low code
S5Mp	Steel frame with unreinforced masonry infill midrise pre-code
S5Hl	Steel frame with unreinforced masonry infill midrise low code
S5Hp	Steel frame with unreinforced masonry infill midrise pre-code
C1Lh	Concrete moment frame lowrise high code
C1Lm	Concrete moment frame lowrise moderate code
C1Ll	Concrete moment frame lowrise low code
C1Lp	Concrete moment frame lowrise pre-code
C1Mh	Concrete moment frame midrise high code
C1Mm	Concrete moment frame midrise moderate code
C1Ml	Concrete moment frame midrise low code
C1Mp	Concrete moment frame midrise pre-code
C1Hh	Concrete moment frame highrise high code
C1Hm	Concrete moment frame highrise moderate code
C1Hl	Concrete moment frame highrise low code
C1Hp	Concrete moment frame highrise pre-code
C2Lh	Concrete shearwall lowrise high code
C2Lm	Concrete shearwall lowrise moderate code
C2Ll	Concrete shearwall lowrise low code
C2Lp	Concrete shearwall lowrise pre-code
C2Mh	Concrete shearwall midrise high code
C2Mm	Concrete shearwall midrise moderate code
C2Ml	Concrete shearwall midrise low code
C2Mp	Concrete shearwall midrise pre-code
C2Hh	Concrete shearwall highrise high code
C2Hm	Concrete shearwall highrise moderate code
C2Hl	Concrete shearwall highrise low code
C2Hp	Concrete shearwall highrise pre-code
C3Ll	Concrete frame with masonry infil lowrise low code
C3Lp	Concrete frame with masonry infil lowrise pre-code
C3Ml	Concrete frame with masonry infil midrise low code
C3Mp	Concrete frame with masonry infil midrise pre-code
C3Hl	Concrete frame with masonry infil highrise low code
C3Hp	Concrete frame with masonry infil highrise pre-code
PC1h	Precast concrete tiltup high code
PC1m	Precast concrete tiltup moderate code
PC1l	Precast concrete tiltup low code
PC1p	Precast concrete frame with cast-in-place shearwalls pre-code
PC2Lh	Precast concrete frame with cast-in-place shearwalls lowrise high code
PC2Lm	Precast concrete frame with cast-in-place shearwalls lowrise moderate code
PC2Ll	Precast concrete frame with cast-in-place shearwalls lowrise low code
PC2Lp	Precast concrete frame with cast-in-place shearwalls lowrise pre-code
PC2Mh	Precast concrete frame with cast-in-place shearwalls midrise high code
PC2Mm	Precast concrete frame with cast-in-place shearwalls midrise moderate code
PC2Ml	Precast concrete frame with cast-in-place shearwalls midrise low code
PC2Mp	Precast concrete frame with cast-in-place shearwalls midrise pre-code
PC2Hh	Precast concrete frame with cast-in-place shearwalls highrise high code
PC2Hm	Precast concrete frame with cast-in-place shearwalls highrise moderate code
PC2Hl	Precast concrete frame with cast-in-place shearwalls highrise low code
PC2Hp	Precast concrete frame with cast-in-place shearwalls highrise pre-code
RM1Lh	Reinforced masonry with flexible diaphragm lowrise high code
RM1Lm	Reinforced masonry with flexible diaphragm lowrise moderate code

Abbrev	Description
RM1Ll	Reinforced masonry with flexible diaphragm lowrise low code
RM1Lp	Reinforced masonry with flexible diaphragm lowrise pre-code
RM1Mh	Reinforced masonry with flexible diaphragm midrise high code
RM1Mm	Reinforced masonry with flexible diaphragm midrise moderate code
RM1Ml	Reinforced masonry with flexible diaphragm midrise low code
RM1Mp	Reinforced masonry with flexible diaphragm midrise pre-code
RM2Lh	Reinforced masonry with rigid diaphragm lowrise high code
RM2Lm	Reinforced masonry with rigid diaphragm lowrise moderate code
RM2Ll	Reinforced masonry with rigid diaphragm lowrise low code
RM2Lp	Reinforced masonry with rigid diaphragm lowrise pre-code
RM2Mh	Reinforced masonry with rigid diaphragm midrise high code
RM2Mm	Reinforced masonry with rigid diaphragm midrise moderate code
RM2Ml	Reinforced masonry with rigid diaphragm midrise low code
RM2Mp	Reinforced masonry with rigid diaphragm midrise pre-code
RM2Hh	Reinforced masonry with rigid diaphragm highrise high code
RM2Hm	Reinforced masonry with rigid diaphragm highrise moderate code
RM2Hl	Reinforced masonry with rigid diaphragm highrise low code
RM2Hp	Reinforced masonry with rigid diaphragm highrise pre-code
URMLl	Unreinforced masonry bearing wall lowrise low code
URMLp	Unreinforced masonry bearing wall lowrise pre-code
URMMl	Unreinforced masonry bearing wall midrise low code
URMMp	Unreinforced masonry bearing wall midrise pre-code
MHh	Mobile home high code
MHm	Mobile home moderate code
MHl	Mobile home low code
MHp	Mobile home pre-code

Table 9. STD09: loss measures

Label	Meaning
Cost	Property repair cost in same units and currency as defined for the asset or portfolio
DF	Damage factor, meaning property repair cost as a fraction of replacement cost new; can refer to buildings or contents
Cas1Rate	Casualty rate, HAZUS-MH severity 1, meaning fraction of occupants experiencing injuries requiring basic medical aid that could be administered by paraprofessionals. These types of injuries would require bandages or observation. Some examples are: a sprain, a severe cut requiring stitches, a minor burn (first degree or second degree on a small part of the body), or a bump on the head without loss of consciousness. Does not include injuries of lesser severity that could be self treated—*no Band-aid injuries*.
Cas1	Like Cas1Rate, but number of occupants instead of fraction
Cas2Rate	Casualty rate, HAZUS-MH severity 2, meaning fraction of occupants experiencing injuries requiring a greater degree of medical care and use of medical technology such as x-rays or surgery, but not expected to progress to a life threatening status. Some examples are third degree burns or second degree burns over large parts of the body, a bump on the head that causes loss of consciousness, fractured bone, dehydration or exposure.
Cas2	Like Cas2Rate, but number of occupants instead of fraction
Cas3Rate	Casualty rate, HAZUS-MH severity 3, meaning fraction of occupants experiencing injuries that pose an immediate life threatening condition if not treated adequately and expeditiously. Some examples are: uncontrolled bleeding, punctured organ, other internal injuries, spinal column injuries, or crush syndrome.
Cas3	Like Cas3Rate, but number of occupants instead of fraction
Cas4Rate	Fatality rate, meaning mean fraction of occupants instantaneously killed or mortally injured.
Cas4	Like Cas4Rate, but number of occupants instead of fraction
MinorInjRate	Fraction of occupants suffering injuries not requiring hospitalization
MinorInj	Like MinorInjRate, but number of occupants instead of fraction
SeriousInjRate	Fraction of occupants suffering injuries requiring hospitalization
SeriousInj	Like SeriousInjRate, but number of occupants instead of fraction
FatalInjRate	Fraction of occupants suffering fatal injuries; same as Cas4Rate
FataInj	Like FatalInjRate, but number of occupants instead of fraction; same as Cas4
DisplRate	Fraction of occupants unable to continue occupying the facility or portfolio of facilities
Displ	Like DisplRate, but number of occupants instead of fraction
Time	Loss of use duration, days
BI	Business interruption loss resulting from physical damage (difference in condition) to the asset under consideration. Units and currency implicit in asset definition.
CBI	Business interruption loss resulting from utility service interruption, loss of customers, inability of employees to get to work, inability to deliver product or services, evacuation requirements, or other causes of business interruption not resulting from difference in condition. Units and currency implicit in asset definition.

Table 10. STD10: damage states

DS Label	Meaning
Green tag	Inspected, lawful occupancy permitted, no apparent structural hazard found.
Yellow tag	Restricted use. Structure inspected and found to be damaged. Entry, occupancy, and lawful use are restricted.
Red tag	Unsafe to enter or occupy. Entry may result in death or injury.
Collapse	At least part of a floor has fallen to the point where it touches the floor below or rests on furnishings, fixtures or equipment standing on the floor below.
Slight ATC-13	Nonzero damage costing up to 1% of facility replacement cost new to repair
Light ATC-13	Damage costing 1-10% of facility replacement cost new to repair
Moderate ATC-13	Damage costing 10-30% of facility replacement cost new to repair
Heavy ATC-13	Damage costing 30-60% of facility replacement cost new to repair
Major ATC-13	Damage costing 60-100% of facility replacement cost new to repair
Destroyed ATC-13	Irreparable damage
Grade 1 EMS 98	Masonry buildings: hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases. Reinforced concrete buildings have fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.
Grade 2 EMS 98	Masonry buildings: cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys. Reinforced concrete buildings cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
Grade 3 EMS 98	Masonry buildings: large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls). Reinforced concrete buildings: cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of concrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.
Grade 4 EMS 98	Masonry buildings: serious failure of walls; partial structural failure of roofs and floors. Reinforced concrete buildings: large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.
Grade 5 EMS 98	Masonry buildings: total or near total collapse. Reinforced concrete buildings: collapse of ground floor or parts (e.g., wings) of buildings.
Operational FEMA 356	No permanent drift. Structure substantially retains original strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. All systems important to normal operation are functional. Complies with acceptance criteria specified in FEMA 356 structural performance level S-1 and nonstructural performance level N-A.
Immediate occupancy FEMA 356	No permanent drift. Structure substantially retains original strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. Elevators can be restarted. Fire protection operable. Complies with acceptance criteria specified in FEMA 356 structural performance level S-1 and nonstructural performance level N-B.
Life safety FEMA 356	Some residual strength and stiffness left in all stories. Gravity-loadbearing elements function. No out-of-plane failure of walls or tipping of parapets. Some permanent drift. Damage to partitions. Building may be beyond economical repair. Complies with the acceptance criteria specified in FEMA 356 for structural performance level S-3 and nonstructural performance level N-C.
Collapse prevention FEMA 356	Little residual stiffness and strength, but loadbearing columns and walls function. Large permanent drifts. Some exits blocked. Infills and unbraced parapets failed or at incipient failure. Building is near collapse. Complies with the acceptance criteria specified in FEMA 356 for structural performance level S-5 and nonstructural performance level N-E
Slight structural HAZUS	varies by structure type; see NIBS and FEMA (2003)
Moderate structural HAZUS	ditto
Extensive structural HAZUS	ditto

Complete structural HAZUS	ditto
Collapse structural HAZUS	Not defined. A reasonable interpretation is that the floor above has fallen and now touches the floor below or rests on furnishings, fixtures or equipment standing on the floor below.
Slight nonstructural drift-sensitive HAZUS	Varies by structure type; see NIBS and FEMA (2003)
Moderate nonstructural drift-sensitive HAZUS	Ditto
Extensive nonstructural drift-sensitive HAZUS	Ditto
Complete nonstructural drift-sensitive HAZUS	Ditto
Slight nonstructural acceleration-sensitive HAZUS	Varies by structure type; see NIBS and FEMA (2003)
Moderate nonstructural acceleration - sensitive HAZUS	Ditto
Extensive nonstructural acceleration - sensitive HAZUS	Ditto
Complete nonstructural acceleration - sensitive HAZUS	Ditto

4 EXPOSURE

4.1 PREFACE TO EXPOSURE DIFS

DIFs presented here are used in exposure definition: they specify the location, value, vulnerability model, and site soil for one or more point assets, i.e., facilities that for purposes of seismic risk estimation can be treated as located at a point. Some notes that are common to all files proposed here:

1. Lines are demarked with both newline and carriage return symbols.
2. Terms shown in square brackets are variable names whose meaning is detailed below.
3. Terms not shown in square brackets are to be written verbatim.
4. A line number is shown in many files in the 1st column, always labeled "ID." It is for reference only to that particular file, and is not an index that relates two or more files.
5. Text strings are delimited by commas and straight double-quotes (Unicode 0022).

4.2 EXP01: A PORTFOLIO OF POINT ASSETS

This exposure-definition DIF specifies seismic attributes of one or more point assets at particular locations. The attributes are latitude, longitude, value, vulnerability model, NEHRP site soil class, Vs30, and the year in which the value was estimated. Assets are labeled with an ID, name, site ID, site name, group ID, and group name, for subsequent financial analysis. The point assets can be individual buildings, or the building stock of a particular type in a census block, or even higher levels of aggregation. The DIF is based on the OpenRisk portfolio file (Porter and Scawthorn 2009), minus fields related to wind and flood risk, insurance, and value uncertainty. There are more fields than can appear on a single line of this page, so a hanging line indicates that it continues from the previous line without a carriage return or line feed.

```
[Explanatory header]
POFID=”[POFID]”
AssetID,AssetName,SiteID,SiteName,AssetGroupID,AssetGroupName,
      Lat,Lon,Value,VulnModel,Soil,Vs30,ValYr
[AID1],[ANM1],[SITE1],[SNM1],[GID1],[GNM1],[LAT1],[LON1],[VAL1],
      [VULN1],[SOIL1],[VS30-1],[VALYR1]
[AID2],[ANM2],[SITS2],[SITENM2],[GID2],[GNM2],[LAT2],[LON2],
      [VAL2],[VULN2],[SOIL2],[VS30-2],[VALYR2]
…
[AIDn],[ANMn],[SITEn],[SITENMn],[GIDn],[GNMn],[LATn],[LONn],
      [VALn],[VULNn],[SOILn],[VS30n],[VALYRn]
```

Figure 1. EXP01 portfolio

AIDr = asset identifier for the asset in record *r* (unique integer in 1, 2, …, meaning that no two lines in the file can have the same value in this field)

ANMr= name of asset in record *r* (text string 255 characters or less, in double quotes).

Explanatory header = as desired by loss modeler, e.g., author, date, project name, etc.

GIDr= ID of a group to which the asset in record *r* belongs (integer in 1, 2, …; need not be unique)

GNMr= label for the group to which the asset in record *r* belongs (text string 255 characters or less, in double quotes). Should be the same for all records with the same value of GID.

LATr= latitude of site in record *r*, decimal degrees north (double-precision floating point)

LONr= longitude of site in record *r*, decimal degrees east (negative west, double-precision floating point).

POFID = unique identifier for this portfolio, a text string ≤ 255 characters long

SITEr= a potentially non-unique identifier for the location of the asset in record *r* (integer in 1, 2, …)

SNMr= label for the site in record *r* such as an address (text string 255 characters or less, in double quotes)

SOILr= NEHRP site soil category for the asset in record *r* per ICC (2006), (text string in {A, AB, B, BC, … E})

VALr= best estimate of value at risk in the asset in record *r*, monetary or number or people (double precision floating point, ≥ 0.00)

VALYRr= year in which value of asset in record *r* is measured (numeric YYYY), for use in update VALr to present year.

VS30r = mean shearwave velocity in the top 30 m of soil for asset in record *r* (m/sec, single-precision floating point, > 0).

VULNr = name of the vulnerability model to use for the asset in record *r*, e.g., "CUREE small house as-is," (text string 255 characters or less, in double quotes, restricted to a list of available models). As used here, vulnerability model is synonymous with structure type.

```
"K Porter 28 Feb 2009 sample EXP01 portfolio"
POFID = "KAP01"
AssetID,AssetName,SiteID,SiteName,AssetGroupID,AssetGroupName,
      Lat,Lon,Value,VulnModel,Soil,Vs30,ValHi,ValLo,ValYr
1,"W1p dwellings 06088",1,"Census tract 06088",1,Dwellings,34.15,
      -118.12,1.06E+08,"W1p",C,490,2007
2,"W1l dwellings 06088",1,"Census tract 06088",1,Dwellings,34.15,
      -118.12,8.92E+08,"W1l",C,490,2007
3,"W1m dwellings 06088",1,"Census tract 06088",1,Dwellings,34.15,
      -118.12,0,W1m,C,490,2007
4,"W1h dwellings 06088",1,"Census tract 06088",1,Dwellings,34.15,
      -118.12,4.88E+08,W1h,C,490,2007
```

Figure 2. Sample EXP01 portfolio

4.3 EXP02: A PORTFOLIO OF POINT ASSETS WITH MORE UNCERTAINTY

This exposure-definition DIF is like EXP01, with the addition of uncertainty information: standard deviation of location uncertainty, standard deviation of Vs30, and upper- and lower-bound estimates of value. The additional information can be used to propagate uncertainty in location, site amplification, and value exposed. Figure 3 specifies the layout of EXP02; Figure 4 provides an illustration, this time at the level of individual buildings.

```
[Explanatory header]
POFID="[POFID]"
AssetID,AssetName,SiteID,SiteName,AssetGroupID,AssetGroupName,
      Lat,Lon,SLoc,Value,VulnModel,Soil,Vs30,SVs30,ValHi,ValLo,ValYr
[AID1],[ANM1],[SITE1],[SNM1],[GID1],[GNM1],[LAT1],[LON1],[SLOC1],
      [VAL1],[VULN1],[SOIL1],[VS301],[SVS30-1],[VALHI1],[VALLO1],
      [VALYR1]
[AID2],[ANM2],[SITE2],[SNM2],[GID2],[GNM2],[LAT2],[LON2],[SLOC2],
      [VAL2],[VULN2],[SOIL2],[VS30-2],[SVS30-2],[VALHI2],[VALLO2],
      [VALYR2]
…
[AIDn],[ANMn],[SITEn],[SNMn],[GIDn],[GNMn],[LATn],[LONn],[SLOCn]
      [VALn],[VULNn],[SOILn],[VS30n],[SVS30-n],[VALHIn],[VALLOn],
      [VALYRn]
```

Figure 3. EXP02 portfolio of point assets with more uncertainty

All terms are the same as in EXP01, plus:

SLOC1 = standard deviation of location in km (double-precision floating point, ≥ 0)

SVS30r = standard deviation of shearwave velocity in the top 30 m of soil for asset in record *r* (m/sec, single-precision floating point, > 0).

VALHIr = upper bound of value of asset in record *r* (double-precision floating point, ≥ VALr). "Upper bound" can be interpreted by the user, but for use in 3-point moment matching (a method of uncertainty propagation), it is intended to reflect the 96th percentile of value.

VALLOr = lower bound of value of asset in record *r* (double-precision floating point, 0 ≤ VALLOr ≤ VALr). "Lower bound" can be interpreted by the user, but for use in 3-point moment matching (a method of uncertainty propagation), it is intended to reflect the 4th percentile of value.

```
"K Porter 28 Feb 2009 sample EXP02 enhanced portfolio"
POFID = "KAP02"
AssetID,AssetName,SiteID,SiteName,AssetGroupID,AssetGroupName,
      Lat,Lon,SLoc,Value,VulnModel,Soil,Vs30,SVs30,ValHi,ValLo,ValYr
1,"House 1",1,"769 N Michigan Ave, Pasadena CA 91104,
      USA",1,Houses,34.15,-
      118.12,0.05,220000,"W1p",C,490,250,330000,110000,2007
2,"Contents 1",1,"769 N Michigan Ave, Pasadena CA, 91104, USA",
      USA,2,Contents,34.15,-118.12,0.05,44000,"W1p
      contents",C,490,250,65000,15000,2007
```

```
3,”House 2”,2,”2501 Bellaire St, Denver CO, 80207,
     USA”,1,Houses,39.75,-
     104.93,0.05,400000,URMLp,C,420,210,500000,360000,2007
4,”Contents 2”,2,”2501 Bellaire St, Denver CO, 80207,
     USA”,2,Contents,39.75,-104.93,0.05,75000,”W1p
     contents”,C,420,210,100000,25000,2007
```

Figure 4. Sample EXP02 enhanced portfolio file

5 HAZARD OUTPUT

5.1 PREFACE TO HAZARD DIFS

The DIFs presented in this section are the output of a hazard analysis, giving intensity for specified sites under specified combinations of earthquake rupture forecast, ground-motion prediction equation, and exceedance frequency. As used here, "intensity" broadly refers to any intensity measure such as spectral acceleration response, peak ground velocity, etc.

Note that this report does not specify hazard models, such as earthquake rupture forecasts and ground-motion prediction equations. Some standards in Section 3 provide labels for earthquake rupture forecasts (Table 1), intensity measure types (Table 2), and ground-motion prediction equations (Table 3).

In this chapter, whenever a label for earthquake rupture forecast is required (these are generally labeled "ERF*r*", where *r* is a record ID), the choices in Table 1 imply default values for the various parameters of each earthquake rupture forecast that must be defined by the developer or caretaker of GEM's earthquake rupture forecasts. In addition to the choices in Table 1, ERF*r* can be an arbitrary text string matching a label in an earthquake rupture forecast in an associated hazard DIF, defined by the developer or caretaker of GEM's earthquake rupture forecasts. The list in Table 1 can be supplemented with non-California earthquake rupture forecasts with their own default parameter values.

Similarly, a list of ground-motion prediction equations drawn from a recent OpenSHA application is shown in Table 3. Whenever a label for a ground-motion prediction equation is required (generally referred to as "GMPE*r*"), the choices in Table 3 imply default values for the various parameters of each ground-motion prediction equation that must be defined by the developer or caretaker of GEM's ground-motion prediction equations. In addition to the choices in Table 3, GMPE1 can be an arbitrary text string matching a label in a ground-motion prediction equation in an associated hazard DIF, defined by the developer or caretaker of GEM's ground-motion prediction equations. The list in Table 3 can be supplemented with new ground-motion prediction equations with their own default parameter values.

5.2 HAZ01A AND B: EXCITATION BY SITE AND SCENARIO EVENT

This hazard-output DIF, in the form of two files, provides intensity information (median and logarithmic standard deviation) for one or more assets, for each of a set of events (ruptures of specified magnitude on given faults and fault segments), given one or more earthquake rupture forecasts and ground-motion prediction equations. The DIF also provides the mean rate of occurrence of each event.

This DIF is based on the output of Field's OpenSHA event set calculator. Some modifications have been proposed and were discussed with Field.

The DIF is referred to here as HAZ01, and the files as HAZ01A and HAZ01B. The first file, HAZ01A, contains an intensity estimate (median, total logarithmic standard deviation, and inter-event logarithmic standard deviation) by earthquake rupture forecast, ground-motion prediction equation, intensity measure type, source, rupture, and site. HAZ01B (Figure 6) provides magnitude and rate information by earthquake rupture forecast, source, and rupture. For simplicity, the flat file does not allow for tabulation of various parameter values that can vary by earthquake rupture forecast and ground-motion prediction equation. Figure 5 provides the layout of HAZ01A. Examples in the format of these DIFs are shown in Figure 7 (HAZ01A) and Figure 8 (HAZ01B). Some notes:

1. This DIF is modified slightly from the OpenSHA event-set calculator: the line number (ID) is added, as are the header line and fields for earthquake rupture forecast and the inter-event shaking uncertainty term LSDE. Sites are shown on separate lines and indicated with a site index, so that the file format need not change from portfolio to portfolio.
2. Some aspects of HAZ01 need additional definition, e.g., parameter values for earthquake rupture forecasts and ground-motion prediction equations. It is assumed these will be developed by or in collaboration with the person creating the hazard-centric DIFs.

```
[Explanatory header]
ID,ERF,Source,Rupture,GMPE,Site,VS30,Dist,IMT,Median,LSDT,LSDE
1,[ERF1],[SRC1],[RUP1],[GMPE1],[SITE1],[VS301],[DIST1],[IMT1],[MED1],
      [LSDT1],[LSDE1]
2,[ERF2],[SRC2],[RUP2],[GMPE2],[SITE2],[VS302],[DIST2],[IMT2],[MED2],
      [LSDT2],[LSDE2]
…
n,[ERFn],[SRCn],[RUPn],[GMPEn],[SITEn],[VS30n],[DISTn],[IMTn],[MEDn],
      [LSDTn], [LSDEn]
```

Figure 5. HAZ01A event-set site intensity estimate

```
[Explanatory header]
ID,ERF,Source,Rupture,Rate,Mag,SourceName
1,[ERF1],[SRC1],[RUP1],[RATE1],[MAG1],"[SourceName1]"
2,[ERF2],[SRC2],[RUP2],[RATE2],[MAG2],"[SourceName2]"
…
n,[ERFn],[SRCn],[RUPn],[RATEn],[MAGn],"[SourceNamen]"
```

Figure 6. HAZ01B source and rupture information

DISTr = rupture-to-site distance (km) as defined by the ground-motion prediction equation GMPEr.

ERFr = ID for earthquake rupture forecast used in record *r*, a text string. Need not be unique. See note on earthquake rupture forecasts in Section 5.1.

Explanatory header = as desired by hazard model, e.g., author, date, project name, etc. Need not be the same in each file.

GMPEr = ID for ground motion prediction equation used in record *r*. Need not be unique. It is a text string of variable length, generally like AAAYYYY, where AAA indicates authors' initials and YYYY is the publication year. See note on ground-motion prediction equations in Section 5.1.

ID = data line number (integer, 1, 2, …). It is for reference only to that particular file, and is not an index that relates two or more files. This field is new to most of DIFs proposed here. In practice it can be very helpful in QA to have reference line numbers.

IMTr = excitation type for record *r* (text string of variable length). An initial list is proposed in Table 2. Note that instrumental measures of acceleration are assumed to be in units of gravity and geometric-mean direction, unless noted otherwise. Instrumental measures of velocity and displacement are assumed to be in units of cm/sec and cm, respectively, and geometric-mean direction, unless noted otherwise.

LSDEr = inter-event portion of LSDTr (double-precision floating point). Intra-event portion is assumed = $(LSDTr^2 – LSDEr^2)^{0.5}$.

LSDTr = total logarithmic standard deviation of ground motion (double-precision floating point) of IMTr at SITr given rupture of SRCr on RUPr, using ATTr. Unitless.

MAGr = magnitude for record *r*, assumed to be moment magnitude, Mw, unless noted in the header (single-precision floating point).

MEDr = natural logarithm of median ground motion (double-precision floating point) of IMTr at SITr given rupture of SRCr on RUPr using GMPEr. Units are implicit in IMTr.

RATEr = mean exceedance rate of rupture (events per year; double-precision floating point).

RUPr = numeric rupture identifier for record *r* (integer; 0, 1, 2, 3, …), an index provided by the hazard model referring to a rupture segment on SRCr.

SITEr = numeric site identifier for record *r* (integer; 0, 1, 2, 3, …), an index provided by the portfolio referring to a particular location (latitude, longitude) where ground motion from this source and rupture is estimated.

SourceNamer = text name of source for record *r* (≤255 characters)

SRCr = numeric source identifier for record *r* (integer; 0, 1, 2, 3, …), an index provided by the hazard model referring to a fault or area source in the hazard model's database.

VS30r = mean shearwave velocity in the top 30 m of soil at site in record *r* (m/sec, single-precision floating point, > 0).

```
"K Porter 29 APR 2009 example HAZ01A event set"
ID,ERF,Source,Rupture,GMPE,Site,VS30,Dist,IMT,Median,LSDT,LSDE
1,UCERF1,1,0,CB2003,1,360,195,SA02,-35.000,0.5835,0.146
2,UCERF1,1,1,CB2003,1,360,192,SA02,-35.000,0.580,0.145
3,UCERF1,1,2,CB2003,1,360,189,SA02,-35.000,0.5765,0.144
4,UCERF1,1,3,CB2003,1,360,186,SA02,-35.000,0.573,0.143
5,UCERF1,1,4,CB2003,1,360,183,SA02,-35.000,0.5695,0.142
6,UCERF1,1,5,CB2003,1,360,180,SA02,-35.000,0.566,0.141
7,UCERF1,1,6,CB2003,1,360,177,SA02,-35.000,0.5625,0.141
8,UCERF1,1,7,CB2003,1,360,174,SA02,-35.000,0.559,0.140
9,UCERF1,1,8,CB2003,1,360,171,SA02,-35.000,0.5555,0.139
10,UCERF1,1,9,CB2003,1,360,168,SA02,-35.000,0.552,0.138
11,UCERF1,1,10,CB2003,1,360,165,SA02,-35.000,0.5485,0.137
```

Figure 7. Example HAZ01A event-set site intensity (extract)

```
"K Porter 28 Feb 2009 example HAZ01B source and rupture info"
ID,ERF,Source,Rupture,Rate,Mag,SourceName
1,UCERF1,1,0,6.765541E-5,6.25,sj13
2,UCERF1,1,1,1.0442353E-4,6.3,sj13
3,UCERF1,1,2,1.3548647E-4,6.35,sj13
4,UCERF1,1,3,1.47773E-4,6.4,sj13
5,UCERF1,1,4,2.3721055E-4,6.45,sj13
6,UCERF1,1,5,2.6143077E-4,6.5,sj13
7,UCERF1,1,6,2.7136767E-4,6.55,sj13
8,UCERF1,1,7,2.2218582E-4,6.6,sj13
9,UCERF1,1,8,2.2070653E-4,6.65,sj13
10,UCERF1,1,9,1.8323724E-4,6.7,sj13
11,UCERF1,1,10,1.3575674E-4,6.75,sj13
```

Figure 8. Example HAZ01B source and rupture information (extract)

5.3 HAZ01C: ENHANCEMENT TO HAZ01 TO QUANTIFY MODEL WEIGHTS

This DIF provides to HAZ01 weights (like probabilities) to assign to each combination of earthquake rupture forecast and ground-motion prediction equation in the HAZ01A DIF. These are often depicted as the weights in a logic tree. The DIF is used during hazard output. Figure 9 specifies the format of HAZ01C; Figure 10 provides an example specifying equal weighting for 3 ground-motion prediction equations under a single earthquake rupture forecast.

```
[Explanatory header]
ID,ERF,GMPE,Weight
1,[ERF1],[GMPE1],[WT1]
2,[ERF2],[GMPE2],[WT2]
…
n,[ERFn],[GMPEn],[WTn]
```

Figure 9. HAZ01C source, magnitude, and rate information

ERFr and GMPEr are as defined in HAZ01A

WTr = weight assigned to the combination of earthquake rupture forecast and ground-motion prediction equation in record *r* (double-precision floating point, $0 \leq$ WTr ≤ 1), and weights sum (over all r) to 1.000 ± 0.001.

```
"K Porter 28 Feb 2009 example HAZ01D event set weighting"
ID,ERF,GMPE,Weight
1,UCERF1,BA2003,0.3334
2,UCERF1,BJF2007,0.3333
3,UCERF1,SEA1997,0.3333
```

Figure 10. Example of HAZ01C source, magnitude, and rate information

5.4 HAZ02: GRIDDED HAZARD FILE LIKE FRANKEL ET AL. (2002)

This hazard-output DIF provides the mean frequency of exceedance of up to 20 specified levels of intensity, at each in an arbitrary set of (lat, lon) pairs points, such as gridpoints on a grid, for a given intensity measure type, earthquake rupture forecast, ground-motion prediction equation, NEHRP site soil class, and mean shearwave velocity in the top 20m of soil. The DIF is borrowed largely from a text version of the data file for Frankel et al.'s (2002) U.S. National Seismic Hazard Maps, with minor modifications for consistency with other DIFs. The modifications are the addition of the 1st two header lines, the rearrangement of the column header line (currently the intensity levels and IMT appear on separate lines), the addition of the ID column, and fixing the number of columns to 20. The DIF is referred to here as HAZ02.

```
[Explanatory header]
[IMT],[ERF],[GMPE],[SOIL],[VS30]
ID,Lat,Lon,[X1],[X2],[X3],…,[X20]
1,[Lat1],[Lon1],[Y1,1],[Y1,2],[Y1,3],…,[Y1,20]
2,[Lat2],[Lon2],[Y2,1],[Y2,2],[Y2,3],…,[Y2,20]
…
n,[Latn],[Lonn],[Yn,1],[Yn,2],[Yn,3],…,[Yn,20]
```

Figure 11. HAZ02 gridded seismic hazard

Explanatory header = as desired by hazard model, e.g., author, date, project name, etc.

ERF = ID for earthquake rupture forecast as defined for HAZ01.

IMT = excitation type (for entire file), as defined for HAZ01.

SOIL = NEHRP site soil category for hazard curves in this file, in {A, AB, B, BC, … E}, e.g., per ICC (2006).

Vs30 = mean shearwave velocity in the top 30 m of soil (m/sec, single-precision floating point, > 0).

X1 = ground motion level 1 (double-precision floating point, > 0)

X2 = ground motion level 2 (double-precision floating point, > X1)

Xc = ground motion level c (double-precision floating point, > Xc-1, c in 2, 3, … 20)

Lat1 = latitude of site in record 1, decimal degrees north (double-precision floating point)

Lon1 = longitude of site in record 1, decimal degrees east (negative west, double-precision floating point).

Y1,1 = mean rate at which X1 is exceeded at the site in record 1, events/yr (double-precision floating point, ≥ 0), given that the site has mean shearwave velocity in the top 30 m of soil indicated by [Vs30].

Y1,2 = mean rate at which X2 is exceeded at the site in record 1, events/yr (double-precision floating point, 0 ≤ Y1,2 ≤ Y1,1)

Yr,c = mean rate at which Xc is exceeded at the site in record r, events/yr (double-precision floating point, 0 ≤ Yr,c ≤ Yr,c-1 for c > 1)

```
"Based on Frankel and Leyendecker (2002) NSHMP gridded hazard file"
SA10,USGS2002,USGS2002,BC,760
ID,Lat,Lon,0.2500E-02,0.3750E-02,0.5630E-02,0.8440E-02,0.1270E-01,0.1900E-
      01,0.2850E-01,0.4270E-01,0.6410E-01,0.9610E-
      01,0.1440E+00,0.2160E+00,0.3240E+00,0.4870E+00,0.7300E+00,0.1090E+01,0.
      1640E+01,0.2460E+01,0.3690E+01,0.5540E+01
1,43.00,-125.00,0.5947E-01,0.5116E-01,0.4206E-01,0.3340E-01,0.2587E-
      01,0.1983E-01,0.1507E-01,0.1145E-01,0.8718E-02,0.6625E-02,0.4948E-
      02,0.3523E-02,0.2314E-02,0.1347E-02,0.6541E-03,0.2396E-03,0.5748E-
      04,0.8609E-05,0.7618E-06,0.3859E-07
2,43.00,-124.95,0.6050E-01,0.5200E-01,0.4273E-01,0.3391E-01,0.2626E-
      01,0.2015E-01,0.1535E-01,0.1174E-01,0.9035E-02,0.6959E-02,0.5277E-
      02,0.3840E-02,0.2601E-02,0.1574E-02,0.8033E-03,0.3157E-03,0.8364E-
      04,0.1419E-04,0.1452E-05,0.8637E-07
3,43.00,-124.90,0.6152E-01,0.5285E-01,0.4340E-01,0.3443E-01,0.2666E-
      01,0.2046E-01,0.1561E-01,0.1199E-01,0.9301E-02,0.7235E-02,0.5540E-
      02,0.4080E-02,0.2826E-02,0.1774E-02,0.9525E-03,0.3978E-03,0.1127E-
      03,0.2040E-04,0.2221E-05,0.1399E-06
4,43.00,-124.85,0.6278E-01,0.5393E-01,0.4427E-01,0.3512E-01,0.2717E-
      01,0.2083E-01,0.1587E-01,0.1220E-01,0.9499E-02,0.7429E-02,0.5697E-
      02,0.4165E-02,0.2834E-02,0.1735E-02,0.9083E-03,0.3712E-03,0.1031E-
      03,0.1831E-04,0.1953E-05,0.1202E-06
5,43.00,-124.80,0.6404E-01,0.5499E-01,0.4511E-01,0.3573E-01,0.2760E-
      01,0.2111E-01,0.1607E-01,0.1237E-01,0.9659E-02,0.7576E-02,0.5799E-
      02,0.4191E-02,0.2786E-02,0.1659E-02,0.8478E-03,0.3407E-03,0.9320E-
      04,0.1628E-04,0.1702E-05,0.1023E-06
```
Figure 12. Sample extract of HAZ02 gridded seismic hazard file

5.5 HAZ03: GROUND MOTION FROM SYNTHETIC CATALOG FOR SIMPLE MCS

This hazard-output DIF provides a single simulation of intensity at each of a set of sites in a series of one or more synthetic catalogs of equal duration. It is intended to serve simple Monte Carlo simulation of site or portfolio risk: a sequence of one or more equiprobable synthetic catalogs of events. That is, each catalog is equiprobable, and contains a sequence of events whose frequency of occurrence within the catalog approximates their ideal frequency within the earthquake rupture forecast. The events themselves within each catalog are not intended to be equiprobable. Each catalog is of a given duration, and includes a variable number of events, each with a date and time of occurrence, source, rupture segment, and magnitude. Fault distance and simulated ground motion at each of one or more sites is provided for each event; the DIF allows for multiple intensity measures in each synthetic event at each site. Figure 13 specifies the proposed DIF; Figure 14 contains an example extract with 2 events and 2 intensity measure types.

```
[Explanatory header]
[DURN]
ID,CAT,EVT,DATE,IMT,Source,Rupture,M,Site,IML
1,[CAT1],[EVT1],[DATE1],[IMT1],[SRC1],[RUP1],[M1],[SITE1],[DIST1],
      [IML1]
2,[CAT2],[EVT2],[DATE2],[IMT2],[SRC2],[RUP2],[M2],[SITE2],[DISTn],
      [IML2]
…
n,[CATn],[EVTn],[DATEn],[IMTn],[SRCn],[RUPn],[Mn],[SITEn],[DISTn],
      [IMLn]
```

Figure 13. HAZ03 site intensity estimate for MCS

DURN = duration of all catalogs, years (double-precision floating point > 0)

CATr = ID of catalog in record *r* (integer, in 1, 2, …)

EVTr = ID of event within catalog CATr in record *r* (integer, in 1, 2, …)

DATEr = date and local time of event in record *r* (YYYYMMDDHHMM, with all obvious constraints on date and time)

IMTr, SRCr, RUPr, Mr, SITEr, DISTr, as previously defined

IMLr = simulated ground motion intensity (measured in terms of IMT) in record *r*

```
"K Porter 28 Feb 2009 example extract of HAZ03 synthetic catalog"
10000
ID,CAT,EVT,DATE,IMT,Source,Rupture,M,Site,IML
1,1,1,264206180830,SA03,21,1,8.0,0.161
2,1,1,264206180830,SA10,21,1,8.0,0.008
3,1,2,531401011437,SA03,21,1,7.6,0.102
4,1,2,531401011437,SA10,21,1,7.6,0.006
```

Figure 14. Example HAZ03 file

5.6 HAZ04: UNIFORM SEISMIC HAZARD DATA

This hazard-output DIF provides intensity with a single specified exceedance frequency at each of a set of sites defined by latitude, longitude, and Vs30, for a given combination of intensity measure type, earthquake rupture forecast, and ground-motion prediction equation. Figure 15 specifies the contents of HAZ04, while Figure 16 illustrates with 2 sites and 4 soil classes.

```
[Explanatory header]
[IMT],[G],[ERF],[GMPE]
ID,SITE,Lat,Lon,VS30,IML
1,[SITE1],[Lat1],[Lon1],[VS30-1],[IML1]
2,[SITE2],[Lat2],[Lon2],[VS30-2],[IML2]
…
n,[SITEn],[Latn],[Lonn],[VS30-n],[IMLn]
```

Figure 15. HAZ04 source, magnitude, and rate information

ERF = earthquake rupture forecast used (text string of variable length, limited to available earthquake rupture forecasts, beginning with the list in Table 1)

G = exceedance frequency of interest, events/yr (double-precision floating point, > 0)

GMPE = ground-motion prediction equation used (text string of variable length, limited to available ground-motion prediction equations). See Section 5.1 for note on ground-motion prediction equations.

IMLr = intensity (measured in terms of the IMT) associated with the given exceedance frequency at the site in record r (double-precision floating point, > 0).

IMT = intensity measure type (variable length text, beginning with the list in Table 2)

LATr = latitude of site in record *r* (double-precision floating point, decimal degrees N, within ± 90.0)

LONr = longitude of site in record *r* (double-precision floating point, decimal degrees E, within ± 180.0)

Vs30 = mean shearwave velocity in the top 30 m of soil (m/sec, single-precision floating point, > 0).

```
"K Porter 28 Feb 2009 sample extract of HAZ04 USH data file"
SA02,0.0004,UCERF2,USGS2006
ID,SITE,Lat,Lon,VS30,IML
1,1,34.00,-118.40,1125,1.78
2,1,34.00,-118.40,550,1.78
3,1,34.00,-118.40,275,1.78
4,1,34.00,-118.40,120,1.60
5,1,34.00,-118.35,1125,1.74
6,1,34.00,-118.35,550,1.74
7,1,34.00,-118.35,275,1.74
8,1,34.00,-118.35,120,1.57
```

Figure 16. Example HAZ04 file of uniform seismic hazard

6 STRUCTURAL RESPONSE DIFS

6.1 PREFACE TO STRUCTURAL RESPONSE DIFS

The structural response DIFs presented in this section are the output of structural analyses of individual building models. They document structural response in terms of story-level accelerations and transient and permanent drift ratios.

6.2 RSP01: STRUCTURAL RESPONSE FOR 1 BUILDING AND 1 IML

This structural-analysis DIF documents structural response estimated using nonlinear dynamic structural analysis of one structural model subjected to one or more ground-motion time histories all with the same IML. The DIF contains an m x n rectangular matrix with an arbitrary explanatory header, a header containing metadata about the analyses, row and column headers, and n response vectors (one for each structural analysis) of m components each (i.e., m response parameters in the vector). Response to each ground-motion time history (if a 2-D analysis is performed) or pair of orthogonal time histories (if 3-D analysis is performed) is expressed in a single column vector. The DIF assumes that if 2-D analysis is performed, the ground motions are in the horizontal direction, applied parallel to the plane of the response parameters, and with the same directions as positive. If 3-D analysis is performed, the DIF assumes that the ground motions are in the horizontal direction, orthogonal to each other, and that the two orthogonal directions are each parallel to a corresponding set of response parameters. Figure 17 defines the DIF; Figure 18 provides an example. Lines in Figure 18 have a hanging indent only to show where new lines begin. The actual data file would not wrap lines.

```
[Explanatory header]
[IMT],[IML],[BB],[DDX],[DDY]
RspParam\GMTHID,[GMTH01],[GMTH02],...,[GMTHj],...[GMTHn]
[PARAM01],[RSP0101],[RSP0102],...,[RSP01jj],...[RSP01n]
[PARAM02],[RSP0201],[RSP0202],...,[RSP02jj],...[RSP02n]
...
[PARAMi],[RSPi01],[RSPi02],...,[RSPij],...[RSPin]
...
[PARAMm],[RSPm01],[RSPm02],...,[RSPmj],...[RSPmn]
```

Figure 17. RSP01 structural response information

IMT = intensity measure type (variable length text, beginning with the list in Table 2)

IML = intensity (measured in terms of the IMT) associated with the ground motion time histories whose response is recorded here. A single IML is reflected in one RSP01 file (double-precision floating point, > 0).

BB = index for building number (01, 02, etc.) (integer ≥ 0)

DDX = direction of (x-component of) ground motion and of the response parameters. If 2-D analysis, give azimuth in decimal degrees clockwise from north of the ground motion (float, -360.0 < DDX < 360). If 3-D analysis, give azimuth in decimal degrees clockwise from north of the first component of ground motion (float, -360.0 < DDX < 360).

DDY = direction of y-component of ground motion and of the response parameters. If 2-D analysis, give DDY = DDX, which will indicate 2-D analysis. If 3-D, give azimuth of the y-component of ground motion and structural response in decimal degrees clockwise from north of the ground motion (float, -360.0 < DDY < 360).

GMTHj = index to ground-motion time histories or pairs of ground-motion time histories, where j is an integer in (01, 02, ... n) and GMTHj is an integer in (01, 02, ...)

PARAMi = label for component i of the structural response vector, where i is in 1, 2, ... m, and PARAMi is a string of any of these forms:

AXfff denotes peak floor acceleration in direction DDX for floor fff (e.g., AX001 for the lowest floor level, AX002 for the next-higher floor level, etc.), where fff is an integer in (001, 002, ...)

AYfff denotes peak floor acceleration in direction DDY for floor fff (e.g., AY001 for the lowest floor level, AY002 for the next-higher floor level, etc.)

PTDXsss to denote peak transient drift of story sss in direction DDX (e.g., PTDX001 to denote peak transient drift ratio in direction DDX of story 1, i.e., between floors 1 and 2)

PTDYsss to denote peak transient drift of story structures in direction DDY (e.g., PTDY001 to denote peak transient drift ratio in direction DDY of story 1, i.e., between floors 1 and 2)

RDXsss to denote residual drift (if calculated) in direction DDX of story sss (e.g., RDX001 to denote residual drift in direction X of story 1, if calculated)

RDYsss to denote residual drift (if calculated) in direction DDY of story sss (e.g., RDY001 to denote residual drift in direction X of story 1, if calculated)

RSPij = absolute value of structural response parameter i when subjected to ground motion j, a real nonnegative value if the structural analysis converges, i.e., RSPij ≥ 0.0. In case a structural analysis fails to converge, fill the response vector with values of -1. Further constraints depend on PARAMi:

If PARAMi is AXnnn or AYnnn, RSPij is peak absolute value of acceleration in the direction indicated (DDX if PARAMi is AXnnn or DDY if PARAMi is AYnnn) in units of gravity

If PARAMi is PTDXnnn or PTDYnnn, RSPij is peak transient drift ratio of story nnn in the direction indicated (DDX if PARAMi is PTDXnnn or DDY if PARAMi is PTDYnnn), defined as the peak absolute value over time of the displacement of the floor above the story relative to the floor below it divided by the vertical distance between the top of finished floor for the floor above and the top of finished floor for the floor below story nnn.

If PARAMi is PRDXnnn or PRDYnnn, RSPij is peak residual drift ratio of story nnn in the direction indicated (DDX if PARAMi is PRDXnnn or DDY if PARAMi is PRDYnnn), defined as the absolute value of the final (at-rest) displacement of the floor above the story relative to the floor below it divided by the vertical distance between the top of finished floor for the floor above and the top of finished floor for the floor below story nnn.

```
"Keith Porter response of California office building 1"
SA02,1.8,1,0,0
RspParam\GMTHID,1,2,3,4,5,6,7,8,9,10,11
AX001,1.080081,1.1139255,1.135998,1.8055305,1.789344,1.188972,1.26549,
     1.032993,1.197801,1.907064,1.595106
AX002,0.444424057,0.726646279,0.554057085,0.905219164,0.956839959,0.68
     1997961,0.562568807,0.81941896,0.699082569,0.91579001,0.62695209
AX003,0.873180428,1.22833843,0.976503568,0.877961264,1.237716616,1.083
     180428,0.698002039,1.663200815,1.100611621,1.367278287,1.01977573
     9
AX004,1.171763507,1.576554536,1.155249745,1.080632008,1.481345566,1.48
     0530071,0.920183486,2.302956167,1.356574924,1.740672783,1.3835881
     75
```

```
AX005,1.414169215,1.872273191,1.331396534,1.142507645,1.828746177,1.82
      1202854,1.203873598,2.287971458,1.714475025,1.822833843,1.5
AX006,1.493272171,2.116513761,1.467991845,1.511620795,2.099898063,2.01
      1213048,1.422629969,2.002038736,1.920081549,1.999592253,1.6164118
      25
PTDX001,0.001751387,0.001394743,0.002243624,0.002918121,0.00207774,0.0
      02232125,0.00245906,0.002553468,0.002519911,0.002463535,0.0022977
      63
PTDX002,0.001822422,0.001485176,0.002424451,0.004288199,0.002495342,0.
      002318489,0.003100828,0.00377706,0.003245135,0.002940373,0.002121
      159
PTDX003,0.001599771,0.001278719,0.001727002,0.0022373,0.001958581,0.00
      1822426,0.001957895,0.002126545,0.002070481,0.002112128,0.0017290
      62
PTDX004,0.001153318,0.000925172,0.001185584,0.001668879,0.001567506,0.
      001297941,0.001432265,0.001511899,0.001548741,0.001628375,0.00119
      7712
PTDX005,0.000614953,0.000493458,0.000617991,0.000956308,0.000893224,0.
      000697664,0.000774065,0.00081215,0.00081986,0.000915421,0.0006418
      22
RDX001,6.59958E-05,2.93134E-
      05,0.000136569,0.000405549,0.000105589,0.000128689,0.000194516,8.
      18136E-05,0.000287603,0.00024178,0.000133761
RDX002,2.17906E-06,2.2893E-
      06,0.000345386,0.001581317,0.00011817,0.000292882,0.000820168,0.0
      01272445,0.000599462,0.000745557,9.56926E-05
RDX003,1.70073E-06,1.78279E-06,7.03854E-06,7.76129E-06,5.85042E-
      07,4.93078E-06,4.57666E-08,2.26567E-09,1.32995E-07,1.14666E-
      06,2.59383E-06
RDX004,1.13449E-06,1.18669E-06,4.71079E-06,5.17162E-06,3.93457E-
      07,3.28047E-06,2.28833E-08,1.58597E-09,8.72284E-08,7.65344E-
      07,1.72545E-06
RDX005,5.79254E-07,6.04932E-07,2.41487E-06,2.63787E-06,2.02693E-
      07,1.67368E-06,3.46997E-09,6.93995E-10,4.3953E-08,3.89794E-
      07,8.79483E-07
```

Figure 18. Example RSP01 file of structural response vectors

7 DAMAGE ANALYSIS DIFS: FRAGILITY AND DAMAGE OUTPUT

7.1 PREFACE TO FRAGILITY DIFS

DIFs presented in the 1st part of this section all address fragility models, and are used in the 1st part of a damage analysis. They are labeled "FRA" to indicate fragility. Fragility is different from vulnerability. Fragility relates the probability of reaching or exceeding a predefined limit state (often referred to as a damage state) as a function of some input excitation. Vulnerability, by contrast, usually refers to loss as a function of input excitation. Probability is bounded by 0 and 1, whereas loss is generally bounded below by 0 and in some cases is for practical purposes unbounded above. In earthquakes, the excitation can be a measure of ground motion or structural response. Ground motion is typically parameterized for use in macroscopic loss estimation in terms of various response spectral displacement and acceleration parameters (including PGA), macroseismic intensity, and perhaps a dozen other less-used measures, collectively referred to here as intensity measures. Structural response is typically parameterized for use in performance-based earthquake engineering in terms of structural member forces and various deformation or displacement measures, such as interstory drift, nodal acceleration, etc. GEM seems primarily interested in macroscopic loss estimation, so for simplicity's sake only intensity measures will be considered here.

7.2 FRA01: HAZUS-BASED FRAGILITY FUNCTION

This damage-analysis DIF provides the probability of each of three HAZUS-MH building components being in each of four damage states, for given combinations of HAZUS-MH structure type, seismic domain (plate boundary or continental interior), magnitude, rupture distance, and an $S_a(0.3)$, $S_a(1.0)$ pair. It provides the mean fraction of building area in the collapse damage state. It also provides in each record an indicator of whether damage states are better estimated by $S_a(0.3)$ or $S_a(1.0)$ (the former if the performance point probably lies on the constant-acceleration portion of the idealized HAZUS-MH demand spectrum, the latter if the performance point probably lies on the constant-velocity portion).

This DIF is used for reporting seismic fragility functions for building-component damage states, created using the HAZUS-MH methodology (e.g., Porter 2009a). In the HAZUS-MH methodology, there are 12 general fragility functions for ordinary buildings: 4 fragility functions for each of 3 general building components: the structural system (e.g., beams, columns, shearwalls, etc.), the nonstructural drift-sensitive component (e.g., interior partitions, glazing, etc.), and the nonstructural acceleration-sensitive component (e.g., contents). The four damage states are qualitatively named and defined: slight, moderate, extensive, and complete. The reader is referred to NIBS and FEMA (2003) for damage-state definitions.

The probability of any component reaching or exceeding a given damage state depends on the structure type, shaking intensity, seismic domain (plate boundary or continental interior), magnitude, distance, and site soil classification. As with the HAZUS-MH vulnerability models, the proper intensity measure to use can vary with intensity. More often than not one should use the 5%-damped spectral acceleration response at 1-second period, but for stiffer structures and low intensities, the proper intensity measure can be 5%-damped spectral acceleration response at 0.3-second period.

In any event, a single seismic fragility function in the FRA01 DIF is spread over many adjacent records with the same abbreviation (ABR, below), seismic domain, magnitude M, distance R, and soil. Records increase in terms of spectral displacement—a hidden variable and immaterial for the seismic vulnerability function—although SA03 and SA10 generally increase with spectral displacement. Figure 35 specifies the layout of the FRA01 HAZUS-MH indoor-casualty-rate vulnerability-function table. An example is shown in Figure 36.

```
[Explanatory header]
ABR,Domain,M,R,Soil,SA03,SA10,IM,P11,P12,P13,P14,P15,P21,P22,P23,P24,P31,P32,P33,P34
[ABR1],[DOM1],[M1],[R1],[SOIL1],[SA03-1],[SA10-1],[IM1],[P11-1],[P12-1],[P13-1],[P14-
       1],[P15-1],[P21-1],[P22-1],[P23-1],[P24-1],[P31-1],[P32-1],[P33-1],[P34-1]
[ABR2],[DOM2],[M2],[R2],[SOIL2],[SA03-2],[SA10-2],[IM2],[P11-2],[P12-2],[P13-2],[P14-
       2],[P15-2],[P21-2],[P22-2],[P23-2],[P24-2],[P31-2],[P32-2],[P33-2],[P34-2]
…
[ABRn],[DOMn],[Mn],[Rn],[SOILn],[SA03-n],[SA10-n],[IMn],[P11-n],[P12-n],[P13-n],[P14-
       n],[P15-n],[P21-n],[P22-n],[P23-n],[P24-n],[P31-n],[P32-n],[P33-n],[P34-n]
```

Figure 19. FRA01 HAZUS-MH component fragility functions

Explanatory header = as desired by vulnerability modeler, e.g., author, date, project name, etc. (text string ≤ 255 characters long)

ABRr = abbreviation for vulnerability model in record *r* (text string up to 25 characters in length).

DOMr = seismic domain for the vulnerability model in record r (text, either WUS for plate boundary or CEUS for continental interior)

Mr = magnitude for the vulnerability model in record r (integer, in 5, 6, 7, 8)

Rr = fault rupture distance (km) for the vulnerability model in record r (integer, in 10, 20, 40, 80, where 10 refers to $R < 15$ km, 20 refers to $15 \leq R < 30$ km, 40 refers to $30 \leq R < 60$ km, and 80 refers to $60 \leq R$).

SOILr = NEHRP site soil classification for the vulnerability model in record r (text, in A, B, C, D, or E)

SA03-r = soil-amplified 5%-damped spectral acceleration response at 0.3-sec period (units of g) for the vulnerability model in record r, SA03-1 ≥ 0.

SA10-r = soil-amplified 5%-damped spectral acceleration response at 1.0-sec period (units of g) for the vulnerability model in record r, SA10-1 ≥ 0.

IMr = better intensity measure to use for the vulnerability model in record r at this level of intensity (text, either “SA03” or “SA10”)

P11-r = probability that the structural component reaches or exceeds slight damage (double-precision floating point, 0 ≤ P11-r ≤ 1) given all the conditions in record r.

P12-r = probability that the structural component reaches or exceeds moderate damage (double-precision floating point, 0 ≤ P12-r ≤ P11-r ≤ 1) given all the conditions in record r.

P13-r = probability that the structural component reaches or exceeds extensive damage (double-precision floating point, 0 ≤ P13-r ≤ P12-r ≤ 1) given all the conditions in record r.

P14-r = probability that the structural component reaches or exceeds complete damage (double-precision floating point, 0 ≤ P14-r ≤ P13-r ≤ 1) given all the conditions in record r.

P15-r = fraction of building area that is in the collapsed damage state (double-precision floating point, 0 ≤ P15-r ≤ P14-r ≤ 1) given all the conditions in record r.

P21-r = probability that the nonstructural drift-sensitive component reaches or exceeds slight damage (double-precision floating point, 0 ≤ P21-r ≤ 1) given all the conditions in record r.

P22-r = probability that the nonstructural drift-sensitive component reaches or exceeds moderate damage (double-precision floating point, $0 \leq$ P22-r $\leq$ P21-r ≤ 1) given all the conditions in record r.

P23-r = probability that the nonstructural drift-sensitive component reaches or exceeds extensive damage (double-precision floating point, $0 \leq$ P23-r $\leq$ P22-r ≤ 1) given all the conditions in record r.

P24-r = probability that the nonstructural drift-sensitive component reaches or exceeds complete damage (double-precision floating point, $0 \leq$ P24-r $\leq$ P23-r ≤ 1) given all the conditions in record r.

P31-r = probability that the nonstructural acceleration-sensitive component reaches or exceeds slight damage (double-precision floating point, $0 \leq$ P11-r ≤ 1) given all the conditions in record r.

P32-r = probability that the nonstructural acceleration-sensitive component reaches or exceeds moderate damage (double-precision floating point, $0 \leq$ P12-r $\leq$ P11-r ≤ 1) given all the conditions in record r.

P33-r = probability that the nonstructural acceleration-sensitive component reaches or exceeds extensive damage (double-precision floating point, $0 \leq$ P13-r $\leq$ P12-r ≤ 1) given all the conditions in record r.

P34-r = probability that the nonstructural acceleration-sensitive component reaches or exceeds complete damage (double-precision floating point, $0 \leq$ P14-r $\leq$ P13-r ≤ 1) given all the conditions in record r.

```
"K Porter 24 Feb 2009 sample HAZUS-based fragility functions"
Abbrev,Domain,M,R,Soil,SA03,SA10,IM,P11,P12,P13,P14,P15,P21,P22,P23,P24,P31,P32,P33,P34
W1h,WUS,7,20,D,0.01,0,SA03,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
W1h,WUS,7,20,D,0.02,0,SA03,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
W1h,WUS,7,20,D,0.02,0,SA03,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
W1h,WUS,7,20,D,0.03,0.02,SA03,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
W1h,WUS,7,20,D,0.03,0.02,SA03,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
W1h,WUS,7,20,D,0.04,0.02,SA03,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
W1h,WUS,7,20,D,0.05,0.02,SA03,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
W1h,WUS,7,20,D,0.07,0.05,SA03,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
W1h,WUS,7,20,D,0.09,0.05,SA03,0.00,0.00,0.00,0.00,0.00,0.01,0.00,0.00,0.00,0.01,0.00,0.00,0.00
W1h,WUS,7,20,D,0.11,0.07,SA03,0.01,0.00,0.00,0.00,0.00,0.02,0.00,0.00,0.00,0.02,0.00,0.00,0.00
W1h,WUS,7,20,D,0.14,0.1,SA03,0.02,0.00,0.00,0.00,0.00,0.03,0.00,0.00,0.00,0.04,0.00,0.00,0.00
W1h,WUS,7,20,D,0.17,0.1,SA03,0.04,0.00,0.00,0.00,0.00,0.05,0.01,0.00,0.00,0.07,0.01,0.00,0.00
W1h,WUS,7,20,D,0.22,0.12,SA03,0.07,0.00,0.00,0.00,0.00,0.09,0.02,0.00,0.00,0.13,0.01,0.00,0.00
W1h,WUS,7,20,D,0.27,0.17,SA03,0.13,0.01,0.00,0.00,0.00,0.14,0.03,0.00,0.00,0.21,0.03,0.00,0.00
W1h,WUS,7,20,D,0.35,0.22,SA03,0.19,0.01,0.00,0.00,0.00,0.21,0.06,0.00,0.00,0.31,0.06,0.01,0.00
W1h,WUS,7,20,D,0.44,0.26,SA03,0.28,0.03,0.00,0.00,0.00,0.29,0.09,0.00,0.00,0.43,0.11,0.01,0.00
W1h,WUS,7,20,D,0.55,0.33,SA03,0.39,0.05,0.00,0.00,0.00,0.39,0.14,0.01,0.00,0.56,0.19,0.03,0.00
W1h,WUS,7,20,D,0.71,0.4,SA03,0.50,0.09,0.00,0.00,0.00,0.50,0.21,0.02,0.00,0.67,0.29,0.06,0.00
W1h,WUS,7,20,D,0.93,0.55,SA03,0.61,0.14,0.01,0.00,0.00,0.61,0.30,0.03,0.01,0.74,0.37,0.09,0.01
W1h,WUS,7,20,D,1.18,0.7,SA03,0.72,0.21,0.02,0.00,0.00,0.71,0.39,0.06,0.01,0.79,0.44,0.12,0.01
W1h,WUS,7,20,D,1.48,0.88,SA03,0.81,0.31,0.03,0.00,0.00,0.79,0.50,0.10,0.02,0.83,0.50,0.15,0.02
W1h,WUS,7,20,D,1.83,1.1,SA03,0.87,0.41,0.05,0.01,0.00,0.86,0.60,0.15,0.04,0.86,0.55,0.18,0.03
W1h,WUS,7,20,D,2.19,1.32,SA03,0.93,0.52,0.09,0.02,0.00,0.91,0.69,0.22,0.07,0.88,0.60,0.22,0.04
W1h,WUS,7,20,D,2.62,1.57,SA03,0.96,0.63,0.14,0.03,0.00,0.95,0.78,0.30,0.11,0.90,0.64,0.26,0.05
W1h,WUS,7,20,D,3.05,1.83,SA03,0.98,0.74,0.21,0.05,0.00,0.97,0.85,0.40,0.16,0.92,0.68,0.29,0.06
W1h,WUS,7,20,D,3.55,2.13,SA03,0.99,0.82,0.29,0.08,0.00,0.98,0.90,0.50,0.23,0.93,0.72,0.33,0.07
W1h,WUS,7,20,D,4.11,2.46,SA03,1.00,0.88,0.39,0.12,0.00,0.99,0.94,0.61,0.31,0.95,0.76,0.37,0.09
W1h,WUS,7,20,D,4.63,2.78,SA03,1.00,0.93,0.50,0.17,0.01,1.00,0.97,0.70,0.41,0.95,0.79,0.41,0.11
W1h,WUS,7,20,D,5.18,3.11,SA03,1.00,0.96,0.60,0.24,0.01,1.00,0.98,0.79,0.50,0.96,0.81,0.45,0.13
W1h,WUS,7,20,D,5.74,3.45,SA03,1.00,0.98,0.71,0.32,0.01,1.00,0.99,0.85,0.60,0.97,0.83,0.48,0.14
W1h,WUS,7,20,D,6.09,3.66,SA03,1.00,0.99,0.79,0.41,0.01,1.00,1.00,0.90,0.69,0.97,0.84,0.50,0.15
W1h,WUS,7,20,D,6.48,3.88,SA03,1.00,1.00,0.86,0.50,0.02,1.00,1.00,0.94,0.77,0.97,0.85,0.50,0.15
W1h,WUS,7,20,D,6.66,3.99,SA03,1.00,1.00,0.91,0.59,0.02,1.00,1.00,0.97,0.84,0.97,0.85,0.50,0.15
W1h,WUS,7,20,D,6.85,4.11,SA03,1.00,1.00,0.95,0.68,0.02,1.00,1.00,0.98,0.89,0.97,0.85,0.50,0.15
W1h,WUS,7,20,D,8.15,4.89,SA10,1.00,1.00,0.97,0.76,0.02,1.00,1.00,0.99,0.93,0.97,0.85,0.50,0.15
W1h,WUS,7,20,D,9.15,5.49,SA10,1.00,1.00,0.98,0.83,0.02,1.00,1.00,1.00,0.96,0.97,0.85,0.50,0.15
W1h,WUS,7,20,D,10.38,6.23,SA10,1.00,1.00,0.99,0.88,0.03,1.00,1.00,1.00,0.98,0.97,0.85,0.50,0.15
W1h,WUS,7,20,D,11.65,6.99,SA10,1.00,1.00,1.00,0.92,0.03,1.00,1.00,1.00,0.99,0.97,0.85,0.50,0.15
W1h,WUS,7,20,D,13.07,7.84,SA10,1.00,1.00,1.00,0.95,0.03,1.00,1.00,1.00,0.99,0.97,0.85,0.50,0.15
W1h,WUS,7,20,D,14.82,8.89,SA10,1.00,1.00,1.00,0.97,0.03,1.00,1.00,1.00,1.00,0.97,0.85,0.50,0.15
W1h,WUS,7,20,D,16.62,9.97,SA10,1.00,1.00,1.00,0.98,0.03,1.00,1.00,1.00,1.00,0.97,0.85,0.50,0.15
W1h,WUS,7,20,D,18.65,11.19,SA10,1.00,1.00,1.00,0.99,0.03,1.00,1.00,1.00,1.00,0.97,0.85,0.50,0.15
W1h,WUS,7,20,D,20.92,12.55,SA10,1.00,1.00,1.00,1.00,0.03,1.00,1.00,1.00,1.00,0.97,0.85,0.50,0.15
W1h,WUS,7,20,D,23.48,14.09,SA10,1.00,1.00,1.00,1.00,0.03,1.00,1.00,1.00,1.00,0.97,0.85,0.50,0.15
W1h,WUS,7,20,D,26.35,15.81,SA10,1.00,1.00,1.00,1.00,0.03,1.00,1.00,1.00,1.00,0.97,0.85,0.50,0.15
W1h,WUS,7,20,D,29.55,17.73,SA10,1.00,1.00,1.00,1.00,0.03,1.00,1.00,1.00,1.00,0.97,0.85,0.50,0.15
W1h,WUS,7,20,D,33.17,19.9,SA10,1.00,1.00,1.00,1.00,0.03,1.00,1.00,1.00,1.00,0.97,0.85,0.50,0.15
W1h,WUS,7,20,D,37.22,22.33,SA10,1.00,1.00,1.00,1.00,0.03,1.00,1.00,1.00,1.00,0.97,0.85,0.50,0.15
W1h,WUS,7,20,D,41.75,25.05,SA10,1.00,1.00,1.00,1.00,0.03,1.00,1.00,1.00,1.00,0.97,0.85,0.50,0.15
W1h,WUS,7,20,D,46.85,28.11,SA10,1.00,1.00,1.00,1.00,0.03,1.00,1.00,1.00,1.00,0.97,0.85,0.50,0.15
W1h,WUS,7,20,D,52.57,31.54,SA10,1.00,1.00,1.00,1.00,0.03,1.00,1.00,1.00,1.00,0.97,0.85,0.50,0.15
```

Figure 20. Sample FRA01 fragility functions

7.3 FRA02: LOGNORMAL FRAGILITY FUNCTION

This damage-analysis DIF provides the median and logarithmic standard deviation of an asset type's capacity to resist one or more specified damage states. It also provides a brief description of the damage states, along with a label for the intensity measure type used to measure capacity.

It provides for the compact definition of one of the most common fragility functions: one that expresses the probability of reaching or exceeding a specified limit state using a lognormal cumulative distribution function. There are of course many other ways to quantify a fragility function, such as cumulative distribution functions of other forms (normal, beta, etc.), or as an arbitrary monotonically increasing curve with y values bounded by 0 and 1 and a scalar x-value bounded below by zero. However, the lognormal CDF fragility function is predominant. This DIF is limited to the situation where

- A given asset type can only be in one of one or more damage states (in addition to the undamaged state)
- Those damage states are sequential, in that an asset must reach or exceed damage state n before it can enter damage state n + 1, or repair from damage state n + 1 necessarily restores it from damage state n
- The probability of the component being in damage state n can be calculated as the difference between the probability of reaching or exceeding damage state n and the probability of reaching or exceeding damage state n + 1
- The capacity of the asset to resist each damage state can be expressed as a lognormally distributed scalar random variable measured in terms of an intensity measure type such as those listed in Table 2.
- For assets with two or more possible damage states, the intensity measure need not be the same one for each fragility function.

```
[Explanatory header]
ID,Abbrev,DS,NDS,Description,IMT,q,b
1,"[ABR1]",[DS1],[NDS1],"[DSDESC1]",[IMT1],[q1],[b1]
2,"[ABR2]",[DS2],[NDS2],"[DSDESC2]",[IMT2],[q2],[b2]
…
n,"[ABRn]",[DSn],[NDSn],"[DSDESCn]",[IMTn],[qn],[bn]
```

Figure 21. FRA02 lognormal fragility function

ABRr = Category of asset reflected by the fragility function; text string < 255 characters long. This is a brief name for the category.

DSr = ID of damage state in record r, integer in {1, 2, … NDSr}

NDSr = number of possible damage states for the category of the asset in row r, in addition to the undamaged state; integer in {1, 2, …. }

DSDESCr = description of the damage state reflected in row r (text string up to 255 characters in length). A set of basic damage state descriptions is provided in Table 10.

IMTr = as described above

qr = median value of IMTr at which the asset reaches or exceeds damage state DSr

br = logarithmic standard deviation of IMTr at which the asset reaches or exceeds damage state DSr

```
"K Porter 1 May 2009 sample fragility function file"
ID,Abbrev,DS,NDS,Description,IMT,q,b
1,"CAPSS Index Building 1 as-is",1,4,"Green tag",SA10,0.05,0.90
2,"CAPSS Index Building 1 as-is",2,4,"Yellow tag",SA10,0.24,0.70
3,"CAPSS Index Building 1 as-is",3,4,"Red tag",SA10,0.31,0.65
4,"CAPSS Index Building 1 as-is",4,4,"Collapse",SA10,0.61,0.30
5,"CAPSS Index Building 1 retrofit 2",1,4,"Green tag",SA03,0.44,0.90
6,"CAPSS Index Building 1 retrofit 2",2,4,"Yellow tag",SA10,0.72,0.65
7,"CAPSS Index Building 1 retrofit 2",3,4,"Red tag",SA10,1.04,0.50
8,"CAPSS Index Building 1 retrofit 2",4,4,"Collapse",SA10,1.32,0.20
```

Figure 22. Sample FRA02 lognormal fragility function

7.4 PREFACE TO DAMAGE-OUTPUT DIFS

DIFs in the remainder of this section all address the damage-analysis output, and are all labeled "DMG" to indicate damage. As used here, damage refers to degradation of an asset's valuable attributes, such as cracks in walls, the occurrence of collapse, etc.

7.5 DMG01: DAMAGE TO POINT ASSETS UNDER AN EVENT SET

This damage-output DIF specifies the probability of various damage states to one or more assets, given an earthquake rupture forecast, ground-motion prediction equation, seismic source, rupture segment or location, and damage state(s) of interest.

```
[Explanatory header]
ID,ERF,GMPE,Source,Rupture,AssetID,DS,P
1,[ERF1],[GMPE1],[SRC1],[RUP1],[AID1],[DS1],[P1]
2,[ERF2],[GMPE2],[SRC2],[RUP2],[AID2],[DS2],[P2]
…
n,[ERFn],[GMPEn],[SRCn],[RUPn],[AIDn],[DSn],[Pn]
```

Figure 23. DMG01 event-set asset damage probability estimate

All variables are as previously defined, with the addition that

Pr = probability that the asset whose ID = AIDr reaches but does not exceed damage state DSr, given ERFr, GMPEr, SRCr, and RUPr. Double-precision floating point, $0 \leq Pr \leq 1.0$

```
"K Porter 1 May 2009 sample event-set damage state probabilities"
ID,ERF,GMPE,Source,Rupture,AssetID,DS,P
1,USGS/CGS2002,USGS2002,1,0,1,"Green tag", 0.142721
2,USGS/CGS2002,USGS2002,1,0,1,"Yellow tag", 0.251158
3,USGS/CGS2002,USGS2002,1,0,1,"Red tag", 0.459740433
4,USGS/CGS2002,USGS2002,1,0,1,"Collapse", 0.14518121
```

Figure 24. Sample DMG01 event-set asset damage probability estimate

7.6 DMG02: DAMAGE PROBABILITY TO POINT ASSETS DURING PERIOD T

This damage-output DIF specifies the probability that one or more assets will experience one or more damage states during a planning period T, given an earthquake rupture forecast and ground-motion prediction equation. Figure 25 presents the layout of LOS02; Figure 26 contains a small sample.

```
[Explanatory header]
T=[T]
ID,ERF,GMPE,AssetID,LM,EAL
1,[ERF1],[GMPE1],[AID1],[DS1],[P1]
2,[ERF2],[GMPE2],[AID2],[DS2],[P2]
…
n,[ERFn],[GMPEn],[AIDn],[DSn],[Pn]
```

Figure 25. DMG02 damage probability to point assets during period T

All terms as are defined above, with the addition of

Pr = probability of that asset AIDr will damage state that the asset whose ID is AIDr, given the values of ERFn, GMPEn, and LTn, in the same units as the value(s) expressed in the portfolio file for this asset. (Nonnegative double-precision floating point.)

T = planning period, years. Double-precision floating point, > 0.

```
"K Porter 29 Apr 2009 sample damage probability to point assets"
T = 1
ID,ERF,GMPE,AssetID,LM,EAL
1,UCERF1,CB2003,1,CAS1,0.0110
2,UCERF1,CB2003,2,CAS1,0.0017
3,UCERF1,CB2003,3,CAS1,0.1806
```

Figure 26. Sample DMG02 damage probability to point assets during period T

8 LOSS ANALYSIS DIFS: VULNERABILITY AND LOSS OUTPUT

8.1 PREFACE TO VULNERABILITY DIFS

DIFs in the 1st part of this section all define vulnerability, which refers here to degree of loss as a function of intensity. They are labeled "VUL" to indicate vulnerability.

8.2 VUL01: MDF AND COV VS. STRUCTURE-INDEPENDENT INTENSITY

VUL01A gives the mean damage factor (loss of a specified loss measure, as a fraction of replacement cost) at each of several specified intensity levels, for one or more vulnerability models. VULN01B provides the coefficient of variation of damage factor at the same intensity levels and vulnerability models. Together, these comprise a probabilistic vulnerability function, used in a loss analysis.

A vulnerability function commonly refers to a function that gives mean loss as a fraction of value exposed (often called mean damage factor) versus a structure-independent intensity measure. A less common term, a probabilistic vulnerability function, refers to an uncertain relationship between damage factor and intensity. If VULN01A and VULN01B are both used, then Xc, IRr, ABRr, and DESCr should match one-to-one across the two files.

```
[Explanatory header]
[LM],[IMT]
ID,Abbrev,Descr,[X1],[X2], … [Xm]
[ID1],[ABR1],"[DESC1]",[Y1,1],[Y1,2],…,[Y1,m]
[ID2],[ABR2],"[DESC1]",[Y2,1],[Y2,2],…,[Y2,m]
…
[IDn],[ABRn],"[DESCn]",[Yn,1],[Yn,2],…,[Yn,m]
```

Figure 27. VUL01A, mean vulnerability functions

```
[Explanatory header]
ID,Abbrev,Descr,[X1],[X2], … [Xm]
[ID1],[ABR1],"[DESC1]",[V1,1],[V1,2],…,[V1,m]
[ID2],[ABR2],"[DESC1]",[V2,1],[V2,2],…,[V2,m]
…
[IDn],[ABRn],"[DESCn]",[Vn,1],[Vn,2],…,[Vn,m]
```

Figure 28. VUL01B, coefficient of variation of vulnerability functions

ABRr = abbreviation for vulnerability model reflected in row r (text string up to 255 characters in length), should be unique with a file.

DESCr = description of vulnerability model reflected in row r (text string up to 255 characters in length), should be unique with a file.

Explanatory header = as desired by vulnerability modeler, e.g., author, date, project name, etc. (text string ≤ 255 characters long)

IDr = ID of vulnerability model reflected in row r (integer in 1, 2, ….), unique within a file.

IMT = intensity measure type (text string of variable length). An initial list is proposed in Section 3. Note that instrumental measures of acceleration are assumed to be in units of gravity and geometric-mean direction, unless noted otherwise. Instrumental measures of velocity and displacement are assumed to be in units of cm/sec and cm, respectively, and geometric-mean direction, unless noted otherwise.

LM = loss measure reflected in these vulnerability functions, (variable length text), selected from available loss measures. An initial list of loss measures is proposed in Section 3.

Vr,c = coefficient of variation of loss to vulnerability model IDr given that it is exposed to excitation equal to X1 (double-precision floating point, 0 ≤ Vr,c)

X1 = ground motion level 1 (double-precision floating point, > 0)

X2 = ground motion level 2 (double-precision floating point, > X1)

Xc = ground motion level c (double-precision floating point, > Xc-1, c in 2, 3, … 20)

Yr,c = mean value of loss to asset type IDr given that it is exposed to excitation equal to Xc (double-precision floating point, 0 ≤ Yr,c ≤ Yr,c+1)

```
"K Porter, 24 Feb 2009, sample vulnerability functions for GEM* DIFs"
"SA02","DF"
ID,Abbrev,Descr,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0
2,CWF-102,"CUREE-Caltech small house typ
      qual",0.003,0.011,0.043,0.070,0.090,0.107,0.121,0.133,0.144,0.154
4,CWF-104,"CUREE-Caltech small house
      retr",0.000,0.000,0.002,0.020,0.037,0.053,0.068,0.082,0.094,0.106
```

Figure 29. Sample vulnerability functions per VUL01A

```
"K Porter, 24 Feb 2009, sample vulnerability functions for GEM* DIFs"
ID,Abbrev,Descr,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0
2,CWF-102,"CUREE-Caltech small house typ
      qual",2.500,2.500,2.240,1.597,1.330,1.179,1.079,1.008,0.954,0.911
4,CWF-104,"CUREE-Caltech small house
      retr",2.500,2.500,2.500,2.500,2.500,1.942,1.629,1.428,1.287,1.184
```

Figure 30. Sample VUL01B vulnerability function coefficients of variation

8.3 VUL02: DAMAGE PROBABILITY MATRIX (DPM)

This loss-analysis DIF provides a damage probability matrix (DPM[1]): the probability of an asset experiencing damage factor within specified ranges (row headers) at each of several specified intensity levels (column headers). Each column represents a probability mass function of loss (generally damage factor).

Let z_i denote a particular value of the uncertain damage factor Y. (Damage factor is defined here as repair cost as a fraction of replacement cost new). The value z_i is stored in element i of a vector of size m, where $i \in \{1, 2, \ldots m\}$ and $0 < z_i < z_{i+1}$ for all $1 \le i < m$.

Let s_j denote a nonnegative scalar intensity measure, stored in element j of a vector of size n, where $j \in \{1, 2, \ldots n\}$, constrained by $0 < s_j < s_{j+1}$ 0 for all $1 < j < n$. Let IMT denote the intensity measure type (e.g., PGA, PGV, etc.) of s.

Let Y_j denote the uncertain damage factor given the occurrence of intensity s_j.

Let $P[\ ]$ denote the probability of the condition inside the brackets.

Let p_{ij} denote the probability

$$
\begin{aligned}
p_{ij} &= P\left[z_i \le Y_j < z_{i+1}\right] & 1 \le i < m \\
&= P\left[z_i \le Y_j\right] & i = m
\end{aligned}
\qquad (1)
$$

And let p_{ij} be stored in element ij of a rectangular matrix of size m x n, and constrained by

$$
\begin{aligned}
0 \le p_{ij} \le 1.0 \\
\sum_{i=1}^{m} p_{ij} \le 1.0
\end{aligned}
\qquad (2)
$$

[1] Despite the use of "damage" in the name "damage probability matrix," this is a vulnerability DIF.

Note there is an implicit assumption that there can be a nonzero P[$Y_j < z_1$], given by

$$P\left[Y_j < z_1\right] = 1 - \sum_{i=1}^{m} p_{ij} \tag{3}$$

This remaining probability is assumed hereafter to refer to the probability of (effectively) zero damage. The matrix {*p*} is referred to here as the damage probability matrix (DPM). A DIF for a DPM is now proposed. Figure 31 defines the VUL02 DIF for DPMs, while Figure 32 provides a sample.

```
[Explanatory header]
[ID],[ABR],[DESC],[IMT],[LM]
LB,[X1],[X2],…[Xm]
[LB1],[Y1,1],[Y1,2],…,[Y1,m]
[LB2],[Y2,1],[Y2,2],…,[Y2,m]
…
[LBn],[Yn,1],[Yn,2],…,[Yn,m]
```

Figure 31. VUL02 damage probability matrix layout

ABR = abbreviation for vulnerability model reflected in the file (text string up to 255 characters in length), unique within a collection of DPMs.

DESC = description of vulnerability model reflected in the file (text string up to 255 characters in length), should be unique within a collection of DPMs.

LB1 = lower bound of loss whose probabilities are reflected in record 1

LBr = lower bound of loss factor whose probabilities are reflected in record r

Explanatory header = as desired by vulnerability modeler, e.g., author, date, project name, etc. (text string ≤ 255 characters long)

ID of vulnerability model reflected in the file (integer in 1, 2, ….), unique within a collection of DPMs.

IMT = intensity measure type (text string of variable length). An initial list is proposed in Table 2. Note that instrumental measures of acceleration are assumed to be in units of gravity and geometric-mean direction, unless noted otherwise. Instrumental measures of velocity and displacement are assumed to be in units of cm/sec and cm, respectively, and geometric-mean direction, unless noted otherwise.

LM = loss measure reflected in the vulnerability model, (variable length text), selected from available loss measures. An initial list of loss measures is proposed in Table 9.

X1 = ground motion level 1 (double-precision floating point, > 0)

Xc = ground motion level c (double-precision floating point, > X(c-1), c in 2, 3, … m)

Yr,c = probability that an asset of the type reflected in this vulnerability model will experience loss between LBr and LB(r+1), given that it is exposed to intensity Xc. For the last row, probability that it will experience loss equal to DFr (double-precision floating point; 0 ≤ Yr,c ≤ 1, sum within a column must be ≤ 1)

```
"K Porter, 24 Feb 2009, sample DPM for GEM* DIFs"
2,"CWF-102","CUREE-Caltech small house typ qual","SA02","DF"
LB, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1
0.001, 0.192, 0.147, 0.036, 0.004, 0.001, 0.000, 0.000, 0.000, 0.000, 0.000
0.002, 0.098, 0.107, 0.041, 0.008, 0.002, 0.000, 0.000, 0.000, 0.000, 0.000
0.003, 0.098, 0.144, 0.081, 0.025, 0.007, 0.002, 0.001, 0.000, 0.000, 0.000
0.005, 0.047, 0.092, 0.072, 0.032, 0.012, 0.005, 0.002, 0.001, 0.000, 0.000
0.007, 0.036, 0.089, 0.091, 0.053, 0.026, 0.012, 0.006, 0.003, 0.001, 0.001
0.010, 0.039, 0.133, 0.202, 0.169, 0.115, 0.073, 0.046, 0.029, 0.018, 0.012
0.020, 0.010, 0.051, 0.117, 0.134, 0.117, 0.094, 0.072, 0.055, 0.040, 0.030
0.030, 0.006, 0.041, 0.127, 0.179, 0.189, 0.179, 0.160, 0.140, 0.119, 0.102
0.050, 0.002, 0.016, 0.066, 0.109, 0.132, 0.141, 0.142, 0.137, 0.130, 0.121
0.070, 0.001, 0.010, 0.054, 0.097, 0.128, 0.148, 0.161, 0.167, 0.170, 0.168
0.100, 0.001, 0.009, 0.062, 0.122, 0.174, 0.219, 0.256, 0.286, 0.313, 0.332
0.200, 0.000, 0.002, 0.018, 0.036, 0.053, 0.070, 0.086, 0.100, 0.115, 0.128
0.300, 0.000, 0.001, 0.011, 0.021, 0.031, 0.041, 0.050, 0.060, 0.069, 0.078
0.500, 0.000, 0.000, 0.003, 0.006, 0.008, 0.010, 0.013, 0.015, 0.017, 0.019
0.700, 0.000, 0.000, 0.002, 0.003, 0.004, 0.004, 0.005, 0.006, 0.006, 0.007
1.000, 0.000, 0.000, 0.001, 0.002, 0.002, 0.002, 0.002, 0.002, 0.002, 0.003
```

Figure 32. Sample DPM according to VUL02

8.4 VUL03: DAMAGE EXCEEDANCE MATRIX (DEM)

This loss-analysis DIF provides a damage exceedance matrix (DEM): the probability of an asset experiencing damage factor equal to or greater than each of several specified levels (row headers) at each of several specified intensity levels (column headers). Each column represents the complement of a cumulative distribution function of loss (generally damage factor).

The DEM is another depiction of facility vulnerability, containing essentially the same information as the damage probability matrix. Recall that the DPM is a set of probability mass functions for loss by intensity level. The DEM instead depicts the complement of the cumulative distribution function. To be precise, the DEM is a rectangular matrix with *m* rows and *n* columns, whose columns reflect particular intensity levels and whose rows reflect particular values of loss. The entries of the DEM give the probability that the uncertain loss will exceed a particular value (the row header), when the facility is exposed to a given intensity level (the column header). Let *i* denote the row index, and let *j* denote the column index, i.e., $i \in \{1, 2, \dots m\}$ and $j \in \{1, 2, \dots n\}$. Let z_i denote the value of the damage factor for row *i*, and let s_j denote the value of intensity for column j. Let Y_j denote the uncertain loss given intensity s_j. Let *P* denote probability, and let q_{ij} denote the entry of the DEM in row *i*, column *j*, i.e., the probability

$$q_{ij} = P\left[Y_j \ge z_i\right] \tag{4}$$

stored in element *ij* of a rectangular matrix of size *m* x *n*, and constrained by

$$\begin{aligned} & s_{j+1} > s_j \\ & z_{i+1} > z_i \\ & 0 \le q_{ij} \le 1.0 \\ & q_{ij} \ge q_{i+1,j} \\ & q_{ij} \le q_{i,j+1} \end{aligned} \tag{5}$$

A DIF for DEMs is now proposed. The file layout is shown in Figure 33. A sample is shown in Figure 34.

```
[Explanatory header]
[ID],[ABR],[DESC],[IMT],[LM]
LB,[X1],[X2],…[Xn]
[LB1],[Y1,1],[Y1,2],…,[Y1,n]
[LB2],[Y2,1],[Y2,2],…,[Y2,n]
…
[LBn],[Yn,1],[Yn,2],…,[Yn,m]
```

Figure 33. VUL03 damage exceedance matrix layout

ABR = abbreviation for vulnerability model reflected in the file (text string up to 255 characters in length), unique within a collection of DEMs.

DESC = description of vulnerability model reflected in the file (text string up to 255 characters in length), should be unique within a collection of DEMs.

LB1 = lower bound of loss whose probabilities are reflected in record 1

LBr = lower bound of loss factor whose probabilities are reflected in record r

Explanatory header = as desired by vulnerability modeler, e.g., author, date, project name, etc. (text string ≤ 255 characters long)

ID = ID of vulnerability model reflected in the file (integer in 1, 2, ….), unique within a collection of DEMs.

IMT = intensity measure type (text string of variable length). An initial list is proposed in Section 3. Note that instrumental measures of acceleration are assumed to be in units of gravity and geometric-mean direction, unless noted otherwise. Instrumental measures of velocity and displacement are assumed to be in units of cm/sec and cm, respectively, and geometric-mean direction, unless noted otherwise.

LM = loss measure reflected in the vulnerability model (variable length text), selected from available loss measures. An initial list of loss measures is proposed in Section 3.

X1 = ground motion level 1 (double-precision floating point, X1 > 0)

Xc = ground motion level c (double-precision floating point, Xc > X(c-1), c in 2, 3, … m)

Yr,c = probability that an asset of the type reflected in this vulnerability model will experience loss of at least LBr, given that it is exposed to intensity Xc (double-precision floating point; 0 ≤ Y(r+1),c ≤ Yr,c ≤ 1)

```
"K Porter, 24 Feb 2009, sample DPM for GEM* DIFs"
2,"CWF-102","CUREE-Caltech small house typ qual","SA02","DF"
LB,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1
0.001,0.5306,0.8413,0.9837,0.9993,1.0000,1.0000,1.0000,1.0000,1.0000,1.0000
0.002,0.3388,0.6941,0.9474,0.9952,0.9995,0.9999,1.0000,1.0000,1.0000,1.0000
0.003,0.2408,0.5868,0.9062,0.9872,0.9979,0.9996,0.9999,1.0000,1.0000,1.0000
0.005,0.1431,0.4429,0.8255,0.9623,0.9908,0.9975,0.9993,0.9998,0.9999,1.0000
0.007,0.0958,0.3510,0.7534,0.9306,0.9786,0.9929,0.9975,0.9990,0.9996,0.9998
0.010,0.0595,0.2624,0.6624,0.8777,0.9528,0.9808,0.9917,0.9962,0.9983,0.9991
0.020,0.0201,0.1296,0.4608,0.7083,0.8379,0.9080,0.9460,0.9671,0.9803,0.9874
0.030,0.0096,0.0783,0.3442,0.5748,0.7204,0.8145,0.8742,0.9125,0.9400,0.9571
0.050,0.0034,0.0376,0.2170,0.3956,0.5310,0.6359,0.7141,0.7726,0.8207,0.8554
0.070,0.0016,0.0218,0.1507,0.2866,0.3991,0.4950,0.5725,0.6354,0.6909,0.7346
0.100,0.0007,0.0115,0.0968,0.1894,0.2713,0.3466,0.4118,0.4684,0.5214,0.5665
0.200,0.0001,0.0029,0.0346,0.0674,0.0975,0.1278,0.1560,0.1825,0.2088,0.2343
0.300,0.0000,0.0011,0.0170,0.0318,0.0448,0.0581,0.0705,0.0824,0.0941,0.1062
0.500,0.0000,0.0003,0.0062,0.0105,0.0138,0.0171,0.0200,0.0228,0.0254,0.0284
0.700,0.0000,0.0001,0.0030,0.0046,0.0056,0.0066,0.0074,0.0082,0.0088,0.0097
1.000,0.0000,0.0000,0.0013,0.0017,0.0019,0.0021,0.0022,0.0024,0.0024,0.0026
```

Figure 34. Sample damage exceedance matrix using VUL03

8.5 VUL04: HAZUS-BASED CASUALTY RATES

This loss-analysis DIF provides the mean fraction of indoor occupants experiencing each of 4 HAZUS-MH casualty severity levels for given combinations of HAZUS-MH structure type, seismic domain (plate boundary or continental interior), magnitude, rupture distance, and an $S_a(0.3)$, $S_a(1.0)$ pair. It also provides in each record an indicator of whether casualty rate is better estimated by $S_a(0.3)$ or $S_a(1.0)$ (the former if the performance point probably lies on the constant-acceleration portion of the idealized HAZUS-MH demand spectrum, the latter if the performance point probably lies on the constant-velocity portion).

This DIF is used for reporting structure-independent seismic vulnerability functions of indoor casualty rate, created using the HAZUS-MH methodology (e.g., Porter 2009a). In the HAZUS-MH methodology, casualty rate (fraction of indoor occupants injured to each of 4 casualty severity levels), depends on structure type and intensity, seismic domain (plate boundary or continental interior), magnitude, distance, and site classification. Furthermore the proper intensity measure to use can vary with intensity. More often than not one should use the 5%-damped spectral acceleration response at 1-second period, but for stiffer structures and low intensities, the proper intensity measure can be 5%-damped spectral acceleration response at 0.3-second period. In any event, a single seismic vulnerability function in the VUL04 DIF is spread over many adjacent records with the same abbreviation (ABR, below), seismic domain, magnitude M, distance R, and soil. Records increase in terms of spectral displacement—a hidden variable and immaterial for the seismic vulnerability function—although SA03 and SA10 generally increase with spectral displacement. Figure 35 specifies the layout of the VUL04 HAZUS-MH indoor-casualty-rate vulnerability-function table. An example is shown in Figure 36, which is an extract of an exhaustive file of HAZUS-based casualty-rate seismic vulnerability functions at http://www.risk-agora.org/dmdownloads/FatalityVFs.zip.

```
[Explanatory header]
ABR,Domain,M,R,Soil,SA03,SA10,IM,CAS1RATE,CAS2RATE,CAS3RATE,CAS4RATE
[ABR1],[DOM1],[M1],[R1],[SOIL1],[SA03-1],[SA10-1],[IM1],[Y1,1],[Y1,2],[Y1,3],[Y1,4]
[ABR2],[DOM2],[M2],[R2],[SOIL2],[SA03-2],[SA10-2],[IM2],[Y2,1],[Y2,2],[Y2,3],[Y2,4]
…
[ABRn],[DOMn],[Mn],[Rn],[SOILn],[SA03-n],[SA10-n],[IMn],[Yn,1],[Yn,2],[Yn,3],[Yn,4]
```

Figure 35. VUL04 HAZUS-MH indoor-casualty-rate vulnerability functions

Explanatory header = as desired by vulnerability modeler, e.g., author, date, project name, etc. (text string ≤ 255 characters long)

ABR1 = abbreviation for vulnerability model in record 1 (text string up to 25 characters in length).

DOM1 = seismic domain for the vulnerability model in record 1 (text, either WUS for plate boundary or CEUS for continental interior)

M1 = magnitude for the vulnerability model in record 1 (integer, in 5, 6, 7, 8)

R1 = fault rupture distance (km) for the vulnerability model in record 1 (integer, in 10, 20, 40, 80, where 10 refers to $R < 15$ km, 20 refers to $15 \leq R < 30$ km, 40 refers to $30 \leq R < 60$ km, and 80 refers to $60 \leq R$).

SOIL1 = NEHRP site soil classification for the vulnerability model in record in (text, in A, B, C, D, or E)

SA03-1 = soil-amplified 5%-damped spectral acceleration response at 0.3-sec period (units of g) for the vulnerability model in record 1, SA03-1 ≥ 0.

SA10-1 = soil-amplified 5%-damped spectral acceleration response at 1.0-sec period (units of g) for the vulnerability model in record 1, SA10-1 ≥ 0.

IM1 = better intensity measure to use for the vulnerability model in record 1 at this level of intensity (text, either "SA03" or "SA10")

$Y_{1,1}$ = mean fraction of indoor occupants injured to HAZUS-MH casualty level 1 given all the conditions in record 1.

$Y_{1,2}$ = mean fraction of indoor occupants injured to HAZUS-MH casualty level 2 given all the conditions in record 1.

$Y_{1,3}$ = mean fraction of indoor occupants injured to HAZUS-MH casualty level 3 given all the conditions in record 1.

$Y_{1,4}$ = mean fraction of indoor occupants injured to HAZUS-MH casualty level 2 given all the conditions in record 1.

$Y_{r,c}$ = mean fraction of indoor occupants injured to HAZUS-MH casualty level c given all the conditions in record r.

```
"K Porter, 24 Feb 2009, sample HAZUS casualty rate functions for GEM* DIFs"
ABR,Domain,M,R,Soil,SA03,SA10,IM,CAS1RATE,CAS2RATE,CAS3RATE,CAS4RATE
W1h,WUS,7,20,D,0.01,0,SA03,1.74512E-08,4.50043E-09,2.85792E-10,4.57783E-10
W1h,WUS,7,20,D,0.02,0,SA03,1.82553E-08,4.50043E-09,2.85792E-10,4.57783E-10
W1h,WUS,7,20,D,0.02,0,SA03,2.12805E-08,4.50043E-09,2.85792E-10,4.57783E-10
W1h,WUS,7,20,D,0.03,0.02,SA03,3.11433E-08,4.50043E-09,2.85792E-10,4.57783E-10
W1h,WUS,7,20,D,0.03,0.02,SA03,6.32042E-08,4.50043E-09,2.85792E-10,4.57783E-10
W1h,WUS,7,20,D,0.04,0.02,SA03,1.58615E-07,4.69077E-09,2.85792E-10,4.57783E-10
W1h,WUS,7,20,D,0.05,0.02,SA03,4.18171E-07,5.48278E-09,2.85792E-10,4.57783E-10
W1h,WUS,7,20,D,0.07,0.05,SA03,1.03751E-06,8.41816E-09,2.85792E-10,4.57783E-10
W1h,WUS,7,20,D,0.09,0.05,SA03,2.50457E-06,1.76968E-08,2.85792E-10,4.57783E-10
W1h,WUS,7,20,D,0.11,0.07,SA03,5.65315E-06,4.54808E-08,2.88229E-10,4.6022E-10
W1h,WUS,7,20,D,0.14,0.1,SA03,1.19463E-05,1.27065E-07,3.18106E-10,4.99244E-10
W1h,WUS,7,20,D,0.17,0.1,SA03,2.36035E-05,3.41026E-07,1.0751E-09,1.68535E-09
W1h,WUS,7,20,D,0.22,0.12,SA03,4.32427E-05,8.79486E-07,3.43431E-09,5.37914E-09
W1h,WUS,7,20,D,0.27,0.17,SA03,7.59915E-05,2.05722E-06,1.03701E-08,1.62343E-08
W1h,WUS,7,20,D,0.35,0.22,SA03,0.00012746,4.60409E-06,2.8456E-08,4.44913E-08
W1h,WUS,7,20,D,0.44,0.26,SA03,0.000203608,9.49449E-06,7.69781E-08,1.20387E-07
W1h,WUS,7,20,D,0.55,0.33,SA03,0.000313638,1.85437E-05,1.96966E-07,3.08222E-07
W1h,WUS,7,20,D,0.71,0.4,SA03,0.00047104,3.49756E-05,4.76877E-07,7.46929E-07
W1h,WUS,7,20,D,0.93,0.55,SA03,0.000692805,6.18734E-05,1.06121E-06,1.66168E-06
W1h,WUS,7,20,D,1.18,0.7,SA03,0.001011966,0.000107065,2.30758E-06,3.61916E-06
W1h,WUS,7,20,D,1.48,0.88,SA03,0.00145797,0.000178158,4.75542E-06,7.47169E-06
W1h,WUS,7,20,D,1.83,1.1,SA03,0.002099115,0.000290709,9.29393E-06,1.46304E-05
W1h,WUS,7,20,D,2.19,1.32,SA03,0.002979198,0.000455825,1.68362E-05,2.65427E-05
W1h,WUS,7,20,D,2.62,1.57,SA03,0.004229346,0.000708555,2.97218E-05,4.69518E-05
W1h,WUS,7,20,D,3.05,1.83,SA03,0.00595336,0.001077293,4.98884E-05,7.89627E-05
W1h,WUS,7,20,D,3.55,2.13,SA03,0.008171758,0.001571859,7.82774E-05,0.000124093
W1h,WUS,7,20,D,4.11,2.46,SA03,0.01110017,0.002258537,0.000119399,0.000189613
W1h,WUS,7,20,D,4.63,2.78,SA03,0.01471855,0.003140901,0.000173793,0.000276426
W1h,WUS,7,20,D,5.18,3.11,SA03,0.01900418,0.004221414,0.000241773,0.000385084
W1h,WUS,7,20,D,5.74,3.45,SA03,0.0236885,0.005427247,0.000318565,0.000507933
W1h,WUS,7,20,D,6.09,3.66,SA03,0.02887371,0.006806677,0.000407808,0.000650907
W1h,WUS,7,20,D,6.48,3.88,SA03,0.03419066,0.008250631,0.000502099,0.000802099
W1h,WUS,7,20,D,6.66,3.99,SA03,0.03937161,0.009681557,0.000596217,0.000953118
W1h,WUS,7,20,D,6.85,4.11,SA03,0.04398549,0.01097105,0.000681446,0.001089939
```

Figure 36. Sample HAZUS-based indoor-casualty-rate vulnerability function per VUL04

8.6 VUL05: HAZUS-BASED MEAN DAMAGE FACTOR

This loss-analysis DIF provides the mean damage factor for given combinations of HAZUS-MH structure type, HAZUS-MH occupancy category, seismic domain (plate boundary or continental interior), magnitude, rupture distance, and an $S_a(0.3)$, $S_a(1.0)$ pair. It also provides in each record an indicator of whether damage factor is better estimated by $S_a(0.3)$ or $S_a(1.0)$ (the former if the performance point probably lies on the constant-acceleration portion of the idealized HAZUS-MH demand spectrum, the latter if the performance point probably lies on the constant-velocity portion).

This DIF is used for reporting structure-independent seismic vulnerability functions of mean property damage factor, created using the HAZUS-MH methodology (e.g., Porter 2009b). In the HAZUS-MH methodology, mean damage factor (mean fraction of building and content value lost), depends on structure type and intensity, occupancy category, seismic domain (plate boundary or continental interior), magnitude, distance, and site classification. Furthermore the proper intensity measure to use can vary with intensity. More often than not one should use the 5%-damped spectral acceleration response at 1-second period, but for stiffer structures and low intensities, the proper intensity measure can be 5%-damped spectral acceleration response at 0.3-second period. In any event, a single seismic vulnerability function in the VUL05 DIF is spread over many adjacent records with the same abbreviation (ABR, below), occupancy category (OCC, below), seismic domain, magnitude M, distance R, and soil. Records increase in terms of spectral displacement—a hidden variable and immaterial for the seismic vulnerability function—although SA03 and SA10 generally increase with spectral displacement. **Error! Reference source not found.** specifies the layout of the VUL05 HAZUS-MH vulnerability-function table. An example is shown in **Error! Reference source not found.** which is an extract of an exhaustive file of HAZUS-based mean-damage-factor seismic vulnerability functions for residential occupancies at http://www.risk-agora.org/dmdownloads/RepairCostVFsRES.zip.

```
[Explanatory header]
ABR,OCC,Domain,M,R,Soil,SA03,SA10,IM,MDF
[ABR1],[OCC1],[DOM1],[M1],[R1],[SOIL1],[SA03-1],[SA10-1],[IM1],[Y1]
[ABR2],[OCC2],[DOM2],[M2],[R2],[SOIL2],[SA03-2],[SA10-2],[IM2],[Y2]
…
[ABRn],[OCCn],[DOMn],[Mn],[Rn],[SOILn],[SA03-n],[SA10-n],[IMn],[Yn]
```

Figure 37. VUL05 HAZUS-MH property vulnerability functions

Explanatory header = as desired by vulnerability modeler, e.g., author, date, project name, etc. (text string ≤ 255 characters long)

ABR1 = abbreviation for vulnerability model in record 1 (text string up to 25 characters in length).

OCC1 = occupancy category for vulnerability model in record 1

DOM1 = seismic domain for the vulnerability model in record 1 (text, either WUS for plate boundary or CEUS for continental interior)

M1 = magnitude for the vulnerability model in record 1 (integer, in 5, 6, 7, 8)

R1 = fault rupture distance (km) for the vulnerability model in record 1 (integer, in 10, 20, 40, 80, where 10 refers to $R < 15$ km, 20 refers to $15 \le R < 30$ km, 40 refers to $30 \le R < 60$ km, and 80 refers to $60 \le R$).

SOIL1 = NEHRP site soil classification for the vulnerability model in record in (text, in A, B, C, D, or E)

SA03-1 = soil-amplified 5%-damped spectral acceleration response at 0.3-sec period (units of g) for the vulnerability model in record 1, SA03-1 ≥ 0.

SA10-1 = soil-amplified 5%-damped spectral acceleration response at 1.0-sec period (units of g) for the vulnerability model in record 1, SA10-1 ≥ 0.

IM1 = better intensity measure to use for the vulnerability model in record 1 at this level of intensity (text, either "SA03" or "SA10")

Y1 = mean fraction of property value lost given all the conditions in record 1.

Yr = mean fraction of property value lost given all the conditions in record r.

```
"K Porter 26 Feb 2009 sample HAZUS-MH vulnerability functions"
Abbrev,Occ,Domain,M,R,Soil,SA03,SA10,IM,MDF
W1h,RES1,WUS,7,20,D,0.01,0,Sa03,0.0000
W1h,RES1,WUS,7,20,D,0.02,0,Sa03,0.0000
W1h,RES1,WUS,7,20,D,0.02,0,Sa03,0.0000
W1h,RES1,WUS,7,20,D,0.03,0.02,Sa03,0.0000
W1h,RES1,WUS,7,20,D,0.03,0.02,Sa03,0.0000
W1h,RES1,WUS,7,20,D,0.04,0.02,Sa03,0.0000
W1h,RES1,WUS,7,20,D,0.05,0.02,Sa03,0.0000
W1h,RES1,WUS,7,20,D,0.07,0.05,Sa03,0.0001
W1h,RES1,WUS,7,20,D,0.09,0.05,Sa03,0.0002
W1h,RES1,WUS,7,20,D,0.11,0.07,Sa03,0.0004
W1h,RES1,WUS,7,20,D,0.14,0.1,Sa03,0.0008
W1h,RES1,WUS,7,20,D,0.17,0.1,Sa03,0.0016
W1h,RES1,WUS,7,20,D,0.22,0.12,Sa03,0.0031
W1h,RES1,WUS,7,20,D,0.27,0.17,Sa03,0.0055
W1h,RES1,WUS,7,20,D,0.35,0.22,Sa03,0.0093
W1h,RES1,WUS,7,20,D,0.44,0.26,Sa03,0.0152
W1h,RES1,WUS,7,20,D,0.55,0.33,Sa03,0.0239
W1h,RES1,WUS,7,20,D,0.71,0.4,Sa03,0.0364
W1h,RES1,WUS,7,20,D,0.93,0.55,Sa03,0.0513
W1h,RES1,WUS,7,20,D,1.18,0.7,Sa03,0.0698
W1h,RES1,WUS,7,20,D,1.48,0.88,Sa03,0.0930
W1h,RES1,WUS,7,20,D,1.83,1.1,Sa03,0.1222
W1h,RES1,WUS,7,20,D,2.19,1.32,Sa03,0.1584
W1h,RES1,WUS,7,20,D,2.62,1.57,Sa03,0.2024
W1h,RES1,WUS,7,20,D,3.05,1.83,Sa03,0.2536
W1h,RES1,WUS,7,20,D,3.55,2.13,Sa03,0.3121
W1h,RES1,WUS,7,20,D,4.11,2.46,Sa03,0.3761
```

```
W1h,RES1,WUS,7,20,D,4.63,2.78,Sa03,0.4426
W1h,RES1,WUS,7,20,D,5.18,3.11,Sa03,0.5079
W1h,RES1,WUS,7,20,D,5.74,3.45,Sa03,0.5702
W1h,RES1,WUS,7,20,D,6.09,3.66,Sa03,0.6252
W1h,RES1,WUS,7,20,D,6.48,3.88,Sa03,0.6717
W1h,RES1,WUS,7,20,D,6.66,3.99,Sa03,0.7093
```

Figure 38. Sample VUL05 HAZUS-based vulnerability functions

8.7 VUL06: HAZUS-BASED MEAN AND COV OF DAMAGE FACTOR

This loss-analysis DIF provides the mean and coefficient of variation of damage factor for given combinations of HAZUS-MH structure type, HAZUS-MH occupancy category, loss type, and S_a(1.0). This DIF is used for reporting structure-independent seismic vulnerability functions of damage factor created using the HAZUS-MH methodology (e.g., Porter 2009b).

In the HAZUS-MH methodology, mean damage factor (mean fraction of building and content value lost), depends on structure type and intensity, occupancy category, seismic domain (plate boundary or continental interior), magnitude, distance, and site classification. Furthermore the proper intensity measure to use can vary with intensity. More often than not one should use the 5%-damped spectral acceleration response at 1-second period, but for stiffer structures and low intensities, the proper intensity measure can be 5%-damped spectral acceleration response at 0.3-second period.

This DIF is imagined for use in probabilistic risk analysis, where for simplicity only Sa(1.0 sec, 5%) is used, and the vulnerability functions are taken for a single combination of seismic domain (WUS), magnitude (7), distance (20 km), and soil (D). In any event, a single seismic vulnerability function in the VUL06 DIF is spread over many adjacent records with the same abbreviation (ABR, below), and increasing unique values of Sa(1.0, 5%). Figure 39 specifies the layout of the VUL06 HAZUS-MH vulnerability-function table. An example is shown in Figure 40, which is an extract of an exhaustive file of HAZUS-based damage-factor seismic vulnerability functions for residential occupancies at http://www.risk-agora.org/dmdownloads/RepairCostVFs-2010.zip.

```
[Explanatory header]
Row,ID,ABR,DisplayName,Height,Matl,Syst,Design,Occ,LossType,IMT,IM,Mean,COV
[ROW1],[ID1],[ABR1],[DN1],[H1],[MAT1],[SYS1],[DL1],[OCC1],[LT1],[IMT1],[IM1],[Y1],[V1]
[ROW2],[ID2],[ABR2],[DN2],[H2],[MAT2],[SYS2],[DL2],[OCC2],[LT2],[IMT2],[IM2],[Y2],[V2]
…
[ROWn],[IDn],[ABRn],[DNn],[Hn],[MATn],[SYSn],[DLn],[OCCn],[LTn],[IMTn],[IMn],[Yn],[Vn]
```

Figure 39. VUL06 HAZUS-MH property vulnerability functions

Explanatory header = as desired by vulnerability modeler, e.g., author, date, project name, etc. (text string ≤ 255 characters long)

ROW1 = row number in the table, i.e., 1 in row 1, 2 in row 2, etc. (long integer 1, 2, … unique)

ID1 = Numerical identifier for the vulnerability function in row 1 (long integer 1, 2, … nonunique). Same value appears on multiple lines to indicate same vulnerability function.

ABR1 = abbreviation for vulnerability model in record 1 (text string up to 25 characters in length). Same value appears on multiple lines to indicate one vulnerability function.

DN1 = display name for the vulnerability function in row 1 (text strong up to 255 characters). Same value appears on multiple lines to indicate one vulnerability function.

H1 = height category of the vulnerability function in row 1, ∈ {*, L, M, H}, meaning not provided, low (1-3 stories), medium (4-7 stories), or high (8+ stories)

MAT1 = material category of the vulnerability functions in row 1, ∈ {*, W, C, S, PC, RM, URM, MH}, meaning not provided, wood, concrete, steel, precast concrete, reinforced masonry, unreinforced masonry, or mobile home.

SYS1 = lateral force resisting system for the vulnerability function in row 1, ∈ {*, light frame, commercial and industrial, moment frame, braced frame, frame with cast-in-place shearwalls, frame with unreinforced masonry shearwalls, shearwalls, tiltup walls, bearing walls with flexible diaphragms, bearing walls with rigid diaphragms, bearing walls}.

DL1 = design level for the vulnerability function in row 1, ∈ {*, p, l, m, h, ls, ms, hs} meaning not provided, precode, low code, moderate code, high code, low code special, moderate code special, high code special.

OCC1 = occupancy category for vulnerability model in record 1, ∈ {*, [see list in Table TBD]}

LT1 = loss type for vulnerability functions in record 1, ∈ {*, Repair cost, Loss of output, Loss of use duration, Value of avoided human injury}

IMT1 = intensity measure to use for the vulnerability model in record 1, ∈ {MMI, JMA, PGA, PGV, SA02, SA03, SA10}

IM1 = intensity measure level for the vulnerability function in record 1, real nonnegative

Y1 = mean value of loss given all the conditions in record 1, real nonnegative.

V1 = coefficient of variation of loss given all the conditions in record 1, real nonnegative.

```
"K Porter 23 Feb 2010 sample HAZUS-MH vulnerability functions"
Row,ID,ABR,DisplayName,Height,Matl,Syst,Design,Occ,LossType,IMT,IM,Mean,COV
1,1,C1H-h-AGR1-RC,*,*,*,*,h,AGR1,Repair cost,SA10,0,2.86E-07,250.0
2,1,C1H-h-AGR1-RC,*,*,*,*,h,AGR1,Repair cost,SA10,0.01,3.60E-07,250.0
3,1,C1H-h-AGR1-RC,*,*,*,*,h,AGR1,Repair cost,SA10,0.02,3.22E-06,161.8
4,1,C1H-h-AGR1-RC,*,*,*,*,h,AGR1,Repair cost,SA10,0.03,3.09E-05,25.81
5,1,C1H-h-AGR1-RC,*,*,*,*,h,AGR1,Repair cost,SA10,0.04,1.24E-04,10.70
6,1,C1H-h-AGR1-RC,*,*,*,*,h,AGR1,Repair cost,SA10,0.05,3.07E-04,7.22
```

Figure 40. Sample VUL06 HAZUS-based vulnerability functions

8.8 VUL07: CASUALTY RATES BY DAMAGE STATE BY STRUCTURE TYPE

This loss-analysis DIF provides the mean fraction of occupants injured or killed by damage state and structure type. It is deterministic in that the rates are fixed. For simplicity it assumes that structure types are identified by 1, 2, or 3 facets of GEM building-type taxonomy. It also assumes that casualty rates are denoted in HAZUS-MH terms (see STD09) and that damage states are denoted in terms defined in STD10.

```
[Explanatory header]
Row,ID,ABR,DS,Cas1Rate,Cas2Rate,Cas3Rate,Cas4Rate
[Row1],[ID1],[ABR1],[DS1],[Cas1Rate1],[Cas2Rate1],[Cas3Rate1],[Cas4Rate1]
[Row2],[ID2],[ABR2],[DS2],[Cas1Rate2],[Cas2Rate2],[Cas3Rate2],[Cas4Rate2]
…
[Rown],[IDn],[ABRn],[DSn],[Cas1Raten],[Cas2Raten],[Cas3Raten],[Cas4Raten]
```

Explanatory header = as desired by modeler, e.g., author, date, project name, etc. (text string ≤ 255 characters long)

ROW1 = row number in the table, i.e., 1 in row 1, 2 in row 2, etc. (long integer 1, 2, … unique)

IDn = Numerical identifier for the casualty-rate function in row n (long integer 1, 2, … nonunique). Same value appears on multiple lines to indicate same casualty-rate function.

ABRn = abbreviation for casualty-rate model in record n (text string up to 25 characters in length). Same value appears on multiple lines to indicate one vulnerability function.

DSLabel = damage state label in record r, text from STD10.

CasXrateN = fraction of indoor occupants injured to HAZUS severity X when a facility of type ABRn is damaged to the damage state indexed by DSr. A real value between 0 and 1.0. Or null (a blank space delimited by a comma) for “do not know.”

```
“K Porter 21 May 2011 Sample HAZUS-MH Casualty rates”
Row,ID,ABR,DSLabel,Cas1Rate,Cas2Rate,Cas3Rate,Cas4Rate
1,1,C1H-h-CR,Slight structural HAZUS,0.0005,0,0,0
2,1,C1H-h-CR,Moderate structural HAZUS,0.0025,0.0003,0,0
3,1,C1H-h-CR,Extensive structural HAZUS,0.01,0.001,0.00001,0.00001
4,1,C1H-h-CR,Complete structural HAZUS,0.05,0.01,0.0001,0.0001
5,1,C1H-h-CR,Collapse structural HAZUS,0.4,0.2,0.05,0.1
6,2,C1H-hs-CR,Slight structural HAZUS,0.0005,0,0,0
7,2,C1H-hs-CR,Moderate structural HAZUS,0.0025,0.0003,0,0
8,2,C1H-hs-CR,Extensive structural HAZUS,0.01,0.001,0.00001,0.00001
9,2,C1H-hs-CR,Complete structural HAZUS,0.05,0.01,0.0001,0.0001
10,2,C1H-hs-CR,Collapse structural HAZUS,0.4,0.2,0.05,0.1
```

The example shows casualty-rate functions for 2 combinations of HAZUS-MH model building type and design level: highrise RC moment frame (C1H) high code (h), and RC moment frame (C1H) high-code special (hs). Casualty rates are copied from NIBS and FEMA (2009) Tables 13-3 through 13-7.

8.9 PREFACE TO LOSS-OUTPUT DIFS

The DIFs presented in the remainder of this section all define loss output data, and are therefore labeled “LOS.”

8.10 LOS01: LOSS TO POINT ASSETS UNDER AN EVENT SET

This loss-output DIF provides the mean and logarithmic standard deviation of loss for one or more assets in each of one or more combinations of earthquake rupture forecast, ground-motion prediction equation, fault, and fault segment. It is essentially the loss for each asset in an event set.

```
[Explanatory header]
ID,ERF,GMPE,Source,Rupture,AssetID,LM,Median,LSDT
1,[ERF1],[GMPE1],[SRC1],[RUP1],[AID1],[LM1],[EL1],[LLSDT1]
2,[ERF2],[GMPE2],[SRC2],[RUP2],[AID2],[LM2],[EL2],[LLSDT2]
…
n,[ERFn],[GMPEn],[SRCn],[RUPn],[AIDn],[LMn],[ELn],[LLSDTn]
```

Figure 41. LOS01 event-set asset loss estimate

All terms as are defined above, with the addition of

ELr = expected value of loss before insurance recovery or other risk transfer to asset whose ID is AIDr, given the values of ERFr, GMPEr, SRCr, RUPr, and LMr (nonnegative double-precision floating point; need not be limited to the value of the asset)

LLSDTr = logarithmic standard deviation of loss before insurance recovery or other risk transfer to the asset whose ID is AIDr, given the values of ERFr, GMPEr, SRCr, RUPr, and LTr (nonnegative double-precision floating point).

```
"K Porter 29 Apr 2009 sample event-set loss estimate"
ID,ERF,GMPE,Source,Rupture,AssetID,LM,Median,LSDT
1,UCERF1,CB2003,1,0,1,CAS1,0.003,2.0
2,UCERF1,CB2003,1,1,1,CAS1,0.004,2.0
3,UCERF1,CB2003,1,2,1,CAS1,0.005,2.0
…
```

Figure 42. Sample LOS01 event-set asset loss estimate

8.11 LOS02: EXPECTED ANNUALIZED LOSS TO POINT ASSETS

This loss-output DIF provides the expected annualized loss to one or more assets, given an earthquake rupture forecast and ground-motion prediction equation. Figure 43 presents the layout of LOS02; Figure 44 contains a small sample.

```
[Explanatory header]
ID,ERF,GMPE,AssetID,LM,EAL
1,[ERF1],[GMPE1],[AID1],[LM1],[EAL1]
2,[ERF2],[GMPE2],[AID2],[LM2],[EAL2]
…
n,[ERFn],[GMPEn],[AIDn],[LMn],[EALn]
```

Figure 43. LOS02 expected annualized loss estimate

All terms as are defined above, with the addition of

EALr = expected annualized loss before insurance recovery or other risk transfer to the asset whose ID is AIDr, given the values of ERFr, GMPEr, and LMr, in the same units as the value(s) expressed in the portfolio file for this asset. (Nonnegative double-precision floating point.)

```
"K Porter 29 Apr 2009 sample expected annualized loss estimate"
ID,ERF,GMPE,AssetID,LM,EAL
1,UCERF1,CB2003,1,CAS1,0.0110
2,UCERF1,CB2003,2,CAS1,0.0017
3,UCERF1,CB2003,3,CAS1,0.1806
…
```

Figure 44. Sample LOS02 expected annualized loss estimate

8.12 LOS03: LOSS EXCEEDANCE CURVE FOR ONE POINT ASSET

This loss-output DIF specifies the loss exceedance frequency for a single asset for each of a set of loss values, given a single earthquake rupture forecast and ground-motion prediction equation. As used here, a loss exceedance curve means the mean frequency (y-axis) with which loss of various levels (x-axis) is exceeded. Figure 45 presents the layout of LOS03; Figure 46 contains a sample.

```
[Explanatory header]
AssetID=[AID]
ERF=[ERF]
GMPE=[GMPE]
LM=[LM]
ID,L,G
1,[L1],[G1]
2,[L2],[G2]
…
n,[Ln],[Gn]
```

Figure 45. LOS03 single-asset loss exceedance curve

Lr = Loss for record r, units of LM

Gr = Mean frequency (events/yr) with which loss Lr is experienced by asset AID, given ERF, GMPE, and the value exposed stated in the asset definition

```
"K Porter 1 May 2009 sample single-asset loss exceedance curve"
AssetID=1
ERF=USGS/CGS2002
GMPE= USGS2002
LM=DF
ID,L,G
1,6.19E-06,0.028819358
2,1.54E-05,0.028799977
3,3.83E-05,0.028664311
4,9.54E-05,0.0280227
5,2.37E-04,0.026063727
6,5.91E-04,0.022033893
7,0.00147,0.016297886
8,0.00366,0.010520453
9,0.0091,0.006178541
10,0.0226,0.003405113
11,0.0563,0.001644897
12,0.14,5.67E-04
13,0.349,1.08E-04
14,0.868,1.05E-05
```

Figure 46. Sample LOS03 single-asset loss exceedance curve

8.13 LOS04: LOSS EXCEEDANCE CURVE TO PORTFOLIO OF ASSETS

This loss-output DIF specify the loss exceedance frequency for a given portfolio of point assets, for each of a set of loss levels, given a single earthquake rupture forecast and ground-motion prediction equation. As used here, a loss exceedance curve means the mean frequency (y-axis) with which loss of various levels (x-axis) is exceeded. Figure 47 presents the layout of LOS04; Figure 48 contains a sample.

```
[Explanatory header]
PortfolioID=[POFID]
ERF=[ERF]
GMPE=[GMPE]
LM=[LM]
ID,L,G
1,[L1],[G1]
2,[L2],[G2]
…
n,[Ln],[Gn]
```

Figure 47. LOS04 portfolio loss exceedance curve

POFID = portfolio ID

Gr = Mean frequency (events/yr) with which loss Lr is experienced by asset AID, given ERF, GMPE, and the value exposed stated in the asset definition

```
"K Porter 1 May 2009 sample portfolio loss exceedance curve"
POFID="KAP01"
ERF=USGS/CGS2002
GMPE= USGS2002
LM=DF
ID,L,G
1,1.9,0.028819358
2,4.6,0.028799977
3,11.5,0.028664311
4,28.6,0.0280227
5,71.1,0.026063727
6,177.3,0.022033893
7,441.0,0.016297886
8,1098.0,0.010520453
9,2730.0,0.006178541
10,6780.0,0.003405113
11,16890.0,0.001644897
12,42000.0,5.67E-04
13,104700.0,1.08E-04
14,260400.0,1.05E-05
```

Figure 48. Sample LOS04 portfolio loss exceedance curve

9 CONCLUSIONS

This report presents a number of proposed data interchange formats (DIFs) and standard taxonomies of structure types, earthquake rupture forecasts, etc. for use in GEM*, including DIFs for hazard output (to be used as input to risk analyses), exposure (i.e., values exposed to seismic risk), vulnerability, and fragility. A companion work by the US Geological Survey (Ned Field) will focus on hazard-related DIFs (especially to specify earthquake rupture forecasts and ground-motion prediction equations).

Samples are provided of each DIF, and in each case, each parameter is explained, assigned a variable type (e.g., integer, text string, double-precision floating point, etc.) and any constraints are specified (e.g., probabilities between 0 and 1).

The proposed DIFs and standards draw on commonly used public sources, e.g., EMS-98, World Housing Encyclopedia, ATC-13, FEMA 154, HAZUS-MH, OpenSHA, OpenRisk, and PAGER. The DIFs presented here are entirely human-readable, plain-text flat files (commas-and-quotes). The emphasis in these DIFs is on simplicity and universality over storage efficiency and elegance.

It is not expected that these DIFs will are exhaustive or final. A suggested wiki-based curatorial system to enhance and supplement curate the DIFs is outlined.

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APPENDIX 1: REVIEW COMMENTARY

The draft of this document was presented and discussed in person or by email in March and April 2009 with David Wald and the PAGER team, Ned Field and the OpenSHA team, and Marco Pagani, Ramakrishnan Krishnamurthy, and Helen Crowley, representing GEM and the EUCENTRE. Awaiting further commentary from GFZ, ETH, or EUCENTRE.

Reviewer(s)	Comment(s)	Response / action
Glenn Rix (Georgia Tech)	Suggests moving site distance from HAZ01C to HAZ01A and delete old HAZ01C	Done
Edward Field (USGS)	ERFs and GMPEs have a number of adjustable parameters that would have to be dealt with somehow	Dealt with this by recommending Field's hazard-related DIF doc deal with this, and by allowing for default earthquake rupture forecasts and ground-motion prediction equations and labels for custom earthquake rupture forecasts and ground-motion prediction equations.
David Wald, Kishor Jaiswal (USGS)	Suggest substituting revised PAGER-STR for ver 1.0	Held further discussions, proposed revisions of PAGER-STR; ver 1.1 was inserted.
Marco Pagani, Ramakrishnan Krishnamurthy, and Helen Crowley (GEM)	No specific comments, although discussed relative merit of XML or relational databases instead vs. flat files.	DIF doc now emphasizes to a greater extent that simplicity is preferable to storage efficiency.