Data Interchange Formats for the Global Earthquake Model (GEM)

Prepared for
GEM1
ETH Zurich

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This is an external report, produced within the scope of the GEM1 project. GEM1 was a focused pilot project of the Global Earthquake Model initiative, which ran from January 1st 2009 to March 31st 2010 and was aimed at generating GEM's first products and developing GEM's initial IT infrastructure. The technical achievements of GEM1 have been summarised in a series of 10 reports; 6 internal and 4 external GEM1 reports. The internal reports are based on the achievements of the GEM1 team, the external reports are written by external experts who had been awarded a sub-contract to carry out a specific task. In addition to reading this external reports, it is suggested to also read the rest of the GEM1 reports and in particular the GEM1 Executive Summary. These can be downloaded from www.globalquakemodel.org/node/747

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www.globalquakemodel.org

EXECUTIVE SUMMARY

Sixteen draft data interchange formats and 7 terminology standards (collectively referred to here as DIFs) are proposed here for use in GEM1. This initial draft includes several DIFs for hazard output (to be used as input to risk analyses), exposure (i.e., values exposed to seismic risk), vulnerability, and fragility. 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 data standards in this draft draw primarily on OpenSHA, OpenRisk, PAGER, and to a limited extent HAZUS-MH, EMS-98, and the World Housing Encyclopedia. The DIFs presented in this draft are entirely human-readable, plain-text flat files (commas-and-quotes); no attempt has been made yet to define XML formats. The emphasis in these DIFs is on simplicity and universality over storage efficiency. It is not intended that these DIFs represent a complete or exhaustive set of what GEM1 will require. Later drafts may add XML format and DIFs for other I/O needs. GEM1 participants are encouraged to contact the authors to recommend additions, modifications, and clarification.

Table E1. Summary list of risk-related DIFs

DIF	Description	Site (S) or Portfolio (P)?	Deterministic (D) or probabilistic (P)?
HAZ01A	Event set: probabilistic ground motion by earthquake rupture forecast, ground-motion prediction equation, IMT, source, rupture, site	S or P	D or P
HAZ01B	Source & rupture rate and magnitude for HAZ01A	Either	Either
HAZ01C	Rupture distance for HAZ01A	Either	Either
HAZ01D	Logic tree weights for HAZ01A	Either	Either
HAZ02	Gridded hazard	Mostly S	Mostly P
HAZ03	Site intensity for MCS	Either	P
HAZ04	Uniform seismic hazard	Mostly S	D
EXP01	Portfolio of point assets	Either	D
EXP02	Portfolio of point assets with uncertainty	Either	P
VULN01A	MDF vs. IML	Either	D
VULN01B	COV of damage factor vs. IML for VULN01A	Either	P
VULN02	Damage probability matrix	Either	P
VULN03	Damage exceedance matrix	Either	P
VULN04	HAZUS-based casualty rates	Either	D
VULN05	HAZUS-based MDF	Either	D
FRAG01	HAZUS-based fragility functions	Either	Either
	Site & portfolio damage & loss: TBD		

Table E2. Summary of proposed taxonomies

Standard	Description
GMPE01	Ground-motion prediction equations
IMT01	Excitation types a.k.a. intensity measure types
ERF01	Earthquake rupture forecasts
SST01	PAGER structure type taxonomy = FEMA + EMS98 + WHE + extras
SST02	ATC-13 facility class taxonomy
SST03	HAZUS-MH structure type taxonomy
LM01	Loss measures

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1 INTRODUCTION

1.1 BACKGROUND

The Global Earthquake Model (GEM) will 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, and GEM1 software will attempt to integrate them into proof-of-concept or prototype software. An issue for successful GEM1 development are data interchange 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 draft interchange formats (DIFs) that are intended to facilate interchange between GEM1 software packages. As used here, DIFs are standards for exchanging information with existing and developing software. A decision immediately presents itself: whether the DIFs should aim for efficiency and integration with software through the use of IP-accessible databases, or whether human-readable text files would be more universally accessible. During the proposal process, it was determined that the latter did not preclude the former, while defining DIFs with a relational database might raise hurdles to GEM1 contributors such as OpenSHA. The DIFs presented here therefore take the form of human-readable text files.

The development of such DIFs is a significant task, and will evolve as GEM develops, but it is necessary to develop draft standards for use with GEM1 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. To a limited extent we will collaborate with developers of hazard-related DIFs, 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 are being addressed separately by GEM1).

Considering GEM1's need for DIFs early in its development, we will continue to survey 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.

Findings of our survey will be assessed within a unifying DIF format, to identify those current DIFs most relevant, acceptable, and adaptable for GEM1's purposes, which we understand involve using or integrating existing hazard and risk software developed by GEM1 participants. To the extent that GEM1-required DIFs do not exist or are unsuitable, we will propose DIFs to meet GEM's needs.

The DIFs discussed here are not exhaustive, but will provide a useful foundation for data interchange for GEM1 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 GEM1 or GEM will depend on the GEM1 software architecture and vice versa. Writing DIFs is an iterative process, and only limited iteration is possible here. We will propose draft DIFs, present them for discussion at the March 2009 GEM meeting and Canberra, and will revise them following those discussions.

1.3 ORGANIZATION OF REPORT

This section has introduced the problem to be addressed and presented the scope of work. Draft DIFs with samples are then presented in the subsequent sections: Section 2 presents those related to hazard, Section 3 to exposure, Section 4 to vulnerability, Section 5 to fragility, and Section 6 to direct loss (site and portfolio property damage and loss). Conclusions and limitations are presented in Section 7. References are presented in Section 8.

2 HAZARD

2.1 PREFACE TO HAZARD DIFS

The DIFs presented in this section are in the form of flat files often based on currently used formats. “Based on” refers to the fact that in several cases new fields are proposed for these current standards to make them slightly more useful. Relational databases can make several of the DIFs use storage space far more efficiently, for example using indices that refer to a separate table, rather than repeating text strings, etc., in each record. In these initial DIFs, however, we have favored simplicity over efficiency. This initial set of DIFs is based on comma-separated-values; XML equivalents will be developed next. Some notes that are common to all flat 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 double-quotes (Unicode 0022).

2.2 HAZ01A, B, AND C: EXCITATION BY SITE AND SCENARIO EVENT

This DIF is based on the output of Field’s OpenSHA event set calculator. These three flat files provide hazard information to input to serve deterministic or probabilistic single-site or portfolio loss estimates that require event-by-event excitation information where the site excitation is assumed to be lognormally distributed and the scenario occurrence rate information is required. One can consider as a special case any combination of single-site (as opposed to portfolio), single-scenario event (as opposed to multiple events), and deterministic excitation (as opposed to uncertain).

The DIF is referred to here as HAZ01, and the three files as HAZ01A, HAZ01B, and HAZ01C. 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 2) provides magnitude and rate information by earthquake rupture forecast, source, and rupture. HAZ01C (Figure 3) provides rupture distance by source, rupture, and site. 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 1 provides the layout of HAZ01A. Examples in the format of these three DIFs are shown in Figure 7 (HAZ01A), Figure 8 (HAZ01B), and Figure 9 (HAZ01C). 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,GMPE,IMT,Source,Rupture,Site,Median,LSDT,LSDE
1,[ERF1],[GMPE1],[IMT1],[SRC1],[RUP1],[SITE1],[MED1],[LSDT1],[LSDE1]
2,[ERF2],[GMPE2],[IMT2],[SRC2],[RUP2],[SITE2],[MED2],[LSDT2],[LSDE2]
…
n,[ERFn],[GMPEn],[IMTn],[SRCn],[RUPn],[SITEn],[MEDn],[LSDTn],[LSDEn]
```

Figure 1. 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 2. HAZ01B source and rupture information

```
[Explanatory header]
ID,ERF,Source,Rupture,Site,Dist
1,[ERF1],[SRC1],[RUP1],[SITE1],[DIST1],"[SourceName1]"
2,[ERF2],[SRC2],[RUP2],[SITE2],[DIST2],"[SourceName2]"
…
n,[ERFn],[SRCn],[RUPn],[SITEn],[DISTn],"[SourceNamen]"
```

Figure 3. HAZ01C rupture distance

DIST1 = source-to-site distance (km) as defined by the ground-motion prediction equation.

ERF1 = ID for earthquake rupture forecast used in record 1, a text string. Need not be unique. An initial list of earthquake rupture forecasts drawn from a recent OpenSHA application is shown in Figure 6. It will need to be supplemented with non-California earthquake rupture forecasts and additional XML to specify values of parameters specific to each earthquake rupture forecast.

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

GMPE1 = ID for ground motion prediction equation used in record 1. 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. An initial list drawn from a recent OpenSHA application is shown in Figure 4.

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.

IMT1 = excitation type for record 1 (text string of variable length). An initial list is proposed in Figure 5. 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.

LSDE1 = inter-event portion of LSDT1 (double-precision floating point). Intra-event portion is assumed = $(\mathrm{LSDT1}^2 - \mathrm{LSDE1}^2)^{0.5}$.

LSDT1 = total logarithmic standard deviation of ground motion (double-precision floating point) of IMT1 at SIT1 given rupture of SRC1 on RUP1, using ATT1. Unitless.

MAG1 = magnitude for record 1, assumed to be moment magnitude, Mw, unless noted in the header (single-precision floating point).

MED1 = natural logarithm of median ground motion (double-precision floating point) of IMT1 at SIT1 given rupture of SRC1 on RUP1 using ATT1. Units are implicit in IMT1.

RATE1 = mean exceedance rate of rupture (events per year; double-precision floating point).

RUP1 = numeric rupture identifier for record 1 (integer; 1, 2, 3, …), an index provided by the hazard model referring to a rupture segment on SRC1.

SITE1 = numeric site identifier for record 1 (integer; 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.

SourceName1 = text name of source for record 1 (≤255 characters)

SRC1 = numeric source identifier for record 1 (integer; 1, 2, 3, …), an index provided by the hazard model referring to a fault or area source in the hazard model's database.

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

Figure 4. GMPE01: initial list of ground-motion prediction equation identifiers

```
PGA = geometric-mean horizontal peak ground acceleration, g
PGAMD = max-direction horizontal peak ground acceleration, g
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
PGV = geometric-mean horizontal peak ground velocity, cm/sec
PGVMD = ditto, maximum-direction
PGD = geometric-mean horizontal peak ground displacement, cm
PGDMD = ditto, maximum-direction
JMA = Japan Meteorological Agency intensity
MMI = Modified Mercalli Intensity
EMS98 = European Macroseismic Scale 1998
```

Figure 5. IMT01: initial list of excitation types (a.k.a. intensity mesaure types IMTs) and units

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

Figure 6. Initial incomplete list of earthquake rupture forecasts

```
"K Porter 28 Feb 2009 example HAZ01A event set"
ID,ERF,GMPE,IMT,Source,Rupture,Site,Median,LSDT,LSDE
1,UCERF1,CB2003,SA10,1,0,1,-35.000,0.5835,0.146
2,UCERF1,CB2003,SA10,1,1,1,-35.000,0.580,0.145
3,UCERF1,CB2003,SA10,1,2,1,-35.000,0.5765,0.144
4,UCERF1,CB2003,SA10,1,3,1,-35.000,0.573,0.143
5,UCERF1,CB2003,SA10,1,4,1,-35.000,0.5695,0.142
6,UCERF1,CB2003,SA10,1,5,1,-35.000,0.566,0.141
7,UCERF1,CB2003,SA10,1,6,1,-35.000,0.5625,0.141
8,UCERF1,CB2003,SA10,1,7,1,-35.000,0.559,0.140
9,UCERF1,CB2003,SA10,1,8,1,-35.000,0.5555,0.139
10,UCERF1,CB2003,SA10,1,9,1,-35.000,0.552,0.138
11,UCERF1,CB2003,SA10,1,10,1,-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)

```
"K Porter 28 Feb 2009 example HAZ01C rupture distance"
ID,ERF,Source,Rupture,Site,Dist
1,UCERF1,1,0,1,232.25076
2,UCERF1,1,1,1,232.25076
3,UCERF1,1,2,1,232.25076
4,UCERF1,1,3,1,232.25076
5,UCERF1,1,4,1,232.25076
6,UCERF1,1,5,1,232.25076
7,UCERF1,1,6,1,232.25076
8,UCERF1,1,7,1,232.25076
9,UCERF1,1,8,1,232.25076
10,UCERF1,1,9,1,232.25076
11,UCERF1,1,10,1,232.25076
```

Figure 9. Example HAZ01C rupture distance information (extract)

2.3 HAZ01D: ENHANCEMENT TO HAZ01 TO QUANTIFY MODEL WEIGHTS

HAZ01 includes no information on weights that one might assign to each combination of earthquake rupture forecast and ground-motion prediction equation, often referred to as epistemic uncertainties. HAZ01D specifies these weights. Figure 10 specifies the format of HAZ01D; Figure 11 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 10. HAZ01D source, magnitude, and rate information

ERFn and GMPEn are as defined in HAZ01A

WTn = weight assigned to the combination of earthquake rupture forecast and ground-motion prediction equation in record n (double-precision floating point, 0 ≤ WTn ≤ 1), and weights sum (over all n) 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 11. Example of HAZ01D source, magnitude, and rate information

2.4 HAZ02: GRIDDED HAZARD FILE LIKE FRANKEL ET AL. (2006)

This flat file serves deterministic or probabilistic single-site or portfolio loss estimates where inter-event correlation of shaking is not needed, such as single-site or portfolio expected annualized ground-up loss, or single-site loss exceedance curve. The DIF is borrowed largely from Frankel et al.'s (2006) 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 12. HAZ02 gridded seismic hazard

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

ERF = ID for earthquake rupture forecast. See above for further detail.

IMT = excitation type (for entire file). An initial list is proposed in Figure 5. See above for further detail.

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 13. Sample extract of HAZ02 gridded seismic hazard file

2.5 HAZ03: GROUND MOTION FROM SYNTHETIC CATALOG FOR SIMPLE MCS

This DIF is intended to serve simple Monte Carlo simulation of site or portfolio risk: a sequence of one or more equiprobable synthetic catalogs of events. 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 14 specifies the proposed DIF; Figure 15 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],[IML
      1]
2,[CAT2],[EVT2],[DATE2],[IMT2],[SRC2],[RUP2],[M2],[SITE2],[DISTn],[IML
      2]
…
n,[CATn],[EVTn],[DATEn],[IMTn],[SRCn],[RUPn],[Mn],[SITEn],[DISTn],[IML
      n]
```

Figure 14. HAZ03 site intensity estimate for MCS

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

CATn = ID of catalog in record n (integer, in 1, 2, …)

EVTn = ID of event within catalog CATn in record n (integer, in 1, 2, …)

DATEn = date and local time of event in record n (YYYYMMDDHHMM, with all obvious constraints on date and time)

IMTn, SRCn, RUPn, Mn, SITEn, DISTn, as previously defined

IMLn = simulated ground motion intensity (measured in terms of IMT) in record n

```
"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 15. Example HAZ03 file

2.6 HAZ04: UNIFORM SEISMIC HAZARD DATA

This DIF provides a format for tabulating ground motion with specified exceedance frequency for one or more locations given a single combination of excitation type (a.k.a. intensity measure type), earthquake rupture forecast, ground-motion prediction equation, and site soil classifications (parameterized here by Vs30). Figure 16 specifies the contents of HAZ04, while Figure 17 illustrates with 2 sites and 4 soil classes.

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

Figure 16. HAZ04 source, magnitude, and rate information

ERF = earthquake rupture forecast used (text string of variable length, limited to available earthquake rupture forecasts, beginning perhaps with the list in Figure 6)

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, beginning perhaps with the list in Figure 4)

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

IMT = intensity measure type (variable length text, beginning perhaps with the list in Figure 5)

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

LONn = longitude of site in record n (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,LAT,LON,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 17. Example HAZ04 file of uniform seismic hazard

3 EXPOSURE

3.1 PREFACE TO EXPOSURE DIFS

DIFs presented in this section are limited to point assets, i.e., facilities that for purposes of seismic risk estimation can be treated as located at a point.

3.2 SST01 – SST03: THREE STRUCTURE TYPE CATEGORY SYSTEMS

Before discussing exposure data files, it is worthwhile to begin with a draft taxonomy for structure types. Several naming systems are listed below. Table 1 lists the PAGER structure type taxonomy, which is an attempt to create an exhaustive structure type system combining the FEMA system (which, with the addition of code era, is the HAZUS-MH taxonomy), EMS-98 (EMS 1998), the World Housing Encyclopedia, and a few types not captured by any of these such as steel-reinforced concrete. Table 2 lists ATC-13 facility classes (Applied Technology Council 1985; the term facility class indicates that these categories include more than structures: contents, vehicles, etc. appear in the table). Table 3 lists the HAZUS-MH structure types, although a more-recent taxonomy (not shown here) subdivides the system into even finer units, with 7 combinations of code era and quality of construction, rather than the 4 code eras shown here. In these tables, lowrise refers to 1-3 stories above grade, midrise means 4-7 stories, and highrise means 8 or more stories above grade. In each system, each structure type is provided with a unique integer ID (1, 2, …), a unique text abbreviation (25 characters or fewer), and a text description (255 characters or fewer).

Table 1. PAGER structure types

ID	Abbrev	Description
1	W	WOOD
2	W1	Woodframe, Wood Stud, with Wood, Stucco, or Brick Veneer < 5000 sf (500 m^2)
3	W2	Woodframe, Heavy Members, or Traditional Japanese Woodframe > 5000 sf (500 m^2)
4	W3	Woodframe, Prefabricated Steel Stud Panels
5	W4	Log building
6	S	STEEL
7	S1	Steel Moment Frame
8	S1L	Steel Moment Frame 1-3 Story
9	S1M	Steel Moment Frame 4-7 Story
10	S1H	Steel Moment Frame 8+ Story
11	S2	Steel Braced Frame
12	S2L	Steel Braced Frame 1-3 Story
13	S2M	Steel Braced Frame 4-7 Story
14	S2H	Steel Braced Frame 8+ Story
15	S3	Steel Light Frame
16	S4	Steel Frame with Cast-in-Place Concrete Shearwalls
17	S4L	Steel Frame with Cast-in-Place Concrete Shearwalls 1-3 Story
18	S4M	Steel Frame with Cast-in-Place Concrete Shearwalls 4-7 Story
19	S4H	Steel Frame with Cast-in-Place Concrete Shearwalls 8+ Story
20	S5	Steel Frame with Unreinforced Masonry Infill Walls
21	S5L	Steel Frame with Unreinforced Masonry Infill Walls 1-3 Story
22	S5M	Steel Frame with Unreinforced Masonry Infill Walls 4-7 Story
23	S5H	Steel Frame with Unreinforced Masonry Infill Walls 8+ Story
24	C	REINFORCED CONCRETE
25	C1	Ductile Reinforced Concrete Moment Frame
26	C1L	Ductile Reinforced Concrete Moment Frame 1-3 Story
27	C1M	Ductile Reinforced Concrete Moment Frame 4-7 Story
28	C1H	Ductile Reinforced Concrete Moment Frame 8+ Story
29	C2	Reinforced Concrete Shearwall
30	C2L	Reinforced Concrete Shearwall 1-3 Story
31	C2M	Reinforced Concrete Shearwall 4-7 Story
32	C2H	Reinforced Concrete Shearwall 8+ Story
33	C3	Nonductile Reinforced Concrete Moment Frame with Masonry Infill Walls
34	C3L	Nonductile Reinforced Concrete Moment Frame with Masonry Infill Walls 1-3 Story
35	C3M	Nonductile Reinforced Concrete Moment Frame with Masonry Infill Walls 4-7 Story
36	C3H	Nonductile Reinforced Concrete Moment Frame with Masonry Infill Walls 8+ Story
37	C4	Nonductile Reinforced Concrete Frame without Masonry Infill Walls
38	C4L	Nonductile Reinforced Concrete Frame without Masonry Infill Walls 1-3 Story
39	C4M	Nonductile Reinforced Concrete Frame without Masonry Infill Walls 4-7 Story
40	C4H	Nonductile Reinforced Concrete Frame without Masonry Infill Walls 8+ Story
41	C5	Steel Reinforced Concrete
42	C5L	Steel Reinforced Concrete 1-3 Story
43	C5M	Steel Reinforced Concrete 4-7 Story
44	C5H	Steel Reinforced Concrete 8+ Story
45	PC1	Tiltup
46	PC2	Precast Concrete Frames with Concrete Shearwalls
47	PC2L	Precast Concrete Frames with Concrete Shearwalls 1-3 Story
48	PC2M	Precast Concrete Frames with Concrete Shearwalls 4-7 Story
49	PC2H	Precast Concrete Frames with Concrete Shearwalls 8+ Story
50	RM	REINFORCED MASONRY

ID	Abbrev	Description
51	RM1	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms
52	RM1L	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms 1-3 Story
53	RM1M	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms 4-7 Story
54	RM2	Reinforced Masonry Bearing Walls with Concrete Diaphragms
55	RM2L	Reinforced Masonry Bearing Walls with Concrete Diaphragms 1-3 Story
56	RM2M	Reinforced Masonry Bearing Walls with Concrete Diaphragms 4-7 Story
57	RM2H	Reinforced Masonry Bearing Walls with Concrete Diaphragms 8+ Story
58	MH	Mobile Home
59	M	MUD WALLS
60	M1	Mud Walls without Horizontal Wood Elements
61	M2	Mud Walls with Horizontal Wood Elements
62	A	ADOBE BLOCK (UNBAKED DRIED MUD BLOCK) WALLS
63	A1	Adobe Block, Mud Mortar, Wood Roof and Floors
64	A2	Adobe Block, Mud Mortar, Wood Roof and Floors, Bamboo, Straw, and Thatch Roof
65	A3	Adobe Block, Mud Mortar, Wood Roof and Floors, Cement-sand Mortar
66	A4	Adobe Block, Mud Mortar, Wood Roof and Floors, Reinforced Concrete Bond Beam, Cane and Mud Roof
67	A5	Adobe Block, Mud Mortar, Wood Roof and Floors, with Bamboo or Rope Reinforcement
68	RE	RAMMED EARTH/PNEUMATICALLY IMPACTED STABILIZED EARTH
69	RS	RUBBLE STONE (FIELD STONE) MASONRY
70	RS1	Field Stones Dry Stacked (No Mortar), Timber Floors, Timber, Earth, or Metal Roof
71	RS2	Field Stones, Mud Mortar, Timber Floors, Timber, Earth, or Metal Roof
72	RS3	Field Stones, Lime Mortar, Timber Floors, Timber, Earth, or Metal Roof
73	RS4	Field Stones, Cement Mortar, Vaulted Brick Roof and Floors
74	RS5	Field Stones, Cement Mortar, Timber Floors, Timber, Earth, or Metal Roof, Reinforced Concrete Bond Beam
75	DS	RECTANGULAR CUT STONE MASONRY BLOCK
76	DS1	Rectangular Cut Stone Masonry, Mud Mortar, Timber Roof and Floors
77	DS2	Rectangular Cut Stone Masonry, Lime Mortar, Timber Roof and Floors
78	DS3	Rectangular Cut Stone Masonry, Cement Mortar, Timber Roof and Floors
79	DS4	Rectangular Cut Stone Masonry, Lime Mortar, Concrete Roof and Floors
80	UFB	UNREINFORCED FIRED BRICK MASONRY
81	UFB1	Unreinforced Brick Masonry, Mud Mortar, no Timber Posts
82	UFB2	Unreinforced Brick Masonry, Mud Mortar, with Timber Posts
83	UFB3	Unreinforced Fired Brick Masonry, Cement Mortar, Timber Floors, Timber or Steel Beams and Columns, Tie Courses
84	UFB4	Unreinforced Fired Brick Masonry, Cement Mortar, Concrete Diaphragms, Timber or Steel Beams and Columns, Tie Courses
85	UCB	UNREINFORCED CONCRETE BLOCK MASONRY, LIME/CEMENT MORTAR
86	MS	MASSIVE STONE MASONRY IN LIME/CEMENT MORTAR
87	INF	INFORMAL CONSTRUCTION (PARTS OF SLUMS/SQUATTERS) Constructions made of wood/plastic sheets/GI Sheets/light metal or composite etc., not confirming to engineering standards.
88	UNK	Unknown Category (Not specified)

Table 2. ATC-13 (1985) facility classes

ID	Abbrev	Description
101	W/F/LR	Wood Frame (Low Rise)
102	M/F/LR	Light Metal (Low Rise)
103	RC/SW-MRF/LR	Reinforced Concrete Shear Wall (with Moment-Resisting Frame) Low Rise
104	RC/SW-MRF/MR	Reinforced Concrete Shear Wall (with Moment-Resisting Frame) Medium Rise
105	RC/SW-MRF/HR	Reinforced Concrete Shear Wall (with Moment-Resisting Frame) High Rise
106	RC/SW-0/LR	Reinforced Concrete Shear Wall (without Moment-Resisting Frame) Low Rise

ID	Abbrev	Description
107	RC/SW-0/MR	Reinforced Concrete Shear Wall (without Moment-Resisting Frame) Medium Rise
108	RC/SW-0/HR	Reinforced Concrete Shear Wall (without Moment-Resisting Frame) High Rise
109	RM/SW-0/LR	Reinforced Masonry Shear Wall (without Moment-Resisting Frame) Low Rise
110	RM/SW-0/MR	Reinforced Masonry Shear Wall (without Moment-Resisting Frame) Medium Rise
111	RM/SW-0/HR	Reinforced Masonry Shear Wall (without Moment-Resisting Frame) High Rise
112	S/BR/LR	Braced Steel Frame Low Rise
113	S/BR/MR	Braced Steel Frame Medium Rise
114	S/BR/HR	Braced Steel Frame High Rise
115	S/MRF-P/LR	Moment-Resisting Steel Frame (Perimeter Frame) Low Rise
116	S/MRF-P/MR	Moment-Resisting Steel Frame (Perimeter Frame) Medium Rise
117	S/MRF-P/HR	Moment-Resisting Steel Frame (Perimeter Frame) High Rise
118	RC/DMRF-D/LR	Moment-Resisting Ductile Concrete Frame (Distributed Frame) Low Rise
119	RC/DMRF-D/MR	Moment-Resisting Ductile Concrete Frame (Distributed Frame) Medium Rise
120	RC/DMRF-D/HR	Moment-Resisting Ductile Concrete Frame (Distributed Frame) High Rise
121	TU	Tilt-up Low Rise
123	MH	Mobile Home
124	SIMPLE-BRIDGE	Conventional Bridge (<500-ft spans) Multiple Simple Spans
125	CONT.-BRIDGE	Conventional Bridge (<500-ft spans) Continuous or Single or Monolithic Spans
130	MAJOR-BRIDGE	Major Bridge (greater than 500-ft span)
131	PIPE-UG	Underground Pipeline
132	PIPE-AG	At-grade Pipeline
135	RC-DAM	Concrete Dam
136	EARTH-DAM	Earthfill and Rockfill Dam
138	AL-TUNNEL	Tunnel through Alluvium
139	RK-TUNNEL	Tunnel through Rock
140	CC-TUNNEL	Cut-and-cover Tunnel
141	UG-LIQUID-TANK	Underground Liquid Storage Tank
142	UG-SOLID-TANK	Underground Solid Storage Tank
143	AG-LIQUID-TANK	On-ground Liquid Storage Tank
144	AG-SOLID-TANK	On-ground Solid Storage Tank
145	EL-LIQUID-TANK	Elevated Liquid Storage Tank
146	EL-SOLID-TANK	Elevated Solid Storage Tank
147	RAILROAD	Railroad
148	HIGHWAY	Highway
149	RUNWAY	Runway
150	URM/CHIMNEY	High Industrial Masonry Chimney
151	RC/CHIMNEY	High Industrial Concrete Chimney
152	S/CHIMNEY	High Industrial Steel Chimney
153	CRANE	Crane
154	CONVEYOR	Conveyor System
155	STD.-ELEC.-TOWER	Conventional Electric Transmission Line Tower (less than 100 ft high)
156	MAJOR-ELEC.-TOWER	Major Electric Transmission Line Tower (more than 100 ft high)
157	BROADCASTING-TOWER	Broadcast Tower
158	OBSERVATION-TOWER	Observation Tower
159	OFFSHORE-TOWER	Offshore Tower
161	CANAL	Canal
162	EARTH-RET.-STRUCTURE	Earth Retaining Structure over 20 ft High
163	WATERFRONT-STRUCTURE	Waterfront Structure
164	RESIDENTIAL-EQUIP.	Residential Equipment
165	OFFICE-EQUIP.	Office Equipment (Furniture, Computers, etc.)
166	ELECTRICAL-EQUIP.	Electrical Equipment
168	MECHANICAL-EQUIP.	Mechanical Equipment
170	HIGH-TECH-EQUIP.	High Technology and Laboratory Equipment
172	S/MRF-D/LR	Moment-Resisting Steel Frame (Distributed Frame) Low Rise

ID	Abbrev	Description
173	S/MRF-D/MR	Moment-Resisting Steel Frame (Distributed Frame) Medium Rise
174	S/MRF-D/HR	Moment-Resisting Steel Frame (Distributed Frame) High Rise
175	URM/BRG-WALL/LR	Unreinforced Masonry Bearing Wall Low Rise
176	URM/BRG-WALL/MR	Unreinforced Masonry Bearing Wall Medium Rise
178	URM/FR/LR	Unreinforced Masonry with Load-Bearing Frame Low Rise
179	URM/FR/MR	Unreinforced Masonry with Load-Bearing Frame Medium Rise
180	URM/FR/HR	Unreinforced Masonry with Load-Bearing Frame High Rise
181	PCC/LR	Precast Concrete other than Tilt-Up Low Rise
182	PCC/MR	Precast Concrete other than Tilt-Up Medium Rise
183	PCC/HR	Precast Concrete other than Tilt-Up High Rise
184	RM/SW/LR	Reinforced Masonry Shear Wall (with Moment-Resisting Frame) Low Rise
185	RM/SW/MR	Reinforced Masonry Shear Wall (with Moment-Resisting Frame) Medium Rise
186	RM/SW/HR	Reinforced Masonry Shear Wall (with Moment-Resisting Frame) High Rise
187	RC/ND-FR-D/LR	Moment-Resisting Non-Ductile Concrete Frame (Distributed Frame) Low Rise
188	RC/ND-FR-D/MR	Moment-Resisting Non-Ductile Concrete Frame (Distributed Frame) Medium Rise
189	RC/ND-FR-D/HR	Moment-Resisting Non-Ductile Concrete Frame (Distributed Frame) High Rise
190	VEHICLES	Trains, Trucks, Airplanes, & other Vehicles
191	LS/LR	Long Span Low Rise

Table 3. HAZUS-MH structure types

ID	Abbrev	Description
201	W1h	Wood frame < 5000 sf high code
202	W1m	Wood frame < 5000 sf moderate code
203	W1l	Wood frame < 5000 sf low code
204	W1p	Wood frame < 5000 sf pre-code
205	W2h	Wood frame ≥ 5000 sf high code
206	W2m	Wood frame ≥ 5000 sf moderate code
207	W2l	Wood frame ≥ 5000 sf low code
208	W2p	Wood frame ≥ 5000 sf pre-code
209	S1Lh	Steel moment frame lowrise high code
210	S1Lm	Steel moment frame lowrise moderate code
211	S1Ll	Steel moment frame lowrise low code
212	S1Lp	Steel moment frame lowrise pre-code
213	S1Mh	Steel moment frame midrise high code
214	S1Mm	Steel moment frame midrise moderate code
215	S1Ml	Steel moment frame midrise low code
216	S1Mp	Steel moment frame midrise pre-code
217	S1Hh	Steel moment frame highrise high code
218	S1Hm	Steel moment frame highrise moderate code
219	S1Hl	Steel moment frame highrise low code
220	S1Hp	Steel moment frame highrise pre-code
221	S2Lh	Steel braced frame lowrise high code
222	S2Lm	Steel braced frame lowrise moderate code
223	S2Ll	Steel braced frame lowrise low code
224	S2Lp	Steel braced frame lowrise pre-code
225	S2Mh	Steel braced frame midrise high code
226	S2Mm	Steel braced frame midrise moderate code
227	S2Ml	Steel braced frame midrise low code
228	S2Mp	Steel braced frame midrise pre-code
229	S2Hh	Steel braced frame highrise high code
230	S2Hm	Steel braced frame highrise moderate code
231	S2Hl	Steel braced frame highrise low code
232	S2Hp	Steel braced frame highrise pre-code
233	S3h	Steel light frame high code
234	S3m	Steel light frame moderate code
235	S3l	Steel light frame low code
236	S3p	Steel light frame pre-code
237	S4Lh	Steel frame with cast-in-place shearwalls lowrise high code
238	S4Lm	Steel frame with cast-in-place shearwalls lowrise moderate code
239	S4Ll	Steel frame with cast-in-place shearwalls lowrise low code
240	S4Lp	Steel frame with cast-in-place shearwalls lowrise pre-code
241	S4Mh	Steel frame with cast-in-place shearwalls midrise high code
242	S4Mm	Steel frame with cast-in-place shearwalls midrise moderate code
243	S4Ml	Steel frame with cast-in-place shearwalls midrise low code
244	S4Mp	Steel frame with cast-in-place shearwalls midrise pre-code
245	S4Hh	Steel frame with cast-in-place shearwalls highrise high code
246	S4Hm	Steel frame with cast-in-place shearwalls highrise moderate code
247	S4Hl	Steel frame with cast-in-place shearwalls highrise low code
248	S4Hp	Steel frame with cast-in-place shearwalls highrise pre-code
249	S5Ll	Steel frame with unreinforced masonry infill lowrise low code
250	S5Lp	Steel frame with unreinforced masonry infill lowrise pre-code

ID	Abbrev	Description
251	S5Ml	Steel frame with unreinforced masonry infill midrise low code
252	S5Mp	Steel frame with unreinforced masonry infill midrise pre-code
253	S5Hl	Steel frame with unreinforced masonry infill midrise low code
254	S5Hp	Steel frame with unreinforced masonry infill midrise pre-code
255	C1Lh	Concrete moment frame lowrise high code
256	C1Lm	Concrete moment frame lowrise moderate code
257	C1Ll	Concrete moment frame lowrise low code
258	C1Lp	Concrete moment frame lowrise pre-code
259	C1Mh	Concrete moment frame midrise high code
260	C1Mm	Concrete moment frame midrise moderate code
261	C1Ml	Concrete moment frame midrise low code
262	C1Mp	Concrete moment frame midrise pre-code
263	C1Hh	Concrete moment frame highrise high code
264	C1Hm	Concrete moment frame highrise moderate code
265	C1Hl	Concrete moment frame highrise low code
266	C1Hp	Concrete moment frame highrise pre-code
267	C2Lh	Concrete shearwall lowrise high code
268	C2Lm	Concrete shearwall lowrise moderate code
269	C2Ll	Concrete shearwall lowrise low code
270	C2Lp	Concrete shearwall lowrise pre-code
271	C2Mh	Concrete shearwall midrise high code
272	C2Mm	Concrete shearwall midrise moderate code
273	C2Ml	Concrete shearwall midrise low code
274	C2Mp	Concrete shearwall midrise pre-code
275	C2Hh	Concrete shearwall highrise high code
276	C2Hm	Concrete shearwall highrise moderate code
277	C2Hl	Concrete shearwall highrise low code
278	C2Hp	Concrete shearwall highrise pre-code
279	C3Ll	Concrete frame with masonry infil lowrise low code
280	C3Lp	Concrete frame with masonry infil lowrise pre-code
281	C3Ml	Concrete frame with masonry infil midrise low code
282	C3Mp	Concrete frame with masonry infil midrise pre-code
283	C3Hl	Concrete frame with masonry infil highrise low code
284	C3Hp	Concrete frame with masonry infil highrise pre-code
285	PC1h	Precast concrete tiltup high code
286	PC1m	Precast concrete tiltup moderate code
287	PC1l	Precast concrete tiltup low code
288	PC1p	Precast concrete frame with cast-in-place shearwalls pre-code
289	PC2Lh	Precast concrete frame with cast-in-place shearwalls lowrise high code
290	PC2Lm	Precast concrete frame with cast-in-place shearwalls lowrise moderate code
291	PC2Ll	Precast concrete frame with cast-in-place shearwalls lowrise low code
292	PC2Lp	Precast concrete frame with cast-in-place shearwalls lowrise pre-code
293	PC2Mh	Precast concrete frame with cast-in-place shearwalls midrise high code
294	PC2Mm	Precast concrete frame with cast-in-place shearwalls midrise moderate code
295	PC2Ml	Precast concrete frame with cast-in-place shearwalls midrise low code
296	PC2Mp	Precast concrete frame with cast-in-place shearwalls midrise pre-code
297	PC2Hh	Precast concrete frame with cast-in-place shearwalls highrise high code
298	PC2Hm	Precast concrete frame with cast-in-place shearwalls highrise moderate code
299	PC2Hl	Precast concrete frame with cast-in-place shearwalls highrise low code
300	PC2Hp	Precast concrete frame with cast-in-place shearwalls highrise pre-code
301	RM1Lh	Reinforced masonry with flexible diaphragm lowrise high code
302	RM1Lm	Reinforced masonry with flexible diaphragm lowrise moderate code

ID	Abbrev	Description
303	RM1Ll	Reinforced masonry with flexible diaphragm lowrise low code
304	RM1Lp	Reinforced masonry with flexible diaphragm lowrise pre-code
305	RM1Mh	Reinforced masonry with flexible diaphragm midrise high code
306	RM1Mm	Reinforced masonry with flexible diaphragm midrise moderate code
307	RM1Ml	Reinforced masonry with flexible diaphragm midrise low code
308	RM1Mp	Reinforced masonry with flexible diaphragm midrise pre-code
309	RM2Lh	Reinforced masonry with rigid diaphragm lowrise high code
310	RM2Lm	Reinforced masonry with rigid diaphragm lowrise moderate code
311	RM2Ll	Reinforced masonry with rigid diaphragm lowrise low code
312	RM2Lp	Reinforced masonry with rigid diaphragm lowrise pre-code
313	RM2Mh	Reinforced masonry with rigid diaphragm midrise high code
314	RM2Mm	Reinforced masonry with rigid diaphragm midrise moderate code
315	RM2Ml	Reinforced masonry with rigid diaphragm midrise low code
316	RM2Mp	Reinforced masonry with rigid diaphragm midrise pre-code
317	RM2Hh	Reinforced masonry with rigid diaphragm highrise high code
318	RM2Hm	Reinforced masonry with rigid diaphragm highrise moderate code
319	RM2Hl	Reinforced masonry with rigid diaphragm highrise low code
320	RM2Hp	Reinforced masonry with rigid diaphragm highrise pre-code
321	URMLl	Unreinforced masonry bearing wall lowrise low code
322	URMLp	Unreinforced masonry bearing wall lowrise pre-code
323	URMMl	Unreinforced masonry bearing wall midrise low code
324	URMMp	Unreinforced masonry bearing wall midrise pre-code
325	MHh	Mobile home high code
326	MHm	Mobile home moderate code
327	MHl	Mobile home low code
328	MHp	Mobile home pre-code

3.3 EXP01: A PORTFOLIO OF POINT ASSETS

This DIF provides the means to specify seismic attributes of one or more point assets at particular locations. 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. It 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]
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 18. EXP01 portfolio

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

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

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

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

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

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

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

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

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

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

VALn = best estimate of value at risk in the asset in record *n*, monetary or number or people (double precision floating point, $\geq$ 0.00)

VALYRn = year in which value of asset in record n is measured (numeric YYYY), for use in update Valn to present year.

VS30n = mean shearwave velocity in the top 30 m of soil for asset in record *n* (m/sec, single-precision floating point, > 0).

VULNn = name of the vulnerability model to use for the asset in record *n*, 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"
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 19. Sample EXP01 portfolio

3.4 EXP02: A PORTFOLIO OF POINT ASSETS WITH MORE UNCERTAINTY

DIF EXP02 is an extension of EXP01, with more-exhaustive treatment of uncertainty. Figure 20 specifies the layout of EXP02; Figure 21 provides an illustration, this time at the level of individual buildings.

```
[Explanatory header]
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 20. 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)

SVS30n = standard deviation of shearwave velocity in the top 30 m of soil for asset in record *n* (m/sec, single-precision floating point, > 0).

VALHIn = upper bound of value of asset in record *n* (double-precision floating point, ≥ Valn). "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 96^{th} percentile of value.

VALLOn = lower bound of value of asset in record *n* (double-precision floating point, 0 ≤ ValLon ≤ Valn). "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 4^{th} percentile of value.

```
"K Porter 28 Feb 2009 sample EXP02 enhanced portfolio"
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 21. Sample EXP02 enhanced portfolio file

4 VULNERABILITY

4.1 VULN01: MDF AND COV VS. STRUCTURE-INDEPENDENT INTENSITY

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. VULN01A alone gives the vulnerability function, while VULN01B provides a coefficient of variation to use for a probabilistic vulnerability function. 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 22. VULN01A, 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 23. VULN01B, 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 Figure 5. 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 Figure 26.

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 GEM1 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 24. Sample vulnerability functions per VULN01A

```
“K Porter, 24 Feb 2009, sample vulnerability functions for GEM1 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 25. Sample VULN01 vulnerability function coefficients of variation

DF = damage factor, meaning property repair cost as a fraction of replacement cost new; can refer to buildings or contents
CAS1 = indoor casualty rate, HAZUS-MH severity 1, meaning fraction of indoor 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*.
CAS2 = indoor casualty rate, HAZUS-MH severity 2, meaning fraction of indoor 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.
CAS3 = indoor casualty rate, HAZUS-MH severity 3, meaning fraction of indoor 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.
CAS4 = indoor fatality rate, meaning mean fraction of indoor occupants instantaneously killed or mortally injured.
TIME = loss of use duration, days

Figure 26. LM01: loss measures

4.2 VULN02: DAMAGE PROBABILITY MATRIX (DPM)

The damage probability matrix (DPM) contains a probability mass function of loss (generally damage factor) for each of several levels of intensity. 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 $1 \leq i < m$.

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

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

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

$$\begin{gathered} 0 \le p_{ij} \le 1.0 \\ \sum_{i=1}^{m} p_{ij} \le 1.0 \end{gathered} \tag{2}$$

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 27 defines the VULN02 DIF for DPMs, while Figure 28 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 27. VULN02 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 row 1

LBr = lower bound of loss factor whose probabilities are reflected in row 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 Figure 5. 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 Figure 26.

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 GEM1 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 28. Sample DPM according to VULN02

4.3 VULN03: DAMAGE EXCEEDANCE MATRIX (DEM)

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., $i \in \{1, 2, \ldots m\}$ and $j \in \{1, 2, \ldots n\}$. 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

$$q_{ij} = P\left[Y_j \geq z_i\right] \qquad (4)$$

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

$$\begin{aligned} & s_{j+1} > s_j \\ & z_{i+1} > z_i \\ & 0 \leq q_{ij} \leq 1.0 \\ & q_{ij} \geq q_{i+1,j} \\ & q_{ij} \leq q_{i,j+1} \end{aligned} \qquad (5)$$

A DIF for DEMs is now proposed. The file layout is shown in Figure 29. A sample is shown in Figure 30.

```
[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 29. VULN03 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 row 1

LBr = lower bound of loss factor whose probabilities are reflected in row 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 Figure 5. 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 Figure 26.

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 GEM1 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 30. Sample damage exceedance matrix using VULN03

4.4 VULN04: HAZUS-BASED CASUALTY RATES

This DIF is used for reporting structure-independent seismic vulnerability functions of indoor casualty rate, created using the HAZUS-MH methodology (e.g., Porter 2009). 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 VULN04 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 31 specifies the layout of the VULN04 HAZUS-MH indoor-casualty-rate vulnerability-function table. An example is shown in Figure 32, 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,CAS1,CAS2,CAS3,CAS4
[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 31. VULN04 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 ≤ R < 30 km, 40 refers to 30 ≤ R < 60 km, and 80 refers to 60 ≤ 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”)

Y1,1 = mean fraction of indoor occupants injured to HAZUS-MH casualty level 1 given all the conditions in record 1.

Y1,2 = mean fraction of indoor occupants injured to HAZUS-MH casualty level 2 given all the conditions in record 1.

Y1,3 = mean fraction of indoor occupants injured to HAZUS-MH casualty level 3 given all the conditions in record 1.

Y1,4 = mean fraction of indoor occupants injured to HAZUS-MH casualty level 2 given all the conditions in record 1.

Yr,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 GEM1 DIFs"
ABR,Domain,M,R,Soil,SA03,SA10,IM,CAS1,CAS2,CAS3,CAS4
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 32. Sample HAZUS-based indoor-casualty-rate vulnerability function per VULN04

4.5 VULN05: HAZUS-BASED MEAN DAMAGE FACTOR

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 VULN05 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. Figure 33 specifies the layout of the VULN05 HAZUS-MH vulnerability-function table. An example is shown in Figure 34 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 33. VULN05 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 34. Sample VULN05 HAZUS-based vulnerability functions

5 FRAGILITY

5.1 PREFACE TO FRAGILITY DIFS

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.

5.2 FRAG01: HAZUS-BASED FRAGILITY FUNCTION

This DIF is used for reporting seismic fragility functions for building-component damage states, created using the HAZUS-MH methodology (e.g., Porter 2009). 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 FRAG01 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 31 specifies the layout of the FRAG01 HAZUS-MH indoor-casualty-rate vulnerability-function table. An example is shown in Figure 32.

```
[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 35. FRAG01 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 $15 \le R < 30$ km, 40 refers to $30 \le R < 60$ km, and 80 refers to $60 \le R$).

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, $0 \leq$ P12-r $\leq$ 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, $0 \leq$ P13-r $\leq$ 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, $0 \leq$ P14-r $\leq$ 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, $0 \leq$ P15-r $\leq$ 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, $0 \leq$ 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 ≤ P14-r ≤ 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
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Figure 36. Sample FRAG01 fragility functions

6 SITE AND PORTFOLIO DAMAGE AND LOSS

TBD.

7 CONCLUSIONS

A number of draft data interchange formats (DIFs) and standard taxonomies of structure types, earthquake rupture forecasts, etc., are proposed here for use in GEM1, including DIFs for hazard output (to be used as input to risk analyses), exposure (i.e., values exposed to seismic risk), vulnerability, and fragility. DIFs are listed in Table 4, standards in Table 5.

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 data standards in this draft draw primarily on OpenSHA, OpenRisk, PAGER, and to a limited extent HAZUS-MH, EMS-98, and the World Housing Encyclopedia. The DIFs presented in this draft are entirely human-readable, plain-text flat files (commas-and-quotes); no attempt has been made yet to define XML formats. The emphasis in these DIFs is on simplicity and universality over storage efficiency.

It is not intended that these DIFs be complete or exhaustive. Other DIFs and XML formats may be considered with the next draft. Readers are encouraged to contact the authors (e.g., kporter@sparisk.com) to recommend additions, modifications, and clarification.

Table 4. Summary list of risk-related DIFs

DIF	Description	Site (S) or Portfolio (P)?	Deterministic (D) or probabilistic (P)?
HAZ01A	Event set: probabilistic ground motion by earthquake rupture forecast, ground-motion prediction equation, IMT, source, rupture, site	S or P	D or P
HAZ01B	Source & rupture rate and magnitude for HAZ01A	Either	Either
HAZ01C	Rupture distance for HAZ01A	Either	Either
HAZ01D	Logic tree weights for HAZ01A	Either	Either
HAZ02	Gridded hazard	Mostly S	Mostly P
HAZ03	Site intensity for MCS	Either	P
HAZ04	Uniform seismic hazard	Mostly S	D
EXP01	Portfolio of point assets	Either	D
EXP02	Portfolio of point assets with uncertainty	Either	P
VULN01A	MDF vs. IML	Either	D
VULN01B	COV of damage factor vs. IML for VULN01A	Either	P
VULN02	Damage probability matrix	Either	P
VULN03	Damage exceedance matrix	Either	P
VULN04	HAZUS-based casualty rates	Either	D
VULN05	HAZUS-based MDF	Either	D
FRAG01	HAZUS-based fragility functions	Either	Either
	Site & portfolio damage & loss: TBD		

Table 5. Summary of proposed taxonomies

Standard	Description
GMPE01	Ground-motion prediction equations
IMT01	Excitation types a.k.a. intensity measure types
ERF01	Earthquake rupture forecasts
SST01	PAGER structure type taxonomy = FEMA + EMS98 + WHE + extras
SST02	ATC-13 facility class taxonomy
SST03	HAZUS-MH structure type taxonomy
LM01	Loss measures

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