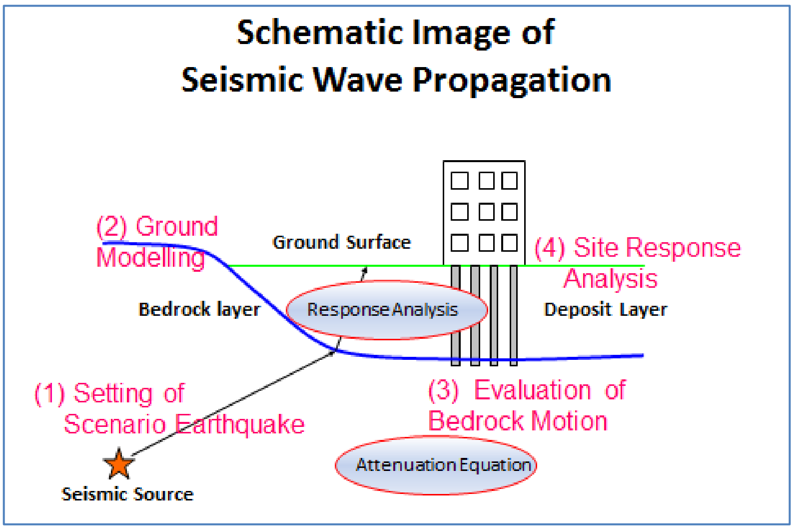
Technical Notes for

Earthquake Ground Motion Estimation

1. Introduction

Seismic hazard assessment was implemented basically along the propagation of seismic ground motion, (1) setting scenario earthquake, (2) modelling the ground, (3) estimation of ground motion at bedrock, and (4) evaluation of the response of the subsurface ground and estimation of seismic ground motion at ground surface.



The shallow and deep ground model compilation for response analysis and bedrock motion calculation by empirical attenuation formula along with the calculation of the distance from fault model were implemented using the original program made for this project. The programs are coded by FORTRAN. The source code is attached to this note with the example of input and output files.

In this note, the flowchart to use the programs and the format of input and output files are written.

2. Note for Ground Modeling

The ground was modelled through three steps; modelling between the rock surface to the Kalimati layer (Klm), modelling between Klm to the ground surface and the integration of them.

Deep Ground Model

DeepModel0315.f is used for modelling between the rock surface to the Kalimati layer (Klm). **Deep_depth_0229.csv** is the input file and **Deep_model_0315.csv** is the output file.

One line of **Deep_depth_0229.csv** corresponds to one 250m grid. Each line includes the depth of top of Weathered Rock, Tarebhir, Lkl, and Klm from ground surface. **DeepModel0315.f** change the format of the ground model which can be used by SHAKE. The S-wave velocity, density and the No. of non-linearity function of each soil layer are added.

Shallow Ground Model

SurfaceModel0315.f is used for modeling between Klm to the ground surface. **Grid250_Geom2.csv** is the input file and **Surface_model_0315.csv** is the output file.

One line of **Grid250_Geom2.csv** corresponds to one 250m grid. Each line includes the altitude and code of Geomorphic Class. **SurfaceModel0315.f** generates the 10m depth interval S-wave structure for each grid except the rock outcrop grid. The S-wave velocity, density and the No. of non-linearity function of each soil layer are added referring to the relation of S-wave velocity and elevation.

Integration

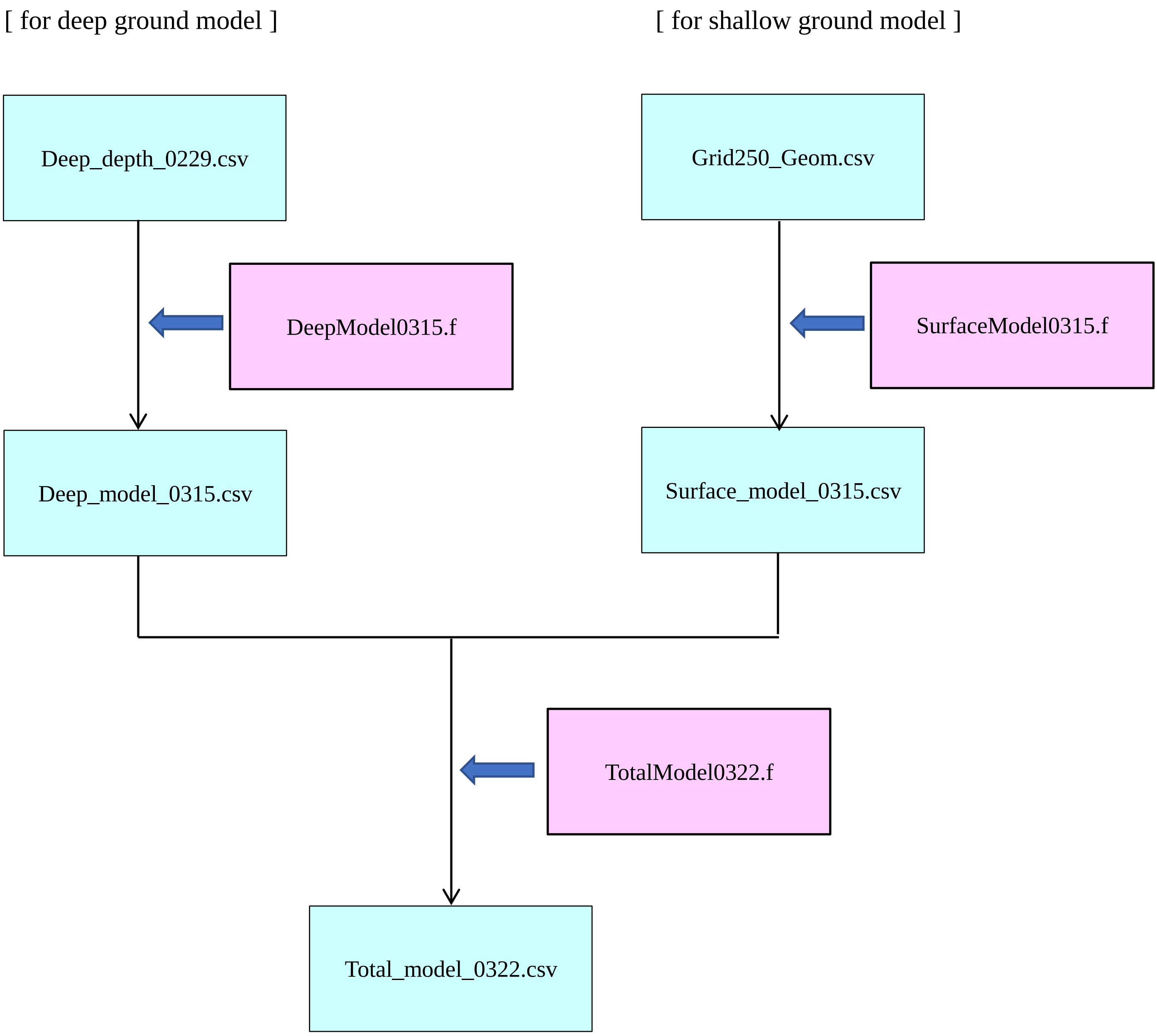
TotalModel0322.f is used for integrating "Deep Ground Model" and "Shallow Ground Model". Input files are **Deep_model_0315.csv** and **Surface_model_0315.csv**. Output file is **Total_Model_0322.csv**.

The total ground model can be created putting the subsurface ground model on it. The issue in connecting the two models is the difficulty to decide the top of Klm in the subsurface ground model. **TotalModel0322.f** detects the depth where the S-wave velocity of the subsurface layer becomes the same as Klm and integrates deep and shallow ground models to total one.

Flowchart for Ground Modeling

: data

: program



File format

a) Deep_depth_0229.csv

GRCODE	Geom2Cod	Tarebhir	Lkl	Klm	Surface	WR_altitude	Tarebhir_al	Lkl_altitude	Klm_altitud	Altitude	WR_depth	Tare_depth	Lkl_depth	Klm_depth
194254	Bs	0	0	0	WR	1589.5	-999	-999	-999	1589.5	0	-999	-999	-999
195254	Bs	1	1	0	Lkl	1516.558	1523.836	1542.5	-999	1542.5	25.9	18.7	0	-999
196254	fa	1	1	0		1461.989	1481.152	1481.938	-999	1501.7	39.7	20.5	19.8	-999
197254	fa	1	1	0		1435.625	1478.839	1482.266	-999	1494.3	58.7	15.5	12	-999
198254	fa	1	1	1		1407.475	1464.575	1471.026	1472.489	1490.3	82.8	25.7	19.3	17.8
199254	fa	1	1	1		1380.009	1442.697	1450.542	1452.2	1477	97	34.3	26.5	24.8

GRCODE: Grid Code

Geom2Code: Geomorphic Class

Tarebhir: if Tarebhir layer exist 1, other 0

Lkl: if Lkl layer exist 1, other 0

Klm: if Klm layer exist 1, other 0

Surface: surface layer if shallow layer don't exist (WR, Tarebhir, Lkl, Klm), blank if shallow layer exist

WR_altitude: altitude (m) of top of Weathered Rock

Tarebhir_altitude: altitude (m) of top of Tarebhir layer

Lkl_altitude: altitude (m) of top of Lkl layer

Klm_altitude: altitude (m) of top of Klm layer

Altitude: altitude (m) of grid

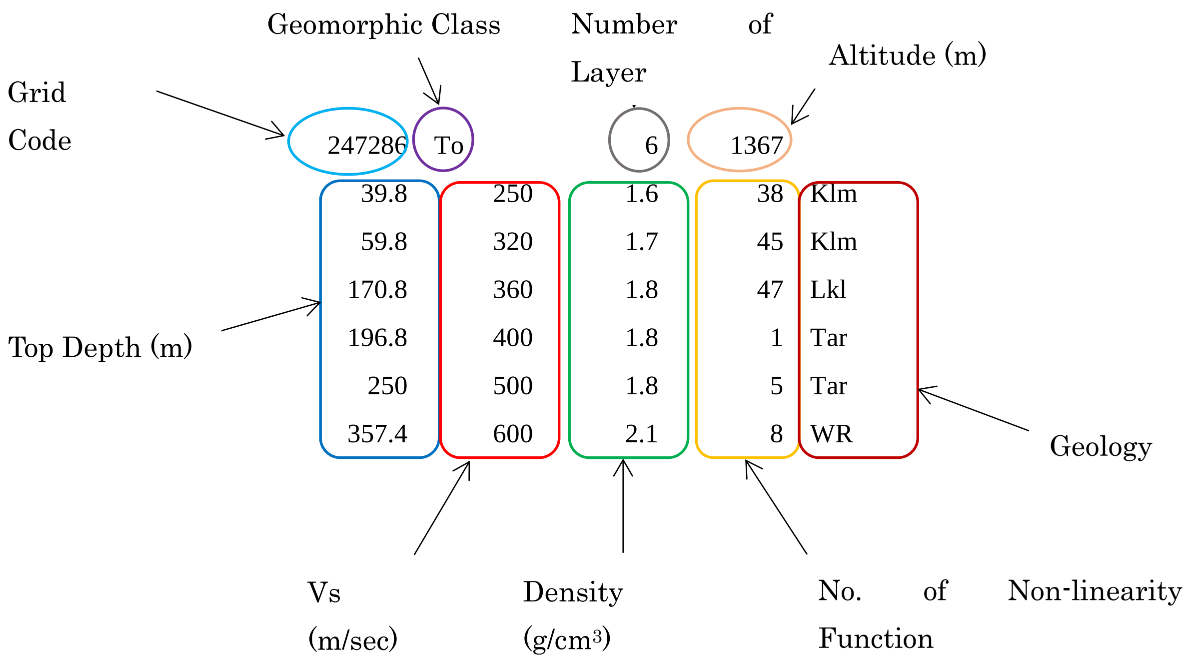
WR_depth: depth (m) of top of Weathered Rock from ground surface

Tarebhir_depth: depth (m) of top of Tarebhir layer from ground surface

Lkl_depth: depth (m) of top of Lkl layer from ground surface

Klm_depth: depth (m) of top of Klm layer from ground surface

b) Deep_model_0315.csv



c) Grid250_Geom2.csv

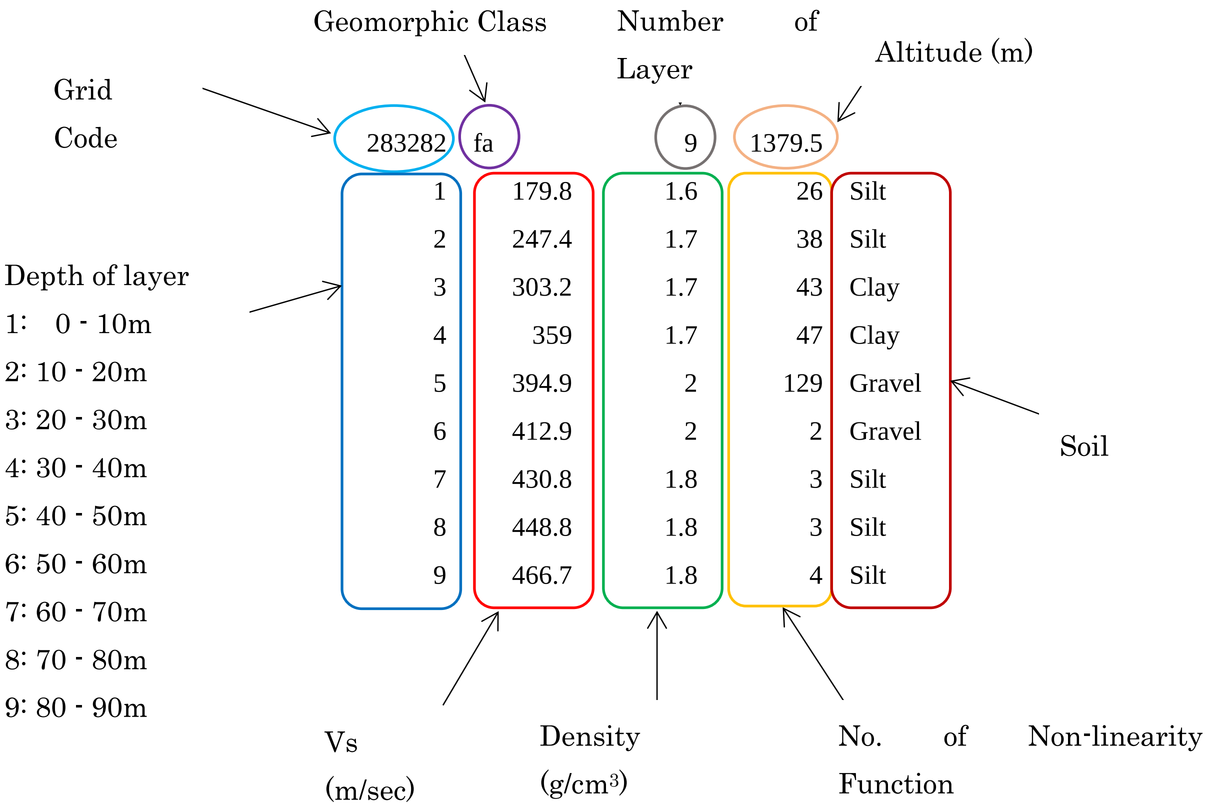
GRCODE	Altitude	Geom2Code
247259	1301.7	al
248259	1294.8	al
249259	1298	nl
250259	1307.5	Pa
251259	1322.5	Th
252259	1333.9	Th
253259	1334.5	Th

GRCODE: Grid Code

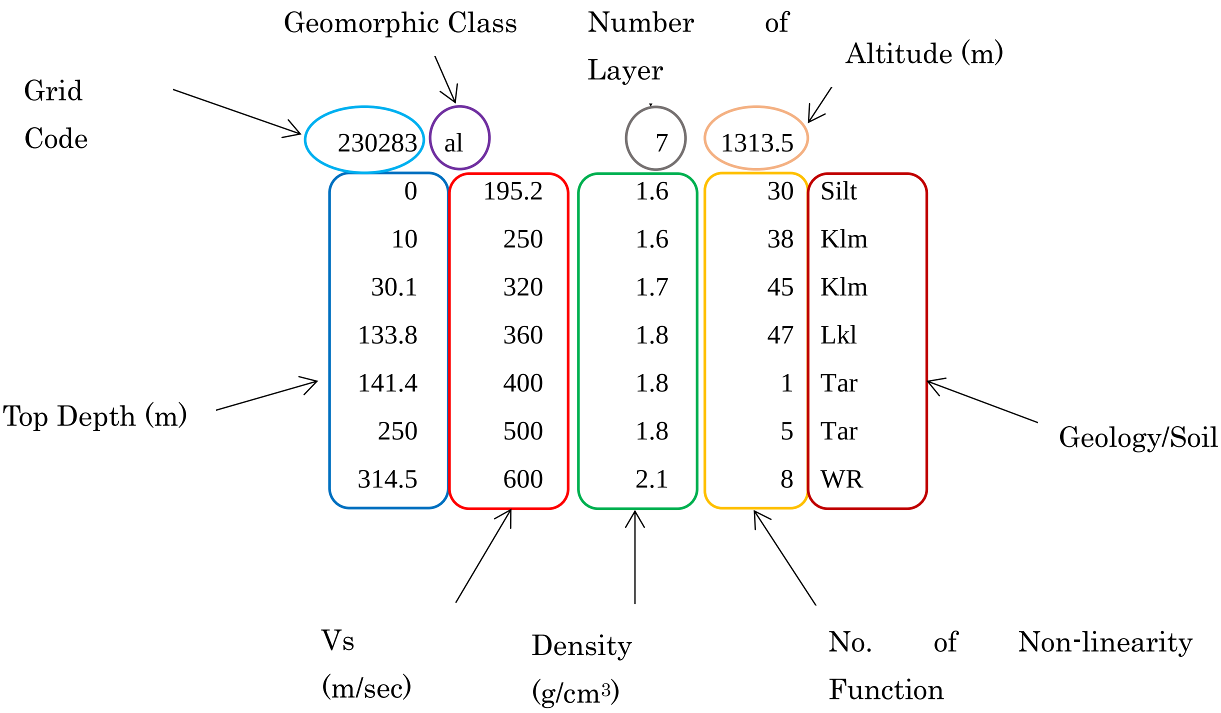
Altitude: altitude (m) of grid

Geom2Code: Geomorphic Class

d) Surface_model_0315.csv



e) Total_model_0322.csv



3. Note for Fault Distance Calculation

The earthquake motion at the baserock was evaluated using the Ground Motion Prediction Equation (GMPE). Distance from the earthquake source to study site is the most important parameter to use GMPE. This study adopted the GMPEs which are developed in NGA project. They use the shortest distance to the fault or Joyner & Boore (JB) distance as the input parameter. **Dista.f** calculates the shortest distance and JB distance.

Dista.f needs two input files. **Grid_250.csv** contains the longitude and latitude of each grid center. Other input file is the parameter of the fault; **xxx_faultdis.dat** is the file to calculate the shortest distance from the fault to grid center and **xxx_JBdis.dat** is the file to calculate JB distance. Output files are **xxx_faultdis.csv**, or **xxx_JBdis.csv**.

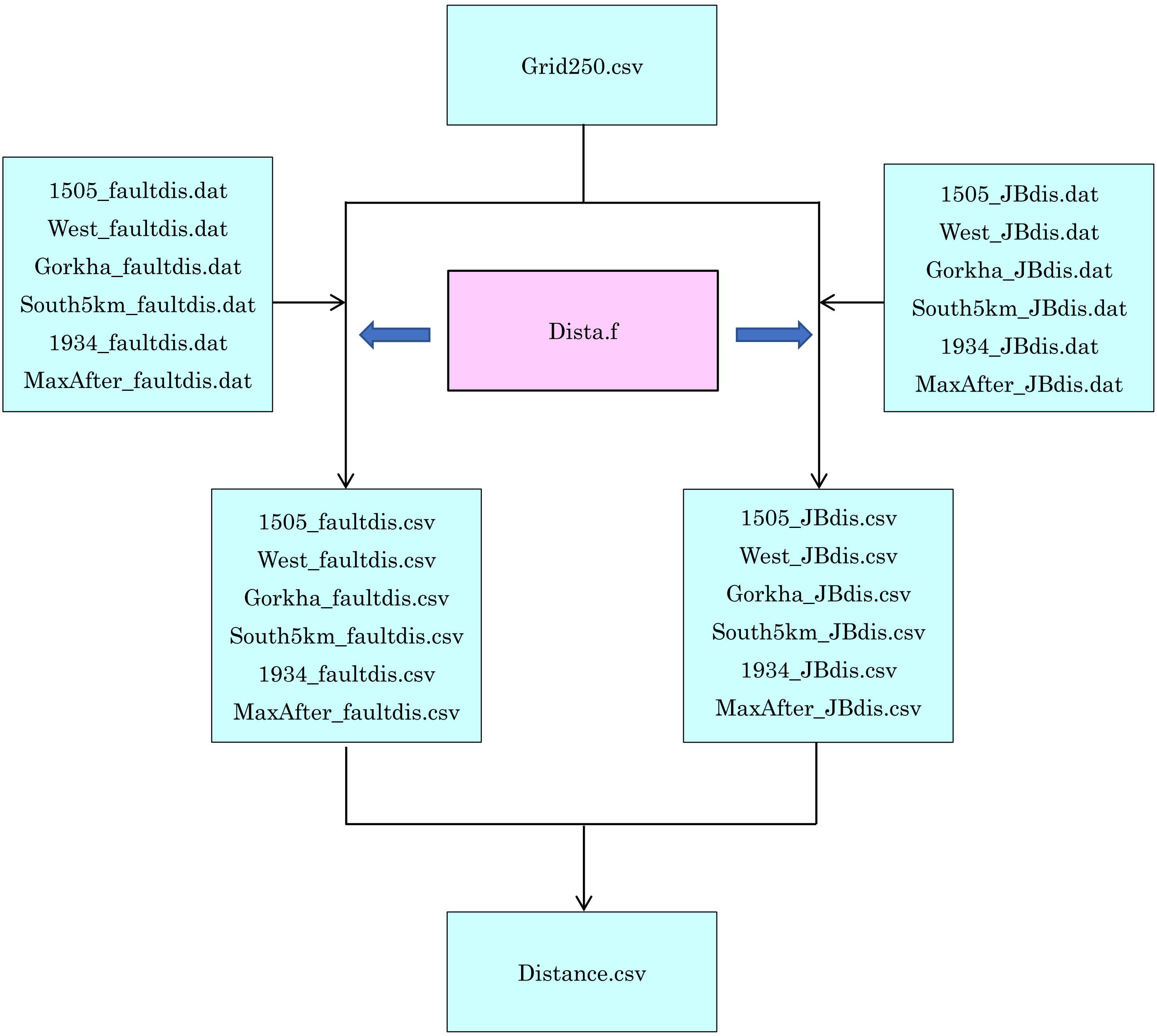
The output files should be integrated to one file named **Distance.csv** by Excel.

Flowchart for Fault Distance Calculation

: data

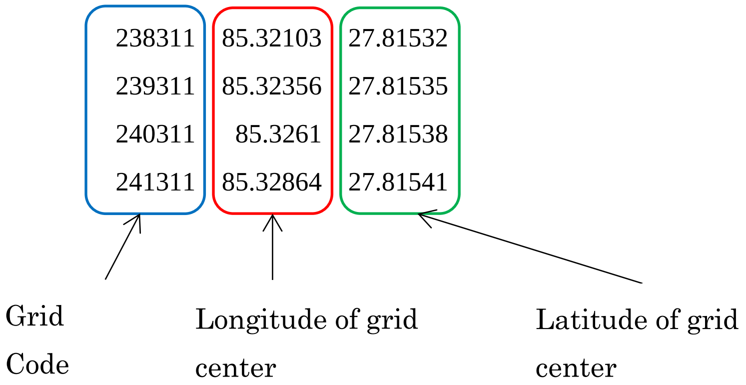
: program

[shortest distance to the fault] [JB distance]



File format

a) Grid_250.csv



b) xxx_faultdis.dat

- Input data to calculate the shortest distance to the fault from grid center

84.4535, 27.9681 : Latitude, Longitude of fault origin

160.8, 60.0, 10.0 : Length, Width, Depth (km)

337.7, 4.0 : Strike (degree, from east, anticlockwise), Dip (degree)

110.819, 98.412 : unit length in km of 1 degree of Latitude and Longitude

c) xxx_JBdis.dat

- Input data to calculate the Joyner & Boore distance to the fault from grid center

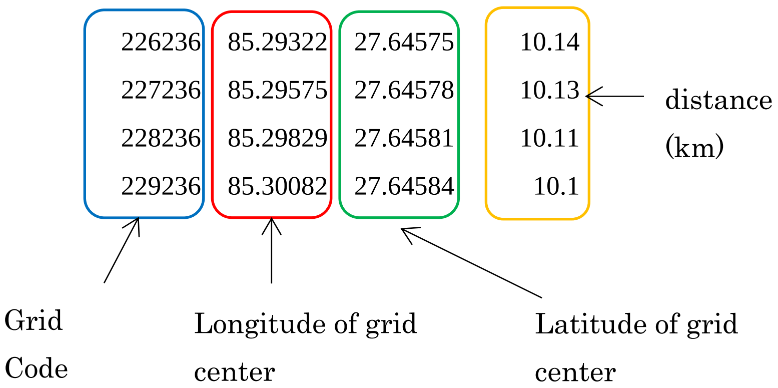
84.4535, 27.9681 : Latitude, Longitude of fault origin

160.8, 60.0, 0.0 : Length, Width (km)

337.7, 0.00001 : Strike (degree, from east, anticlockwise)

110.819, 98.412 : unit length in km of 1 degree of Latitude and Longitude

d) xxx_faultdis.csv, xxx_JBdis.csv



d) Distance.csv

Grid	X	Y	1505_fault	1505_JB	West_fault	West_JB	Gorkha_fau	Gorkha_JB	South5km_	South5km_	1934_fault	1934_JB	MA_fault	MA_JB
238311	85.32103	27.81532	204.58	203.8	85.54	84.68	11.14	0	18.56	16.55	76.35	75.73	57.06	55.06

Grid: Grid Code

X: Latitude of grid center

Y: Longitude of grid center

xxx_fault: shortest distance to the fault from grid center (km)

xxx_JB: Joyner & Boore distance to the fault from grid center (km)

4. Note for Bedrock Motion Calculation

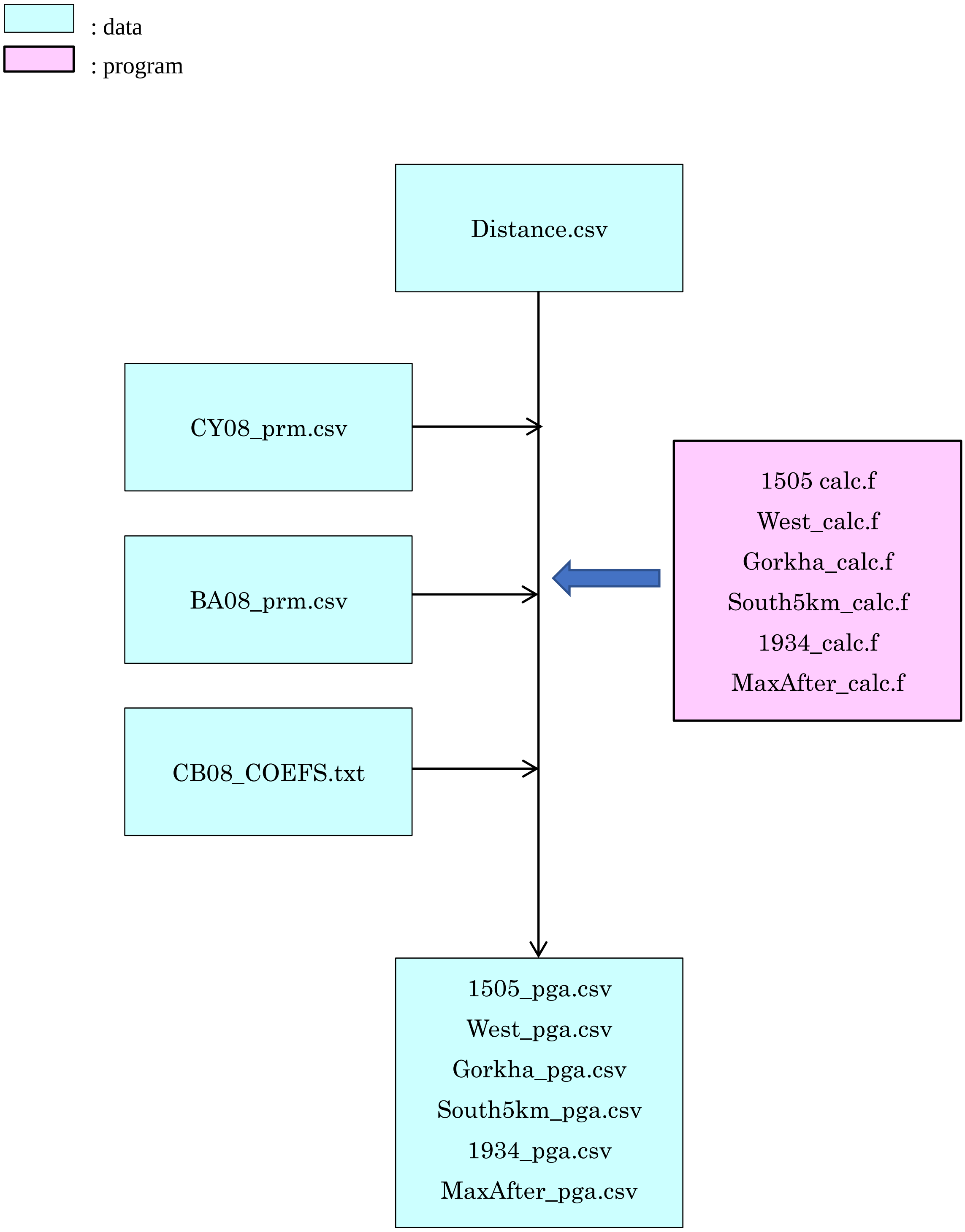
The adopted GMPEs in this project are;

(AS08) Abrahamson N. and W. Silva (2008)
(BA08) Boore D. M. and G. M. Atkinson (2008)
(CB08) Campbell K. W. and Y. Bozorgnia (2008)
(CY08) Chiou B. S.-J. and R. R. Youngs (2008).

The programs of **xxx_calc.f** calculate the PGA at each grid center for scenario earthquakes or earthquakes for confirmation by AS08, BA08, CB08 and CY08, and average of four GMPEs. Input file is **Distance.csv**. Output files are **xxx_pga.csv**.

CY08_prm.csv, **BA08_prm.csv** and **CB08_COEFS.txt** are the coefficients of GMPEs.

Flowchart for Bedrock Motion Calculation



File format

a) Distance.csv

Grid	X	Y	1505_fault	1505_JB	West_fault	West_JB	Gorkha_fau	Gorkha_JB	South5km_	South5km_	1934_fault	1934_JB	MA_fault	MA_JB
238311	85.32103	27.81532	204.58	203.8	85.54	84.68	11.14	0	18.56	16.55	76.35	75.73	57.06	55.06

Grid: Grid Code

X: Latitude of grid center

Y: Longitude of grid center

xxx_fault: shortest distance to the fault from grid center (km)

xxx_JB: Joyner & Boore distance to the fault from grid center (km)

b) CY08_prm.csv

- Coefficients for Chiou and Youngs (2008)

c) BA08_prm.csv

- Coefficients for Boore and Atkinson (2008)

d) CB08_COEFS.txt

- Coefficients for Campbell and Bozorgnia (2008)

e) xxx_pga.csv

GridID	AS08	BA08	CB08	CY08	Average
238311	644.7	556	425.6	626.9	563.3
239311	644.4	556	425.4	626.6	563.1
240311	644.1	556	425.2	626.3	562.9
241311	644.1	556	425.2	626.3	562.9

Grid: Grid Code

AS08: calculated PGA(gal) by Abrahamson and Silva (2008)

BA08: calculated PGA(gal) by Boore and Atkinson (2008)

CB08: calculated PGA(gal) by Campbell and Bozorgnia (2008)

CY08: calculated PGA(gal) by Chiou and Youngs (2008)

Average: average of above 4 attenuation formula

1) Abrahamson N. and W. Silva (2008)

$$\ln Sa(g) = f_1(M, R_{rup}) + a_{12}F_{RV} + a_{13}F_{NM} + a_{15}F_{AS} + f_5(P\hat{G}A_{1100}, V_{S30})$$
$$+ F_{HW}\, f_4(R_{jb}, R_{rup}, R_x, W, \delta, Z_{T_1OR}, M) + f_6(Z_{TOR}) + f_8(R_{rup}, M) + f_{10}(Z_{1.0}, V_{S30})$$

$$f_1(M, R_{rup}) = \begin{cases} a_1 + a_4(M - c_1) + a_8(8.5 - M)^2 + [a_2 + a_3(M - c_1)]\ln(R) & \text{for } M \le c_1 \\ a_1 + a_5(M - c_1) + a_8(8.5 - M)^2 + [a_2 + a_3(M - c_1)]\ln(R) & \text{for } M > c_1 \end{cases}$$

$$R = \sqrt{R_{rup}^2 + c_4^2}$$

$$f_5(P\hat{G}A_{1100}, V_{S30}^*) = \begin{cases} a_{10}\ln\left(\dfrac{V_{S30}^*}{V_{LIN}}\right) - b\ln(P\hat{G}A_{1100} + c) + b\ln\left(P\hat{G}A_{1100} + c\left(\dfrac{V_{S30}^*}{V_{LIN}}\right)^n\right) & \text{for } V_{S30} < V_{LIN} \\ (a_{10} + bn)\ln\left(\dfrac{V_{S30}^*}{V_{LIN}}\right) & \text{for } V_{S30} \ge V_{LIN} \end{cases}$$

$$V_{S30}^* = \begin{cases} V_{S30} & \text{for } V_{S30} < V_1 \\ V_1 & \text{for } V_{S30} \ge V_1 \end{cases}$$

$$V_1 = \begin{cases} 1500 \text{ m/s} & \text{for } T \le 0.50 \text{ sec} \\ \exp[8.0 - 0.795\ln(T/0.21)] & \text{for } 0.50 \text{ sec} < T \le 1 \text{ sec} \\ \exp[6.76 - 0.297\ln(T)] & \text{for } 1 \text{ sec} < T < 2 \text{ sec} \\ 700 \text{ m/s} & \text{for } T \ge 2 \text{ sec} \\ 862 \text{ m/s} & \text{for PGV} \end{cases}$$

$$f_4(R_{jb}, R_{rup}, R_x, W, \delta, Z_{T_1OR}, M) = a_{14}T_1(R_{jb})T_2(R_x, W, \delta)T_3(R_x, Z_{TOR})T_4(M)T_5(\delta)$$

$$T_1(R_{jb}) = \begin{cases} 1 - \dfrac{R_{jb}}{30} & \text{for } R_{jb} < 30 \text{ km} \\ 0 & \text{for } R_{jb} \ge 30 \text{ km} \end{cases}$$

$$T_2(R_x, W, \delta) = \begin{cases} 0.5 + \dfrac{R_x}{2W\cos(\delta)} & \text{for } R_x \le W\cos(\delta) \\ 1 & \text{for } R_x > W\cos(\delta), \text{or } \delta = 90° \end{cases}$$

$$T_3(R_x, Z_{TOR}) = \begin{cases} 1 & \text{for } R_x \ge Z_{TOR} \\ \dfrac{R_x}{Z_{TOR}} & \text{for } R_x < Z_{TOR} \end{cases}$$

$$T_4(M) = \begin{cases} 0 & \text{for } M \le 6 \\ M - 6 & \text{for } 6 < M < 7 \\ 1 & \text{for } M \ge 7 \end{cases}$$

$$T_5(\delta) = \begin{cases} 1 - \dfrac{\delta - 70}{20} & \text{for } \delta \ge 70 \\ 1 & \text{for } \delta < 70 \end{cases}$$

$$f_6(Z_{TOR}) = \begin{cases} \dfrac{a_{16} Z_{TOR}}{10} & \text{for } Z_{TOR} < 10 \text{ km} \\ a_{16} & \text{for } Z_{TOR} \geq 10 \text{ km} \end{cases}$$

$$f_8(R_{rup}, M) = \begin{cases} 0 & \text{for } R_{rup} < 100 \text{ km} \\ a_{18}(R_{rup} - 100) T_6(M) & \text{for } R_{rup} \geq 100 \text{ km} \end{cases}$$

$$T_6(M) = \begin{cases} 1 & \text{for } M < 5.5 \\ 0.5(6.5 - M) + 0.5 & \text{for } 5.5 \leq M \leq 6.5 \\ 0.5 & \text{for } M > 6.5 \end{cases}$$

$$f_{10}(Z_{1.0}, V_{S30}) = a_{21} \ln\left(\frac{Z_{1.0} + c_2}{\hat{Z}_{1.0}(V_{S30}) + c_2} \right) + \begin{cases} a_{22} \ln\left(\dfrac{Z_{1.0}}{200} \right) & \text{for } Z_{1.0} \geq 200 \\ 0 & \text{for } Z_{1.0} < 200 \end{cases}$$

where $\hat{Z}_{1.0}(V_{S30})$ is the median $Z_{1.0}$ (in m) given by

$$\ln\left(\hat{Z}_{1.0}(V_{S30})\right) = \begin{cases} 6.745 & \text{for } V_{S30} < 180 \text{ m/s} \\ 6.745 - 1.35 \ln\left(\dfrac{V_{S30}}{180} \right) & \text{for } 180 \leq V_{S30} \leq 500 \text{ m/s} \\ 5.394 - 4.48 \ln\left(\dfrac{V_{S30}}{500} \right) & \text{for } V_{S30} > 500 \text{ m/s} \end{cases}$$

$$a_{21} = \begin{cases} 0 & \text{for } V_{S30} \geq 1000 \\ \dfrac{-(a_{10} + bn) \ln\left(\dfrac{V_{S30}^*}{\min(V_1, 1000)} \right)}{\ln\left(\dfrac{Z_{1.0} + c_2}{\hat{Z}_{1.0} + c_2} \right)} & \text{for } (a_{10} + bn) \ln\left(\dfrac{V_{S30}^*}{\min(V_1, 1000)} \right) + e_2 \ln\left(\dfrac{Z_{1.0} + c_2}{\hat{Z}_{1.0} + c_2} \right) < 0 \\ e_2 & \text{otherwise} \end{cases}$$

$$e_2 = \begin{cases} 0 & \text{for } T < 0.35 \text{ sec or } V_{S30} > 1000 \\ -0.25 \ln\left(\dfrac{V_{S30}}{1000} \right) \ln\left(\dfrac{T}{0.35} \right) & \text{for } 0.35 \leq T \leq 2 \text{ sec} \\ -0.25 \ln\left(\dfrac{V_{S30}}{1000} \right) \ln\left(\dfrac{2}{0.35} \right) & \text{for } T > 2 \text{ sec} \end{cases}$$

$$a_{22} = \begin{cases} 0 & \text{for } T < 2 \text{ sec} \\ 0.0625(T - 2) & \text{for } T \geq 2 \text{ sec} \end{cases}$$

M : Moment magnitude

R_{RUP} : Rupture distance (km)

R_{JB} : Joyner-Boore distance (km)

R_X : Horizontalite distance (km) from top edge of rupture

Z_{TOR} : Depth to top of rupture (km)

F_{RV} : Flag for rverse faulting earthquake : 1 for $30° \le \lambda \le 150°$, 0 otherwise

F_{NM} : Flag for normal faulting earthquake : 1 for $-120° \le \lambda \le -60°$, 0 otherwise

λ : rake angle

F_{AS} : Flag for aftershocks

F_{HW} : Flag for hanging wall sites

δ : Fault dip in degrees

V_{S30} : Shear - wave velocity over the top 30 m (m/sec)

$Z_{1.0}$: Depth to Vs = 1.0 km/s at the site (m)

$P\hat{G}A_{1100}$: Median peak acceleration (g) for $V_{S30} = 1100$ m/s

W : Down-dip rupture width (km)

2) Boore D. M. and G. M. Atkinson (2008)

$$\ln Y = F_M(M) + F_D(R_{JB}, M) + F_S(V_{30}, R_{JB}, M) + \varepsilon_{TU}\sigma_{TU} + \varepsilon_{TM}\sigma_{TM}$$

mechanism unspecified : $\sigma_{TU} = 1, \sigma_{TM} = 0$

mechanism specified : $\sigma_{TU} = 0, \sigma_{TM} = 1$

For $M \le M_h$

$$F_M(M) = e_1 U + e_2 SS + e_3 NS + e_4 RS + e_5(M - M_h) + e_6(M - M_h)^2$$

For $M > M_h$

$$F_M(M) = e_1 U + e_2 SS + e_3 NS + e_4 RS + e_7(M - M_h)$$

mechanism unspecified : $U = 1, SS = NS = RS = 0$

strike slip : $SS = 1, U = NS = RS = 0$

normal : $NS = 1, U = SS = RS = 0$

reverse : $RS = 1, U = NS = SS = 0$

$$F_D(R_{JB}, M) = \left[c_1 + c_2\left(M - M_{ref}\right)\right]\ln\left(R/R_{ref}\right) + c_3\left(R - R_{ref}\right)$$

$$R = \sqrt{R_{JB}{}^2 + h^2}$$

$$F_S = F_{LIN} + F_{NL}$$

$$F_{LIN} = b_{lin} \cdot \ln(V_{S30}/V_{ref})$$

For $pga4nl \le a_1$

$$F_{NL} = b_{nl} \cdot \ln(pga\_low/0.1)$$

For $a_1 < pga4nl \le a_2$

$$F_{NL} = b_{nl} \cdot \ln(pga\_low/0.1) + c\left[\ln(pga4nl/a_1)\right]^2 + d\left[\ln(pga4nl/a_1)^3\right]$$

For $a_2 < pga4nl$

$$F_{NL} = b_{nl} \cdot \ln(pga4nl/0.1)$$

$$c = (3\Delta y - b_{nl}\Delta x)/\Delta x^2$$

$$d = -(2\Delta y - b_{nl}\Delta x)/\Delta x^3$$

$$\Delta x = \ln(a_2/a_1)$$

$$\Delta y = b_{nl} \cdot \ln(a_2/pga\_low)$$

For $V_{S30} \le V_1$

$b_{nl} = b_1$

For $V_1 < V_{S30} \le V_2$

$b_{nl} = (b_1 - b_2) \cdot \ln(V_{S30} / V_2) / \ln(V_1 / V_2) + b_2$

For $V_2 < V_{S30} < V_{ref}$

$b_{nl} = b_2 \cdot \ln(V_{S30} / V_{ref}) / \ln(V_2 / V_{ref})$

For $V_{ref} \le V_{S30}$

$\mathrm{b_{nl}} = 0.0$

Y : PGA(g) , $\mathrm{Sa}_{\mathrm{h=5\%}}$(g) or PGV(cm/sec)

M : moment magnitude

R_{JB} : closest horizontal distance to the vertical projection of the rupture(km)

V_{S30} : average shear - wave velocity to a depth of 30m (m/sec)

b_1, b_2, b_{lin} : period - dependent coefficient

b_{nl} : function of period as well as V_{S30}

V_{ref} : specified reference velocity (= 760m/sec)

pga_low := 0.06g

$pga4nl$: predicted PGA in g for $V_{ref} = 760$m/sec

V_1 : 180m/sec

V_2 : 300m/sec

3) Campbell K. W. and Y. Bozorgnia (2008)

$$\ln Y = f_{mag} + f_{dis} + f_{flt} + f_{hng} + f_{site} + f_{sed} + \varepsilon$$

$$f_{mag} = \begin{cases} c_0 + c_1 M & M \le 5.5 \\ c_0 + c_1 M + c_2 (M - 5.5) & 5.5 < M \le 6.5 \\ c_0 + c_1 M + c_2 (M - 5.5) + c_3 (M - 6.5) & 6.5 < M \end{cases}$$

$$f_{dis} = (c_4 + c_5 M) \ln \sqrt{{R_{rup}}^2 + {c_6}^2}$$

$$f_{flt} = c_7 F_{RV} f_{flt,Z} + c_8 F_{NM}$$

$$f_{flt,Z} = \begin{cases} Z_{TOR} & ; Z_{TOR} < 1 \\ 1 & ; Z_{TOR} \ge 1 \end{cases}$$

reverse and reverse - oblique fault ($30° < \lambda < 150°$) : $F_{RV} = 1, F_{NM} = 0$

normal and normal - oblique fault ($-150° < \lambda < -30°$) : $F_{RV} = 0, F_{NM} = 1$

otherwise : $F_{RV} = 0, F_{NM} = 0$

$$f_{hng} = c_9 f_{hng,R} f_{hng,M} f_{hng,z} f_{hng,\delta}$$

$$f_{hng,R} = \begin{cases} 1 & ; R_{JB} = 0 \\ \left[\max(R_{RUP}, \sqrt{R_{JB}^2 + 1}) - R_{JB} \right] / \max(R_{RUP}, \sqrt{R_{JB}^2 + 1}) & ; R_{JB} > 0, Z_{TOR} < 1 \\ (R_{RUP} - R_{JB}) / R_{RUP} & ; R_{JB} > 0, Z_{TOR} \ge 1 \end{cases}$$

$$f_{hng,M} = \begin{cases} 0 & ; M \le 6.0 \\ 2(M - 6.0) & ; 6.0 < M < 6.5 \\ 1 & : M \ge 6.5 \end{cases}$$

$$f_{hng,Z} = \begin{cases} 0 & ; Z_{TOR} \ge 20 \\ (20 - Z_{TOR}) / 20 & ; 0 \le Z_{TOR} < 20 \end{cases}$$

$$f_{hng,\delta} = \begin{cases} 1 & ; \delta \le 70 \\ (90 - \delta) / 20 & ; \delta > 70 \end{cases}$$

$$f_{site} = \begin{cases} c_{10} \ln\left(\frac{V_{S30}}{k_1}\right) + k_2 \left\{ \ln\left[A_{1100} + c\left(\frac{V_{S30}}{k_1}\right)^n \right] - \ln\left[A_{1100} + c\right] \right\} & ; V_{S30} < k_1 \\ (C_{10} + k_2 n) \ln\left(\frac{V_{S30}}{k_1}\right) & ; k_1 \le V_{S30} < 1100 \\ (c_{10} + k_2 n) \ln\left(\frac{1100}{k_1}\right) & ; V_{S30} \ge 1100 \end{cases}$$

$$f_{sed} = \begin{cases} c_{11}(Z_{2.5} - 1) & ; Z_{2.5} < 1 \\ 0 & ; 1 \le Z_{2.5} \le 3 \\ c_{12} k_3 e^{-0.75} \left[1 - e^{-0.25(Z_{2.5} - 3)} \right] & ; Z_{2.5} > 3 \end{cases}$$

Y : PGA(g), $Sa_{h=5\%}$(g) or PGV(cm/sec)

M : moment magnitude

R_{RUP} : closest distance to coseismic rupture(km)

R_{JB} : closest distance to the surface projection of the coseismic rupture plane (km)

λ : rake angle

δ : dip of the rupture plane

V_{S30} : average shear - wave velosity to a depth of 30m (m/sec)

A_{1100} : value of PGA on rock with $V_{30} = 1100$m/sec

$Z_{2.5}$: depth to the 2.5km/sec shear - wave velocity horizon (km)

Z_{TOR} : depth to the top of the coseismic rupture plane (km)

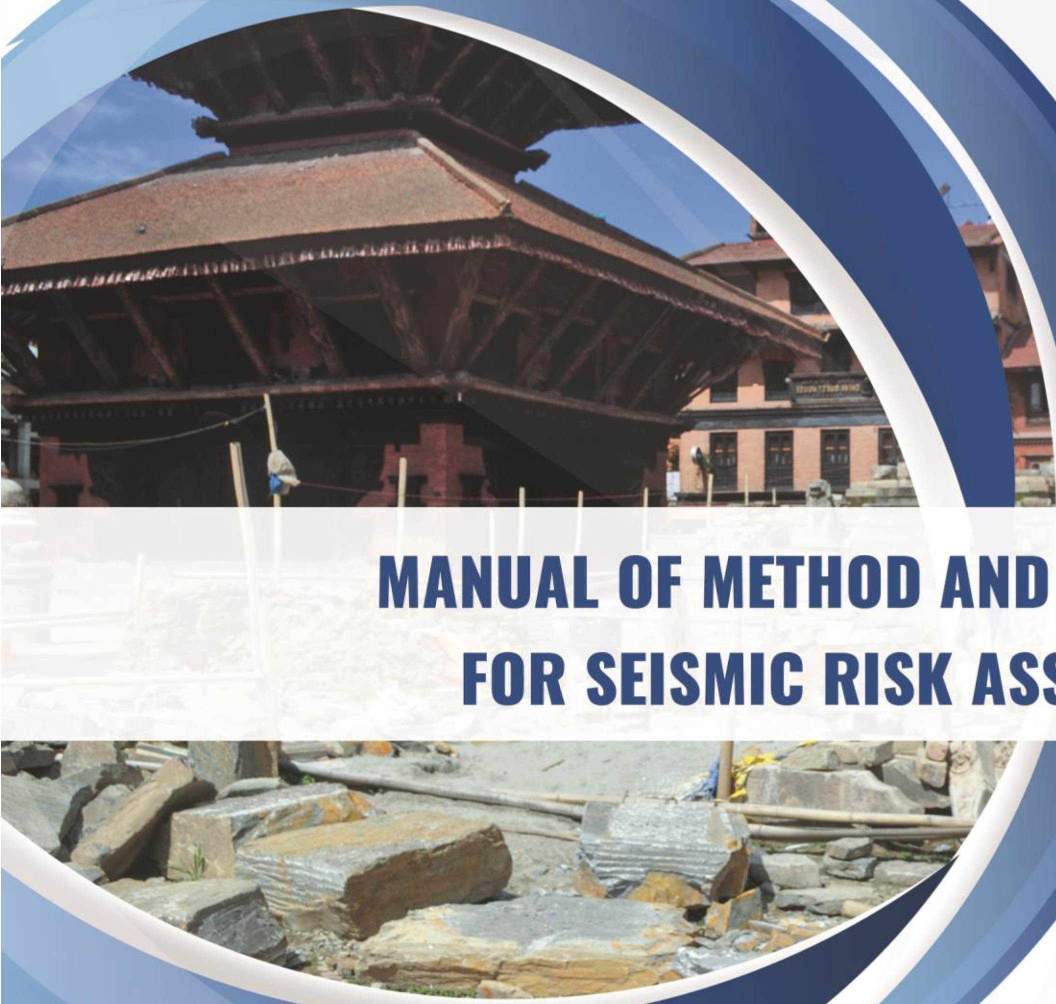
4) C Chiou B. S.-J. and R. R. Youngs (2008)

$$
\begin{aligned}
\ln(y_{ref_{ij}}) &= c_1 + c_{1a}F_{RV_i} + c_{1b}F_{NM_i} + c_7\left(Z_{TOR} - 4\right)\left(1 - AS_i\right) + \left[c_{10} + c_{7a}(Z_{TOR_i} - 4)\right]AS_i \\
&+ c_2\left(M_i - 6\right) + \frac{c_2 - c_3}{c_n}\ln\left(1 + e^{c_n(c_M - M_i)}\right) \\
&+ c_4 \ln\left[R_{RUP\,ij} + c_5 \cosh\left\{c_6 \max\left(M_i - c_{HM}, 0\right)\right\}\right] \\
&+ \left(c_{4a} - c_4\right)\ln\left(\sqrt{R_{RUP_{ij}}{}^2 + c_{RB}{}^2}\right) \\
&+ \left\{c_{r1} + \frac{c_{r2}}{\cosh\left[\max\left(M - c_{r3}, 0\right)\right]}\right\}R_{RUP\,ij} \\
&+ c_9 F_{HW_{ij}} \tanh\left(\frac{R_{X_{ij}} \cos^2 \delta_i}{c_{9a}}\right)\left\{1 - \frac{\sqrt{R_{JB_{ij}}^2 + Z_{TOR_i}^2}}{R_{RUP_{ij}} + 0.001}\right\}
\end{aligned}
$$

$$
\begin{aligned}
\ln(y_{ij}) &= \ln(y_{ref_{ij}}) + \Phi_1 \cdot \min\left(\ln\left(\frac{V_{30_j}}{1130}\right), 0\right) \\
&+ \Phi_2\left\{e^{\Phi_3\left(\min\left(V_{30_j}, 1130\right) - 360\right)} - e^{\Phi_3(1130 - 360)}\right\}\ln\left(\frac{y_{ref_{ij}} + \Phi_4}{\Phi_4}\right) \\
&+ \Phi_5\left(1 - \frac{1}{\cosh\left[\Phi_6 \cdot \max\left(0, Z_{1.0} - \Phi_7\right)\right]}\right) + \frac{\Phi_8}{\cosh\left[0.15 \cdot \max\left(0, Z_{1.0} - 15\right)\right]} \\
&+ \eta_i + \varepsilon_{ij}
\end{aligned}
$$

y : PGA(g), Sa $_{h=5\%}$(g) or PGV(cm/sec)
M : Moment magnitude
R_{RUP} : Closest distance to the rupture plane (km)
R_{JB} : Joyner - Boore distance to the rupture plane (km)
R_X : Site coodinate (km) measured perpendicular to the fault strike from the surface projection of the updip edge of the fault rupture, with the down dip direction being positive
F_{HW} : Hanging – wall flag : 1 for $R_X \geq 0$ and 0 for $R_X < 0$
δ : Fault dip angle
Z_{TOR} : Depth to top of rupture(km)
F_{RV} : Reverse faulting flag : 1 for $30° \leq \lambda \leq 150°$ (combined reverse and reverse - oblique), 0 otherwise
F_{NM} : Normal faulting flag : 1 for $-120° \leq \lambda \leq -60°$ (excludes normal - oblique), 0 otherwise
λ : rake angle
AS : Aftershock flag : 1 if the event is an aftershock, 0 otherwise
V_{S30} : Average shear - wave velocity for top 30 m (m/sec)
$Z_{1.0}$: Depth to shear wave velocity of 1.0 km/s (m)

The Project for Assessment of Earthquake Disaster Risk for the Kathmandu Valley in Nepal



MANUAL OF METHOD AND PROCEDURE FOR SEISMIC RISK ASSESSMENT

December 2017

Oriental Consultants Global Co., Ltd.

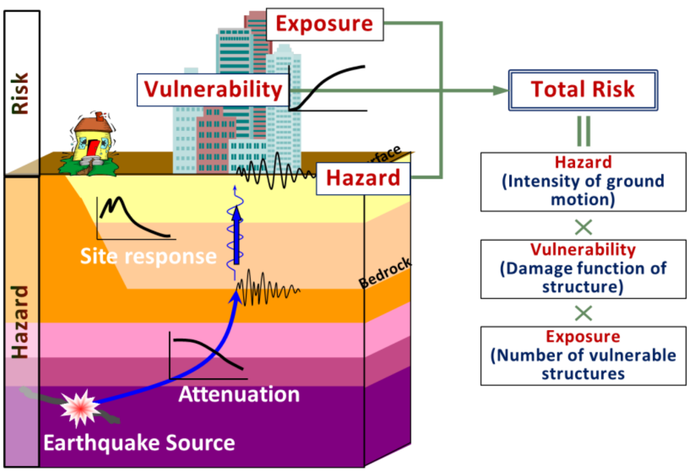
OYO International Corporation

Table of Contents

1. Introduction

Gorkha earthquake, occurred in 25 April 2015, caused a great catastrophe in Nepal including Kathmandu Valley (KV), the capital region of Nepal and alarmed for the future earthquake risk. Although Nepal is concentrated on recovery and reconstruction at the moment under the concept of Build Back Better (BBB), it should be pointed out that it is essential, in the meantime, to make the long term disaster risk reduction and management plan for the concrete and effective disaster risk reduction in the future. As promoted by the priorities for action of Sendai Framework for DRR: (1) understanding disaster risk and (2) strengthening disaster risk governance to manage disaster risk, seismic risk assessment for KV was carried out in this project for the purpose of providing basic information for the formulation of disaster risk reduction and management plan for the three pilot municipalities of Lalitpur metropolitan city (LMC), Bhaktapur municipality and Budhanilkantha municipality. The assessment covers building, including general building, school building, health facility building and government building, road, bridge, water supply network, sewage network, power distribution network, mobile Base Transceiver Station (BTS) and human casualty. The assessment is basically conducted by EXCEL file. The method of risk assessment and the procedure of calculation with EXCEL are described hereinafter for the purpose of possible update in the future by Nepal experts. For more detail information on the method and results of risk assessment, please refer to the project report when needed.

Seismic risk was assessed by a scenario oriented deterministic approach. The risk was estimated by considering seismic hazard, represented by PGA, PGV, MMI or response spectrum according to structure, vulnerability of structure, i.e. damage function, and exposure, the total number of vulnerable structures, as illustrated in Figure 1.1. The damage function for building and human casualty were created with taking into account the damage data of Gorkha earthquake, while the others were mainly referred to those used in Japan due to the lack of damage data in Nepal.



Source: JICA Project Team

Figure 1.1 Conceptual scheme of seismic risk assessment

The main features of seismic risk assessment of this project are:

- ❖ Building damage data, human casualty data and latest research results of Gorkha earthquake are utilized for the creation of damage function.
- ❖ Building inventory for LMC, Bhaktapur and Budhanilkantha municipalities was developed based on the building survey for all buildings, while the building inventory for the other municipalities was estimated based on satellite image and sample structure type survey results.
- ❖ Damage function of building was created based on the experiences of Japan by considering the building damage data and characteristics of ground motion observed from Gorkha earthquake and the seismic resistant capacity of structures which follow NBC requirements.
- ❖ Damage assessment for bridges was carried out by a statistical empirical method. The flexural strength of pier was estimated for RC bridges and response ductility factor was utilized to classify the damage degree of bridge.
- ❖ Death rate and injured rate were calculated from the death and injured data of Gorkha earthquake for different building damage levels and different structure types.
- ❖ Human casualty was estimated for different earthquake occurrence times. Population inside building when earthquake occurs was considered in the estimation.

<u>Notes:</u>

- Scenario earthquake is not the prediction of future earthquake.
- Risk assessment was carried out with assumptions and based on the available data at the moment. Its results may include uncertainties and are not the guarantee of the damage of future earthquake.

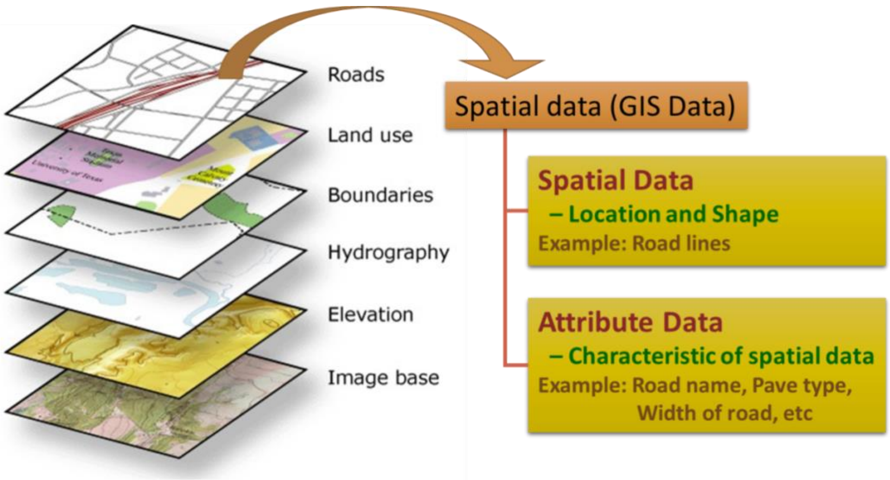
2. Preparation of Spatial Database

In this project, the Geographical Information System (GIS) is utilized as one of the fundamental tools for spatial data analysis using a great variety of basic data for natural and social conditions at the stages of seismic hazard and risk assessment. All the spatial data collected for the assessment was stored in the spatial database. The main purpose of the spatial database development is to streamline the management procedure of spatial data which are updated and modified frequently as the project goes on and to contribute to efficient technical transfer of the assessment to experts in Nepal. By organizing all spatial data necessary for the assessment in a structured manner and offering those data compiled in the database with appropriate technical manual, Nepal experts can easily understand which spatial data are utilized for each assessment process and which spatial data should be updated when they will carry out the assessment again by themselves in the future.

2.1. Spatial Database Organization

(1) What is Spatial Data

Spatial data which is often called as GIS data is composed of a combination object data to define the spatial distribution and shape of each segment and attribute data to define the characteristic of each segment as shown in Figure 2.1.



Source: JICA Project Team

Figure 2.1 Conceptual Diagram of Basic Component of Spatial Data

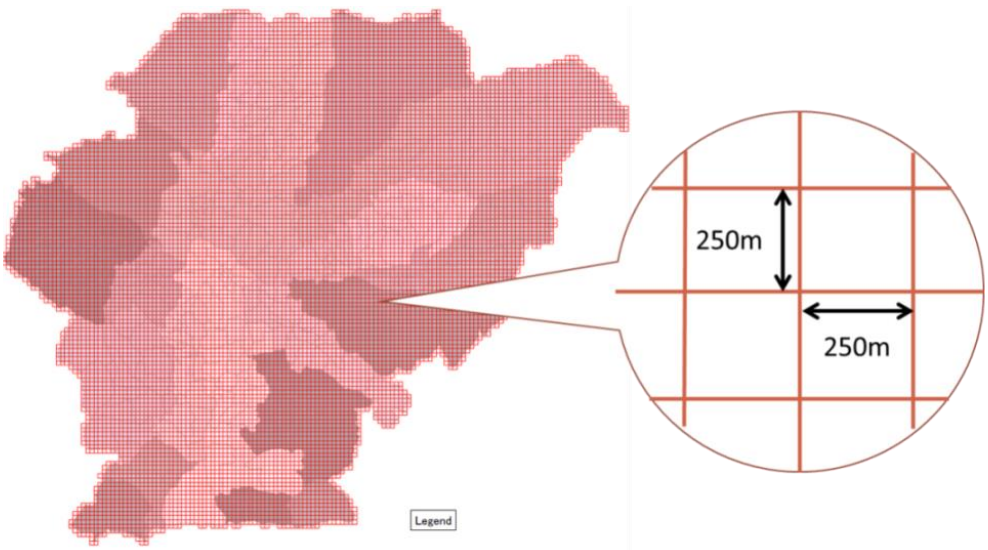
For instance, road network consists of object data which defines topology of network including coordinates of start and end points of each road segment and attribute data which defines road category, pavement type, road width and other information for each road segment. The types of spatial data are divided into vector data ad raster data and the vector data is classified into three types of object data namely point, line and polygon. Spatial data is shown hierarchically by GIS software and processed by several spatial analysis methods for any purpose of data processing.

(2) Definition of Geodetic Reference System

For showing, processing and managing all the spatial data under same operating environment, it is required to define a geodetic reference system. In general, there are two ways to define the system. One is to set a reference ellipsoid of the earth, and the other is to set a specific geodetic system such as Japan Geodetic System. In Nepal, there are a few types of local geodetic systems, and the basic systems of spatial data collected in this project are different for every spatial data by objective scale, target area and produced date. Therefore in this project, the World Geodetic System 1984 (WGS-84) was adopted for consolidation of the geodetic reference system. WGS-84 is one of famous world geodetic systems used in the world as seamless system, and it's not difficult to convert a local geodetic system in Nepal into WGS-84. In addition, Universal Transverse Mercator (UTM) Zone-45 North was adopted as a map projection system to project spherical surface of the earth to flat surface.

(3) Definition of Evaluation Grid

Seismic hazard assessment based on scenario earthquake and parts of risk assessment were carried out by grid-base analysis to segment the study area into minimum evaluation units. The minimum unit should be determined by considering the precision of seismic hazard analysis, the scale of original map and the positional accuracy of each object in spatial database. After the verification of data available for the purpose of the assessment in this project, the mesh-grid of 250m * 250m (hereinafter referred to as "evaluation grid") was set as a minimum evaluation unit of the assessment. The overview image of the evaluation grid is shown in Figure 2.2. The total number of units of the evaluation grid is 11,933, which covers the whole study area in the Kathmandu valley. The ground motion calculated from scenario earthquake such as peak ground acceleration (PGA) and peak ground velocity (PGV) have different values for each evaluation grid.



Source: JICA Project Team

Figure 2.2 Overview Image of Evaluation Grid (250m * 250m)

2.2. Category of Spatial Data Accumulated in Spatial Database

The spatial data accumulated in the spatial database is categorized as Fundamental Data, Hazard Assessment Relevant Data and Risk Assessment Relevant Data. The fundamental data includes evaluation grid, administrative boundaries, population, inventory for building, transportation infrastructure and lifeline and other social conditions. All the fundamental data was developed based on the primary data, surveyed by the project, and second hand data, collected from Nepal government and related organizations, like UNDP.

Table 2.1 Category of Fundamental Data

Category of Inventory Data	Types of Data	Sources of Data
Evaluation Grid (Mesh-grid of 250m*250m) ・Total number of girds: 11,933	Grid-wise Data (Polygon Data)	JICA ERAKV, 2017
Administrative Boundary (Study Area, District, Municipality, Ward) ・Number of Districts in study area: 3 ・Number of Municipalities in study area: 20 ・Number of Wards in study area: 232	Polygon Data	DoS, 2015 MoFALD, 2017 JICA ERAKV, 2017
Population (The results of Census 2001 and 2011)	Ward-wise Data (Polygon Data)	CBS, 2001, 2011
Estimated Population data for Daytime and Nighttime ・Estimated number in 2016: 2,786,929 persons ・Estimated number in 2030: 3,805,926 persons	Ward-wise Data (Polygon Data)	JICA ERAKV, 2017
General Building (The result of Census 2011)	Ward-wise Data (Polygon Data)	CBS, 2011
Estimated General Building Distribution ・Estimated number in 2016: 444,554 buildings ・Estimated number in 2030: 606,506 buildings (For the general building distribution in 2030, six (6) different cases of building structure component ratios were set in consideration of the different progresses of building seismic performance strengthening in 2030.)	Grid-wise Data (Polygon Data)	JICA ERAKV, 2017
School ・2,115 schools, 5,731 buildings	Individual Building Data (Point Data)	DoE, 2015 Flagship 1 of NRRC, 2014 JICA ERAKV, 2017
Health Facility ・363 facilities, 584 buildings	Individual Building Data (Point Data)	DoH, 2015 Flagship 1 of NRRC, 2014 JICA ERAKV, 2017
Governmental Building ・478 buildings	Individual Building Data (Point Data)	DUDBC, 2015 JICA ERAKV, 2017
Road Network It is including the national highways, feeder roads strategic urban roads, districts and village roads ・Total length of roads: 5,811km	Network Data (Line Data)	DoR, 2015 DoLIDAR, 2015 JICA ERAKV, 2017 UNDP/CDRMP, 2013
Bridge ・145 bridges	Individual Bridge Data (Point Data)	DoR, 2015 JICA ERAKV, 2017
Water Supply Network (Existing) ・Total length of pipelines: 1,167km	Network Data (Line Data)	KUKL,2005

Category of Inventory Data	Types of Data	Sources of Data
Water Supply Network (Planned) ・Total length of pipelines: 699km	Network Data (Line Data)	KUKL,2016
Sewage Network (Existing) ・Total length of pipelines: 1,192km	Network Data (Line Data)	KUKL,2015
Estimated Power Pole Distribution ・190,851 poles	Grid-wise Data (Polygon Data)	NEA, 2016 JICA ERAKV, 2017
Base Transceiver Station (BTS) ・1,043 stations	Individual BTS Data (Point Data)	NTA, NTC, Ncell, 2015 JICA ERAKV, 2017
Land Use	Polygon Data	UNDP/CDRMP, 2013
Open Space	Polygon Data	KVDA, 2014 JICA ERAKV, 2017
Major River and streams	Line Data	2002 JICA Project, 2002 UN OCHA, 2014 JICA ERAKV, 2017

Source: JICA Project Team

The hazard assessment relevant data is classified into natural condition data used for ground modelling and scenario model setting, and estimated seismic hazard data such as seismic shaking, landslide and liquefaction potential estimated based on several scenario models.

Table 2.2 Category of Hazard Assessment Relevant Data

Category of Inventory Data	Types of Data	Sources of Data
Geomorphologic Map	Polygon Data	JICA ERAKV, 2016
Altitude Distribution	Raster Data	UNDP/KVDA, 2013
Estimated VS30Distribution from Ground Modeling	Grid-wise Data (Polygon Data)	JICA ERAKV, 2016
Predominant Period of Ground	Grid-wise Data (Polygon Data)	JICA ERAKV, 2016
Peak Ground Acceleration (PGA) at Surface (4earthquake scenarios)	Grid-wise Data (Polygon Data)	JICA ERAKV, 2016
Peak Ground Velocity (PGV) at Surface (4earthquake scenarios)	Grid-wise Data (Polygon Data)	JICA ERAKV, 2016
Seismic Intensity (MMI) (4earthquake scenarios)	Grid-wise Data (Polygon Data)	JICA ERAKV, 2016
Acceleration Response Spectrum (4earthquake scenarios)	Grid-wise Data (Polygon Data)	JICA ERAKV, 2016
Potential of Liquefaction in Rainy and Dry Seasons (4earthquake scenarios)	Grid-wise Data (Polygon Data)	JICA ERAKV, 2016
Potential of Slope Failure (4earthquake scenarios)	Grid-wise Data (Polygon Data)	JICA ERAKV, 2016
AVS30 Map (Base on Geomorphological Unit)	Polygon Data	JICA ERAKV, 2016
Liquefaction Susceptibility map (Base on Geomorphological Unit)	Polygon Data	JICA ERAKV, 2016
Earthquake Induced Slope Failure Susceptibility Map (Base on Geomorphological Unit)	Polygon Data	JICA ERAKV, 2016

Source: JICA Project Team

All of risk assessment result was stored as the risk assessment relevant data. The detailed method of risk assessment including how to utilize the damage calculation form is explained in the Chapter 3 of this technical manual.

Table 2.3 Category of Risk Assessment Relevant Data

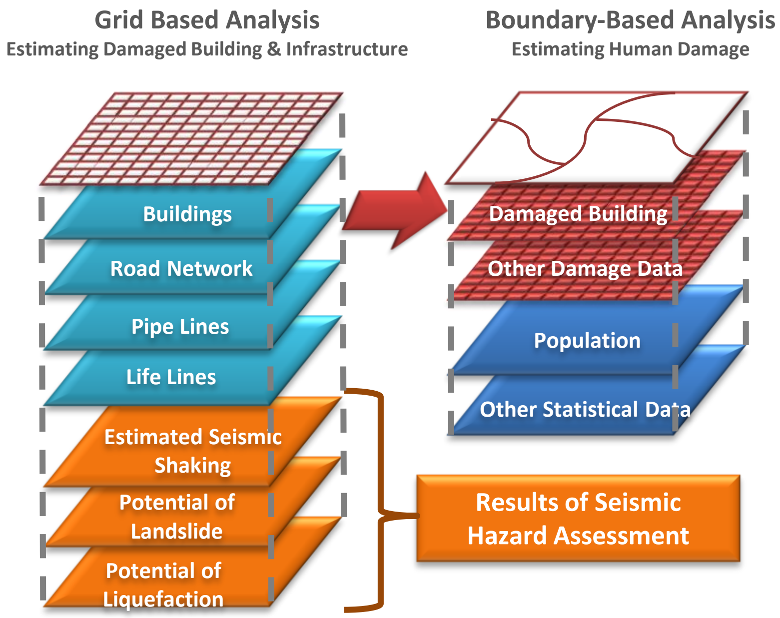
Category of Inventory Data	Types of Data	Sources of Data
Damaged General Building & Ratio in 2016 (4earthquake scenarios)	Grid-wise Data (Polygon Data)	JICA ERAKV, 2017
Damaged General Building & Ratio for 2030 (4earthquake scenarios) ・Without Building Seismic Performance Strengthening (BSPS) ・With BSPS Case 01 to 05 (five cases)	Grid-wise Data (Polygon Data)	JICA ERAKV, 2017
School Building Damage (4earthquake scenarios)	Individual Building Data (Point Data)	JICA ERAKV, 2017
Health Facility Building Damage (4earthquake scenarios)	Individual Building Data (Point Data)	JICA ERAKV, 2017
Government Building Damage (4earthquake scenarios)	Individual Building Data (Point Data)	JICA ERAKV, 2017
Possible Damage of Road by Liquefaction (4earthquake scenarios)	Grid-wise Data (Polygon Data)	JICA ERAKV, 2017
Possible Damage of Road by Slope Failure (4earthquake scenarios)	Grid-wise Data (Polygon Data)	JICA ERAKV, 2017
Possible Link Blockage of Road by Building Damage (4earthquake scenarios)	Grid-wise Data (Polygon Data)	JICA ERAKV, 2017
Damage of Bridge (45 Bridges) (4earthquake scenarios)	Individual Bridge Data (Point Data)	JICA ERAKV, 2017
Rank of Bridge for Priority of Retrofitting and Reconstruction (145 Bridges)	Individual Bridge Data (Point Data)	JICA ERAKV, 2017
Water Supply Network Damage (Exiting) (4earthquake scenarios)	Grid-wise Data (Polygon Data)	JICA ERAKV, 2017
Water Supply Network Damage (Planned) (4earthquake scenarios)	Grid-wise Data (Polygon Data)	JICA ERAKV, 2017
Sewage Network Damage (4earthquake scenarios)	Grid-wise Data (Polygon Data)	JICA ERAKV, 2017
Power Pole Damage (4earthquake scenarios)	Grid-wise Data (Polygon Data)	JICA ERAKV, 2017
BTS Tower Damage (4earthquake scenarios)	Individual Building Data (Point Data)	JICA ERAKV, 2017
Number & Ratio of Death, Injured and Evacuee in 2016 ・Night (2:00 am) :Ratio of inside building 100% ・Weekday Noon (12:00 pm): Ratio of inside building 90% ・Weekend Afternoon (18:00 pm): Ratio of inside building 70% (4earthquake scenarios)	Municipality-wise Data (Polygon Data)	JICA ERAKV, 2017

Source: JICA Project Team

2.3. General Procedure of Risk Assessment based on Spatial Database

(1) General Method of Seismic Risk Assessment using Spatial Data

Seismic risk assessment for building, infrastructure and lifeline was basically carried out based on the evaluation grid as a minimum unit of the risk assessment. This analysis method is generally called as the Grid-Based Analysis. As shown in Figure 2.3, each grid has unique value of hazard assessment result such as seismic shaking, landslide potential and liquefaction potential. And the number of damaged buildings, damage ratio of affected infrastructures or damage probability of individual building was estimated quantitatively by the common evaluation gird. On the other hand, the human casualty and economic losses were estimated by administrative area such as municipality or ward since almost all the statistical data related to social and economic situation in Kathmandu valley are organized by municipality or ward. This approach is called as the Boundary-Based Analysis.



Source: JICA Project Team

Figure 2.3 Conceptual Diagram of Seismic Risk Assessment Flow using Spatial Data

Buildings, road network, bridges, water supply pipelines, sewage pipelines, pole distribution for power supply network, BTS towers for mobile communication, human casualty and direct economic losses were considered as evaluation targets of the risk assessment in this project. Table 2.4 shows which kinds of attribute data were required as inputs for the damage estimation by dividing into external forces such as results of seismic hazard assessment and exposures to hazard such as general building distribution. Also which kinds of outputs were obtained from the assessment is putted down with. Estimated grid-wise building damage ratio was used for estimation of possible road link blockage, failure poles distribution and human casualty as one of the external forces.

Table 2.4 Attributes of input and output data for the risk assessment

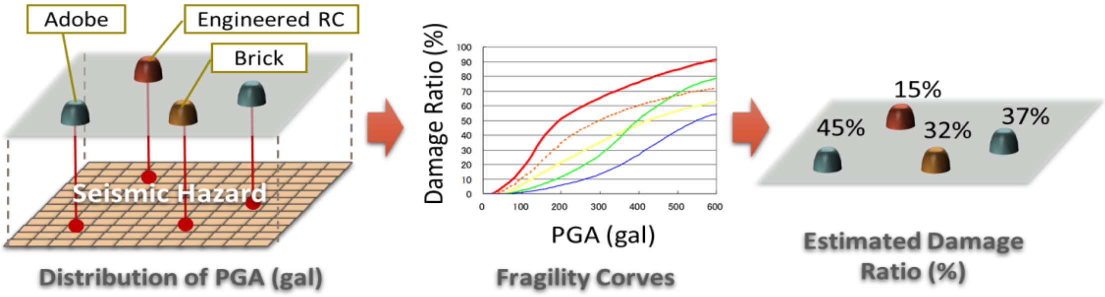
Evaluation Target	**Input1:** **Exposures to hazard** Necessary Attribute Data	**Input2:** **External forces** Necessary Attribute Data	**Output of Risk Assessment** Names and units estimated based on exposures and external forces
General Buildings	· Grid-wise building number · Grid-wise building structure component ratio	· Predominant period · PGA (gal)	· Gird-wise damaged building number · Grid-wise damaged building ratio (%)
School Buildings Health Facilities Government Buildings	· Coordinate of building · Building structure type	· Predominant period · PGA (gal)	· Damage probability of building (%)
Road Network	· Road category · Length (km) by segment · Road width (m) by segment · Pavement type by segment	· Slope failure potential · Liquefaction potential	· Total road length on high slope failure or liquefaction potential area (km)
		· Gird-wise damaged building number	· Gird-wise rate of road-link blockage (%)
Bridges	· Coordinate of bridge · Dimension data of bridge	· Acceleration response spectrum (Sa: gal)	· Damage Degree based on response ductility factor (μ_r)
Water Supply Pipeline Network	· Length (m) by segment · Type of material by segment · Diameter (mm) by segment · Ground condition by segment	· PGV (kine) · Liquefaction Potential	· Grid-wise damage rate of water supply network (No. of damage spot / km)
Sewage Pipeline Network	· Length (m) by segment · Type of material by segment · Diameter (mm) by segment	· PGA (gal) · Liquefaction Potential	· Grid-wise damage length of sewage network (Km)
Pole Distribution for Power Supply Network	· Grid-wise number of utility pole	· PGA (gal)	· Grid-wise number of failure poles
BTS Tower for Mobile Communication	· Coordinate of tower · Tower type · Building structure type	· Predominant period · PGA (gal)	· Damage Probability of BTS tower
Human Casualty	· Population for Daytime and Nighttime · Death and Injured rate · Earthquake occurrence scene (inside building ratio)	· Building number with heavy and moderate damage	· Number and ratio of Death, Injured and Evacuee
Direct Economic Losses	· Unit cost of construction for building and infrastructure · Economic statistical data	· Estimated damage of building and Infrastructure	· Direct loss due to building and infrastructure damage

Source: JICA Project Team

(2) Risk Assessment Procedure for the case of Point Feature

The type of spatial data for individual buildings, bridges and Base BTS tower for mobile communication is point feature containing the exact coordinates of objects. The risk assessment for these targets was carried out using the fragility curves depending on building structures or mechanistic analysis based on specific seismic values by grid where objective structure is located.

For instance, as shown in Figure 2.4, in the case of building damage estimation, first PGA value is identified from the grid where the target building is located, and then the building damage ratio is estimated in order to input PGA value to formula of fragility curve selected from the target building structure.



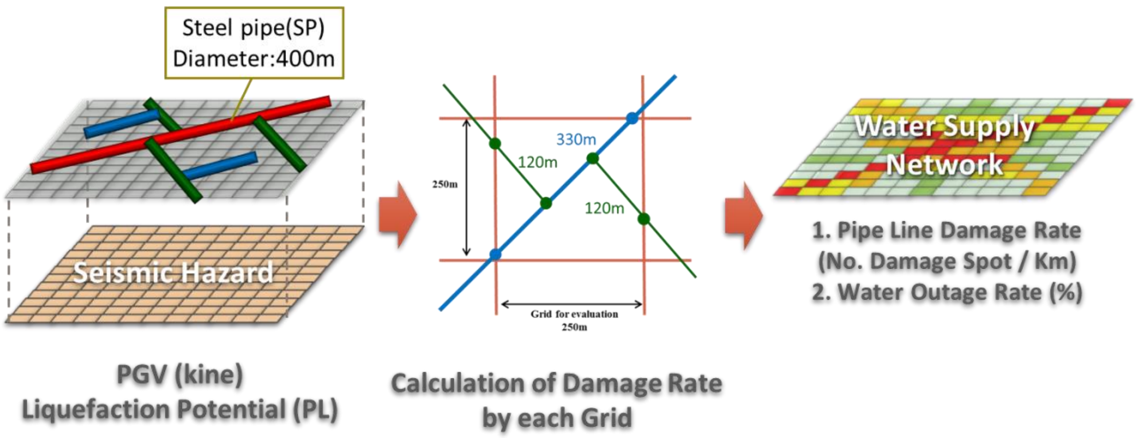
Source: JICA Project Team

Figure 2.4 Conceptual diagram of risk assessment procedure for the case of point feature

(3) Risk Assessment Procedure for the Case of Line Feature

The type of spatial data of road network, water supply and sewage network is line feature. The risk assessment for these targets is carried out by estimating the total damage length or ratio based on specific seismic values by grid where objective structure is located.

For instance, as shown in Figure 2.4, in the case of damage evaluation of water supply pipeline network, first the PGV value and the liquefaction potential are identified from the target grid, and then the damage ratio for each pipe segment is calculated in consideration of pipe material, diameter and other factors. Finally, the number of damage points of water supply pipes is estimated to multiply the length of pipe segment by the damage ratio.

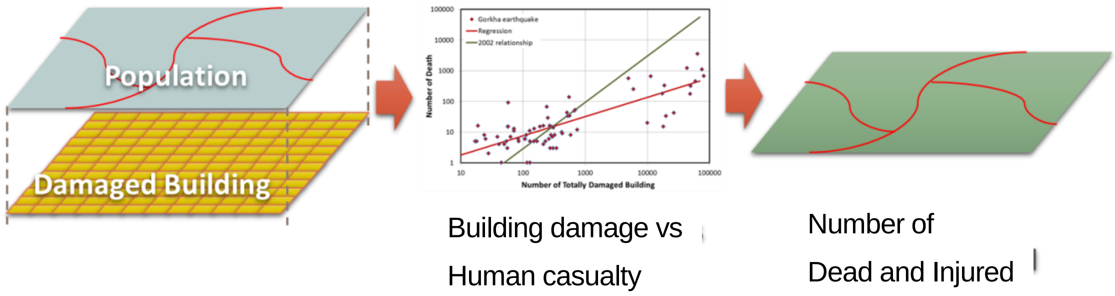


Source: JICA Project Team

Figure 2.5 Conceptual Diagram of risk assessment procedure for the case of line feature

(4) Risk assessment procedure based on boundary-base analysis

The human casualty is estimated based on boundary-base analysis. For instance, as shown in Figure 2.6, in the case of dead and injured evaluation by municipality, firstly grid-wise building damage numbers in same municipality are summed up in proportion with area ratio for each grid in the boundary of target municipality. Then, the estimated number of dead and injured is calculated by using the damage function between the building damage number and human casualty taking into consideration the indoor population ratio.



Source: JICA Project Team

Figure 2.6 Conceptual Diagram of risk assessment based on boundary-base analysis

3. Risk Assessment

3.1. Building Damage Assessment

3.1.1. General building

(1) Method

A flow diagram of building damage assessment is shown in Figure 3.1. The building damage assessment was carried out by estimating the number of damaged buildings for each grid that was set by dividing area of the Kathmandu valley into small units of 250 meters square. The number of damaged buildings was calculated using proposed damage functions by building structure type. The gird wise building distribution data in which estimated building numbers and component ratios of building structure were stored by grid and the gird wise PGA (Peak Ground Acceleration) distribution data were used as input for this calculation.

Proposed damage functions by building structure type are shown in Figure 3.2. Damage functions for general (center) area and perimeter area of the Kathmandu valley were used depending on the predominant period of the ground. This allocation was done based on the response analysis at each grid for average building period of 0.3 to 0.7sec. against predominant period of the ground. The category of the damage functions and building structural types of each category are shown in Figure 3.2. Those six damage functions show the damage ratios for general buildings by category, and the damage probability for public buildings, since the number is limited at the each grid.

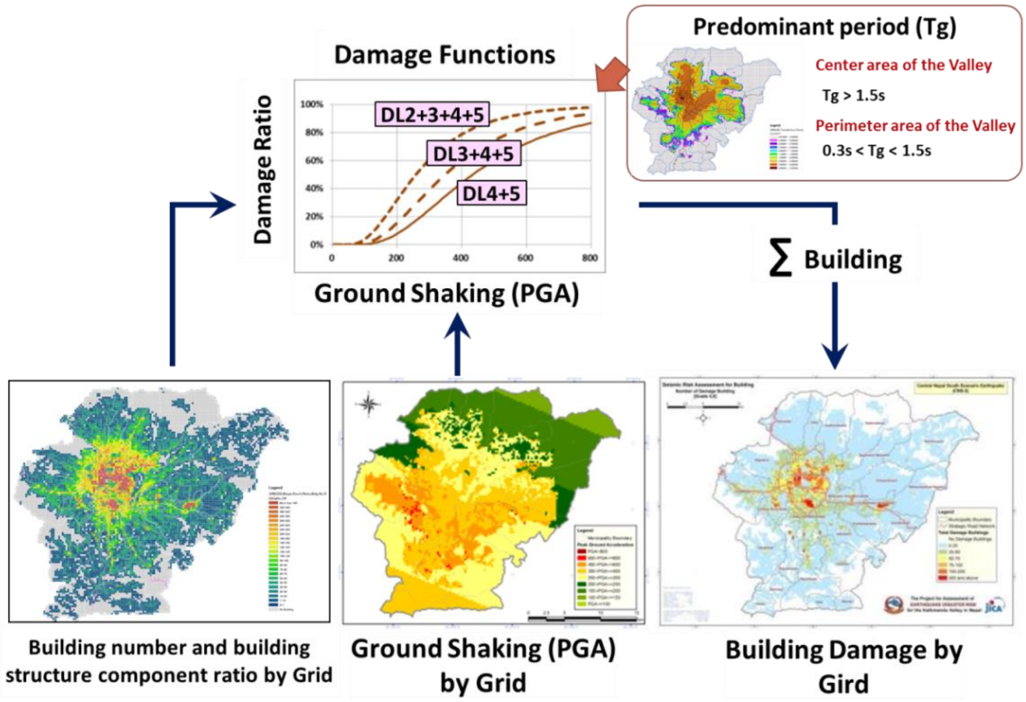


Figure 3.1 Flow diagram of building risk assessment

	Category	Structural type	
1	Masonry 1	• Adobe	
2	Masonry 2	• Brick masonry with mud mortar, flex roof & over 20 years after construction (BMM_1)	• Stone with mud mortar (SMM)
3	Masonry 3	• Brick masonry with mud mortar, flex roof & 20 years and under after construction (BMM_2) • Brick masonry with mud mortar & rigid roof (BMM_3)	
4	Masonry 4	• Brick masonry with cement mortar (BCM)	• Stone with cement mortar (SCM) • Others
5	RC 1	• Non-engineered RC (RC_N_Eng)	
6	RC 2	• Engineered RC with low to mid-rise (RC_Eng)	

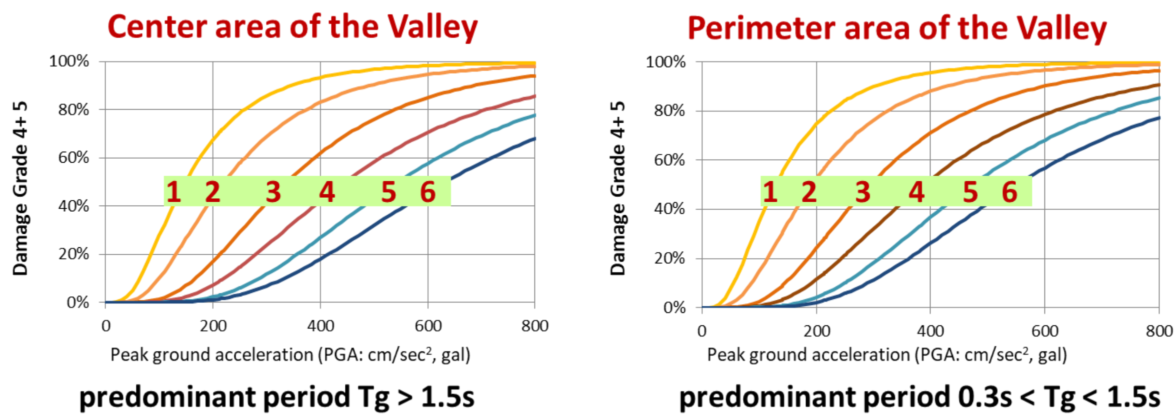


Figure 3.2 Proposed damage functions and the category of damage functions

(2) Data Processing using Calculation Form

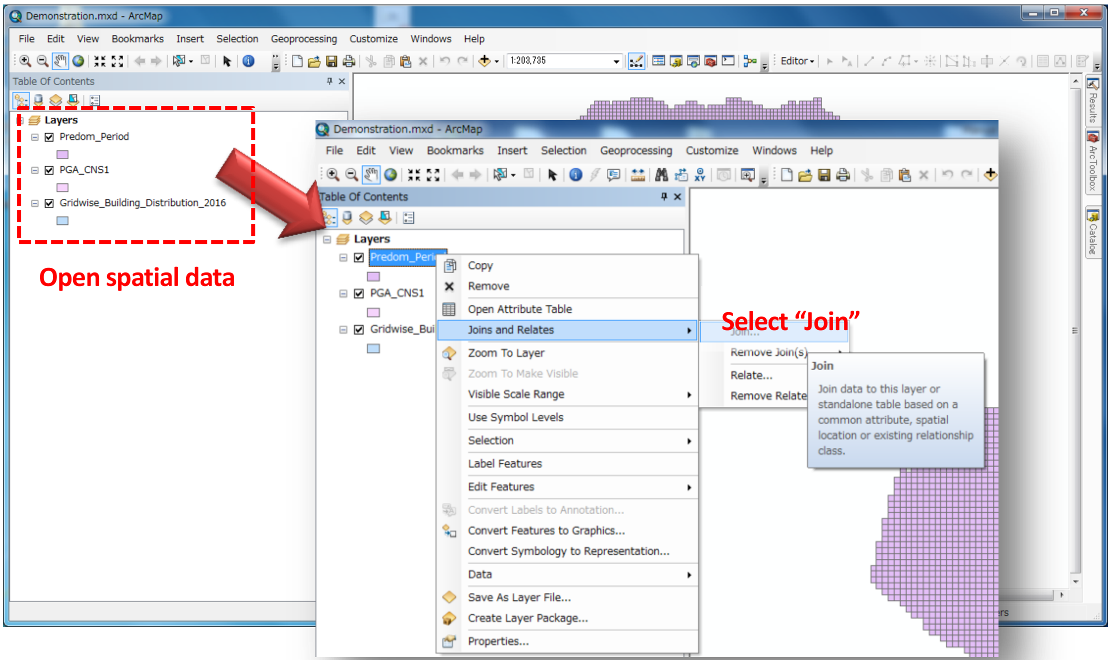
The number of damaged buildings was calculated by grid that has unique Gird-Code. For preparation of input data of the table calculation using MS Excel, following spatial data should be integrated using GIS software.

(i) Input data

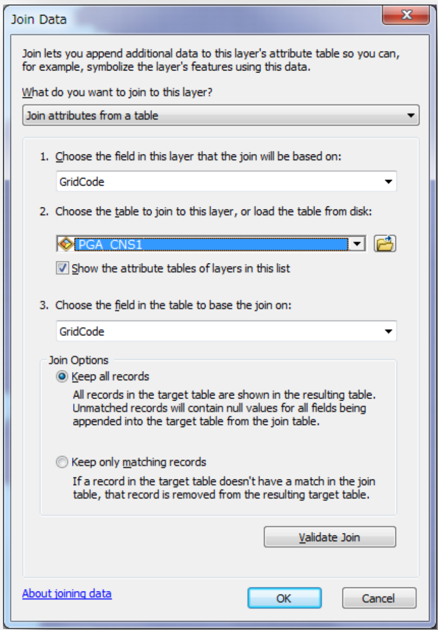
- Grid-wise Predominant Period of Ground;
- Grid-wise PGA;
- Grid-wise General Building Distribution including Estimated Building Number and Component ratio for each building structure type by gird;

STEP 1: Open spatial data related for building damage estimation from spatial database using GIS software.

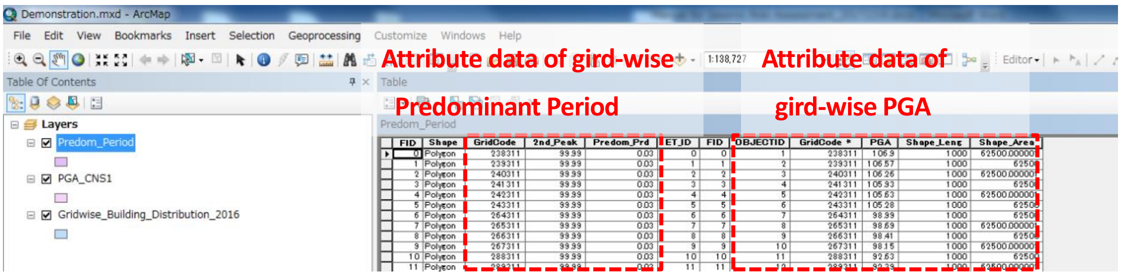
STEP 2: Start integrating of three grid-wise spatial data. First right click on a base layer (e.g. Predominant Period), and then select “Join” as following.



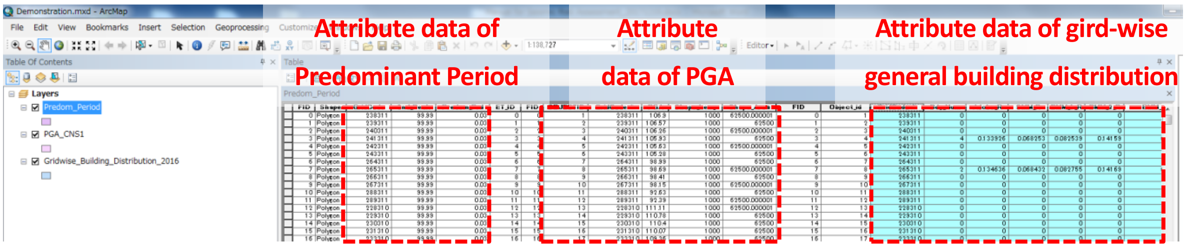
STEP 3: Join two gird-wise spatial data (e.g. Predominant Period and PGA) using the Join Tool. Choose “Grid Code” that the join is based on and select “Table name” that is joined (e.g. GPA_CNS1). After setting condition as following, click “OK” and start processing.



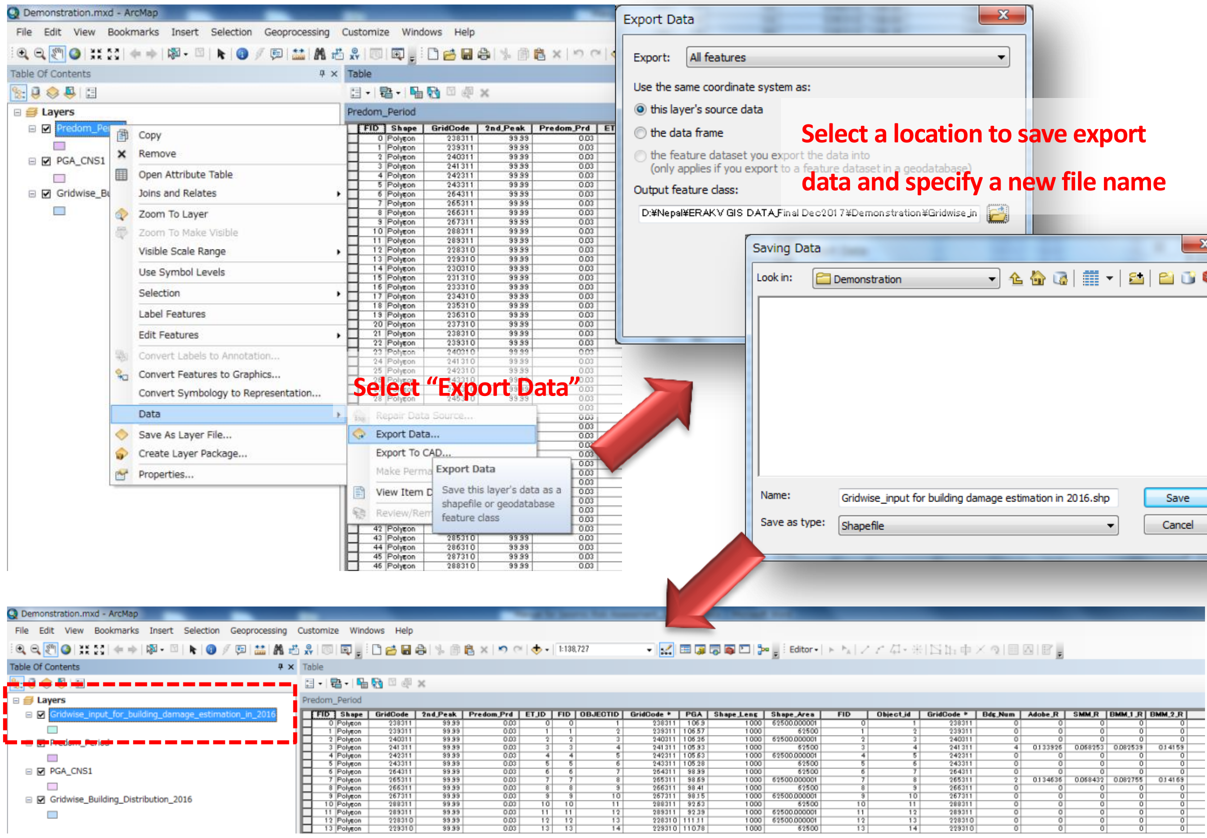
STEP 4: After this processing, all of attribute data in two gird-wise spatial data are integrated based on Grid-Code as shown in below.



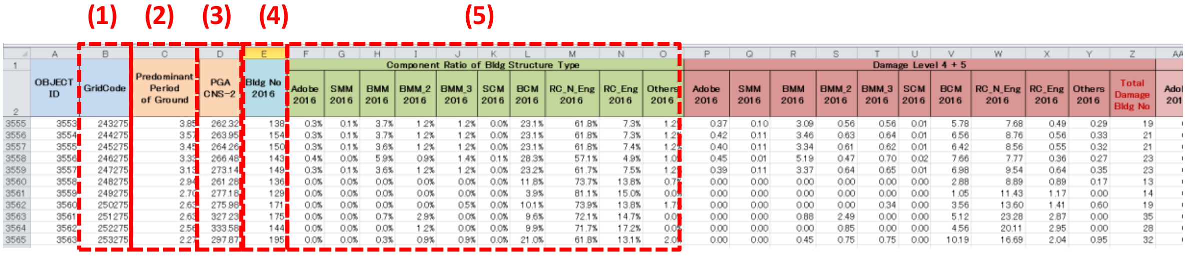
STEP 5: Furthermore, join the other gird-wise spatial data (e.g. General Building Distribution) to the base layer (e.g. Predominant Period). Open "Join Tool" again and choose name of the other spatial data as "Table name" that is be joined. After this processing, attribute data of the other spatial data (e.g. General Building Distribution) is integrated to the base layer as shown in below.



STEP 6: Export this joined layer as a new grid-wise spatial data. Right click on the base layer, and then select "Expert Data". And then, after select a location to save export data and specify a new file name (e.g. Gridwise_input_for_building_damage_estimation_in_2016), a new spatial data is processed as a new layer.



STEP 7: Open a dbf file of the new spatial data by MS Excel and copy and paste all data used for building damage estimation into appropriate columns of calculation from as following,



	OBJECT ID	GridCode	Predominant Period of Ground	PGA CNS-2	Bldg No 2016	Component Ratio of Bldg Structure Type: Adobe 2016	SMM 2016	BMM 2016	BMM_2 2016	BMM_3 2016	SCM 2016	BCM 2016	RC_N_Eng 2016	RC_Eng 2016	Others 2016	Damage Level 4 + 5: Adobe 2016	SMM 2016	BMM 2016	BMM_2 2016	BMM_3 2016	SCM 2016	BCM 2016	RC_N_Eng 2016	RC_Eng 2016	Others 2016	Total Damage Bldg No
3555	3553	243275	3.85	262.32	138	0.3%	0.1%	3.7%	1.2%	1.2%	0.0%	23.1%	61.8%	7.3%	1.2%	0.37	0.10	3.09	0.56	0.56	0.01	5.78	7.68	0.49	0.29	19
3556	3554	244275	3.57	263.95	154	0.3%	0.1%	3.7%	1.2%	1.2%	0.0%	23.1%	61.8%	7.3%	1.2%	0.42	0.11	3.46	0.63	0.64	0.01	6.56	8.76	0.56	0.33	21
3557	3555	245275	3.45	264.26	150	0.3%	0.1%	3.6%	1.2%	1.2%	0.0%	23.1%	61.8%	7.4%	1.2%	0.40	0.11	3.34	0.61	0.62	0.01	6.42	8.56	0.55	0.32	21
3558	3556	246275	3.33	266.48	143	0.4%	0.0%	5.9%	0.9%	1.4%	0.1%	28.3%	57.1%	4.9%	1.0%	0.45	0.01	5.19	0.47	0.70	0.02	7.66	7.77	0.36	0.27	23
3559	3557	247275	3.13	273.14	149	0.3%	0.1%	3.6%	1.2%	1.2%	0.0%	23.2%	61.7%	7.5%	1.2%	0.39	0.11	3.37	0.64	0.65	0.01	6.98	9.54	0.64	0.35	23
3560	3558	248275	2.94	261.28	136	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	11.8%	73.7%	13.8%	0.7%	0.00	0.00	0.00	0.00	0.00	0.00	2.88	8.89	0.89	0.17	13
3561	3559	249275	2.70	277.18	129	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.9%	81.1%	15.0%	0.0%	0.00	0.00	0.00	0.00	0.00	0.00	1.05	11.43	1.17	0.00	14
3562	3560	250275	2.63	275.98	171	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	10.1%	73.9%	13.8%	1.7%	0.00	0.00	0.00	0.00	0.34	0.00	3.56	13.60	1.41	0.60	19
3563	3561	251275	2.63	327.23	175	0.0%	0.0%	0.7%	2.9%	0.0%	0.0%	9.6%	72.1%	14.7%	0.0%	0.00	0.00	0.88	2.49	0.00	0.00	5.12	23.28	2.87	0.00	35
3564	3562	252275	2.56	333.58	144	0.0%	0.0%	0.0%	1.2%	0.0%	0.0%	9.9%	71.7%	17.2%	0.0%	0.00	0.00	0.00	0.85	0.00	0.00	4.56	20.11	2.95	0.00	28
3565	3563	253275	2.27	297.87	195	0.0%	0.0%	0.3%	0.9%	0.9%	0.0%	21.0%	61.8%	13.1%	2.0%	0.00	0.00	0.45	0.75	0.75	0.00	10.19	16.69	2.04	0.95	32

(1) Grid code

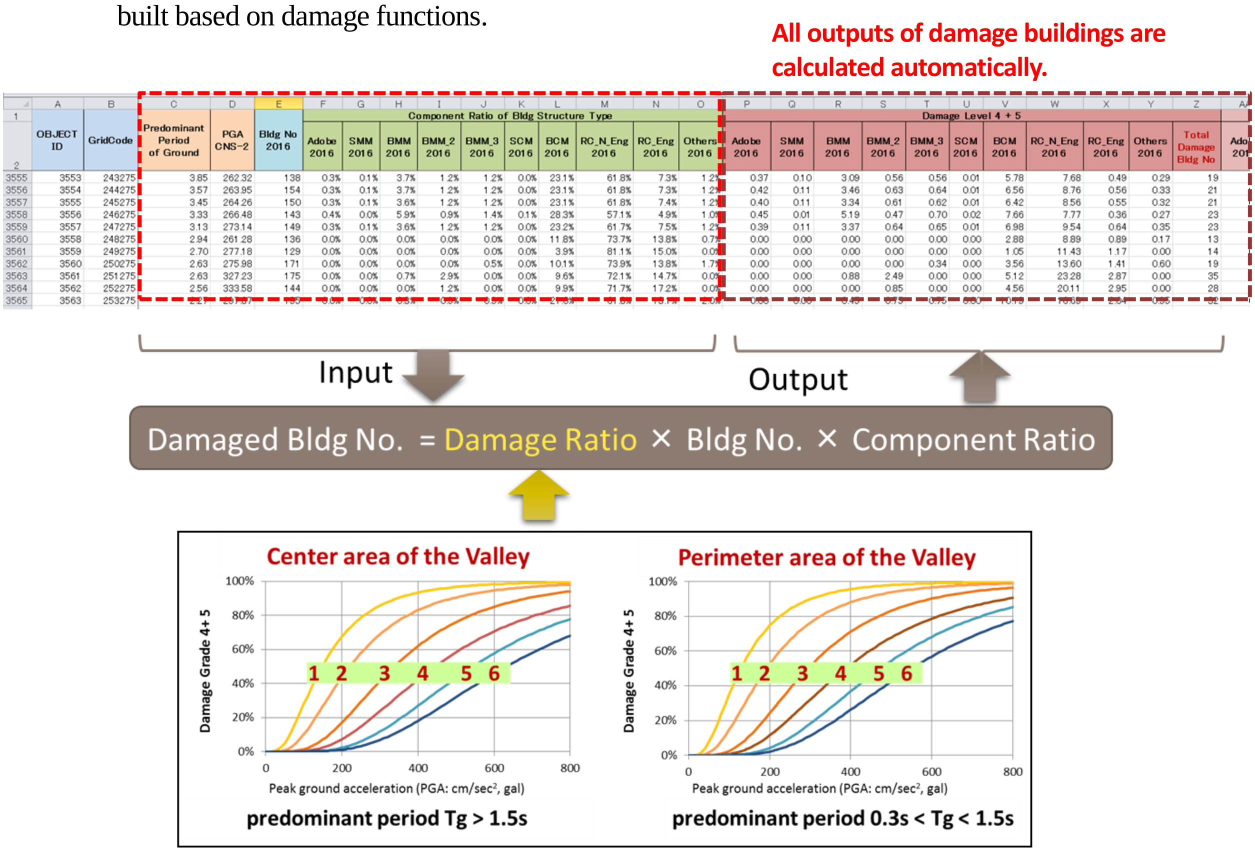
(2) Predominant Period of Ground

(3) PGA

(4) Estimated General Building Number

(5) Component ratio for each building structure type

STEP 8: Calculate number of building damage for each level (DL4+5. DL3+4+5, DL2+3+4+5) using calculation form where all formula necessary for building damage estimation were already built based on damage functions.



(ii) Output

The form has several types of calculation fields in order to calculate following outputs.

- Total number of damaged buildings [Damage Level 4+5];
- Number of damaged buildings for each building structure type [Damage Level 4+5];

Number of damaged buildings for each building structure type **Total Damaged building Number**

	A	B	P	Q	R	S	T	U	V	W	X	Y	Z
1			Damage Level 4 + 5										
2	OBJECT ID	GridCode	Adobe 2016	SMM 2016	BMM 2016	BMM_2 2016	BMM_3 2016	SCM 2016	BCM 2016	RC_N_Eng 2016	RC_Eng 2016	Others 2016	Total Damage Bldg No
3	Total		5,868	1,757	18,365	3,071	2,311	110	17,270	14,328	1,263	971	65,314
4		GridCode	Adb_D45	SMM_D45	BM1_D45	BM2_D45	BM3_D45	SCM_D45	BCM_D45	RCN_D45	RCE_D45	Ohr_D45	N_TDB_D45
8315	8311	247236	0.27	0.13	0.16	0.18	0.03	0.00	0.28	0.07	0.01	0.04	1
8316	8312	248236	0.14	0.06	0.08	0.09	0.01	0.00	0.14	0.03	0.00	0.02	1
8317	8313	249236	0.07	0.03	0.04	0.04	0.01	0.00	0.07	0.02	0.00	0.01	0
8318	8314	250236	1.05	0.47	2.28	0.69	0.37	0.03	2.73	2.01	0.23	0.18	10
8319	8315	251236	1.05	0.24	40.03	1.93	6.93	0.18	32.32	19.65	0.55	0.56	103
8320	8316	252236	0.35	0.15	1.33	0.54	0.31	0.02	3.38	5.48	0.63	0.25	12
8321	8317	253236	0.73	0.30	0.63	0.38	0.12	0.02	1.32	0.56	0.06	0.16	4
8322	8318	254236	0.25	0.09	0.81	0.26	0.15	0.01	1.34	2.06	0.20	0.11	5
8323	8319	255236	0.52	0.19	1.62	0.51	0.29	0.02	2.51	3.77	0.36	0.21	10
8324	8320	256236	0.29	0.12	1.08	0.43	0.25	0.02	2.65	4.29	0.48	0.20	10
8325	8321	257236	0.27	0.11	1.00	0.38	0.22	0.01	2.23	3.52	0.38	0.17	8

- Total number of damaged buildings [Damage Level 3+4+5];
- Number of damaged buildings for each building structure type [Damage Level 3+4+5];

Number of damaged buildings for each building structure type **Total Damaged building Number**

	A	B	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK
1			Damage Level 3+ 4 + 5										
2	OBJECT ID	GridCode	Adobe 2016	SMM 2016	BMM 2016	BMM_2 2016	BMM_3 2016	SCM 2016	BCM 2016	RC_N_Eng 2016	RC_Eng 2016	Others 2016	Total Damage Bldg No
3	Total		7,053	2,465	24,867	4,915	3,701	189	29,499	30,900	3,011	1,654	108,254
4		GridCode	Adb_D345	SMM_D345	BM1_D345	BM2_D345	BM3_D345	SCM_D345	BCM_D345	RCN_D345	RCE_D345	Ohr_D345	N_TDB_D345
8315	8311	247236	0.31	0.16	0.20	0.27	0.04	0.01	0.47	0.14	0.02	0.05	2
8316	8312	248236	0.15	0.08	0.10	0.13	0.02	0.00	0.23	0.07	0.01	0.03	1
8317	8313	249236	0.07	0.04	0.05	0.07	0.01	0.00	0.12	0.04	0.00	0.02	0
8318	8314	250236	1.17	0.59	2.88	1.04	0.55	0.06	4.54	4.27	0.56	0.30	16
8319	8315	251236	1.16	0.31	50.34	2.88	10.34	0.30	53.24	41.30	1.36	0.93	162
8320	8316	252236	0.38	0.19	1.64	0.78	0.45	0.03	5.44	11.11	1.48	0.40	22
8321	8317	253236	0.80	0.37	0.77	0.54	0.18	0.03	2.10	1.12	0.15	0.25	6
8322	8318	254236	0.28	0.12	1.05	0.41	0.24	0.01	2.31	4.61	0.53	0.19	10
8323	8319	255236	0.59	0.24	2.14	0.81	0.47	0.03	4.40	8.62	0.97	0.35	19
8324	8320	256236	0.32	0.15	1.34	0.63	0.36	0.03	4.27	8.76	1.15	0.32	17
8325	8321	257236	0.30	0.14	1.25	0.56	0.32	0.02	3.68	7.40	0.94	0.23	15

- Total number of damaged buildings [Damage Level 3+4+5];
- Number of damaged buildings for each building structure type [Damage Level 3+4+5];

Number of damaged buildings for each building structure type **Total Damaged building Number**

	A	B	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV
1			Damage Level 2 + 3+ 4 + 5										
2	OBJECT ID	GridCode	Adobe 2016	SMM 2016	BMM 2016	BMM_2 2016	BMM_3 2016	SCM 2016	BCM 2016	RC_N_Eng 2016	RC_Eng 2016	Others 2016	Total Damage Bldg No
3	Total		7,745	3,291	31,481	8,057	5,969	336	51,805	58,337	6,086	2,31[illegible]	176,02[illegible]
4		GridCode	Adb_D2345	SMM_D2345	BM1_D2345	BM2_D2345	BM3_D2345	SCM_D2345	BCM_D2345	RCN_D2345	RCE_D2345	Ohr_D2345	N_TDB_D2345
8315	8311	247236	0.32	0.19	0.23	0.39	0.06	0.01	0.79	0.26	0.03	0.1[illegible]	[illegible]
8316	8312	248236	0.16	0.10	0.12	0.20	0.03	0.01	0.39	0.13	0.02	0.05	[illegible]
8317	8313	249236	0.08	0.05	0.06	0.10	0.02	0.00	0.20	0.07	0.01	0.02	[illegible]
8318	8314	250236	1.22	0.70	3.39	1.52	0.80	0.09	7.54	7.76	1.15	0.49	[illegible]
8319	8315	251236	1.21	0.36	58.91	4.17	14.97	0.49	87.51	74.09	2.74	1.53	[illegible]
8320	8316	252236	0.40	0.22	1.89	1.10	0.63	0.05	8.67	19.29	2.88	0.54	[illegible]
8321	8317	253236	0.83	0.42	0.89	0.75	0.25	0.05	3.30	1.91	0.29	0.40	[illegible]
8322	8318	254236	0.30	0.14	1.26	0.63	0.36	0.03	4.01	8.78	1.14	0.31	[illegible]
8323	8319	255236	0.62	0.30	2.60	1.26	0.73	0.05	7.79	16.81	2.13	0.54	[illegible]
8324	8320	256236	0.33	0.18	1.55	0.89	0.51	0.04	6.85	15.29	2.24	0.51	[illegible]
8325	8321	257236	0.32	0.17	1.47	0.82	0.47	0.04	6.05	13.28	1.89	0.46	[illegible]

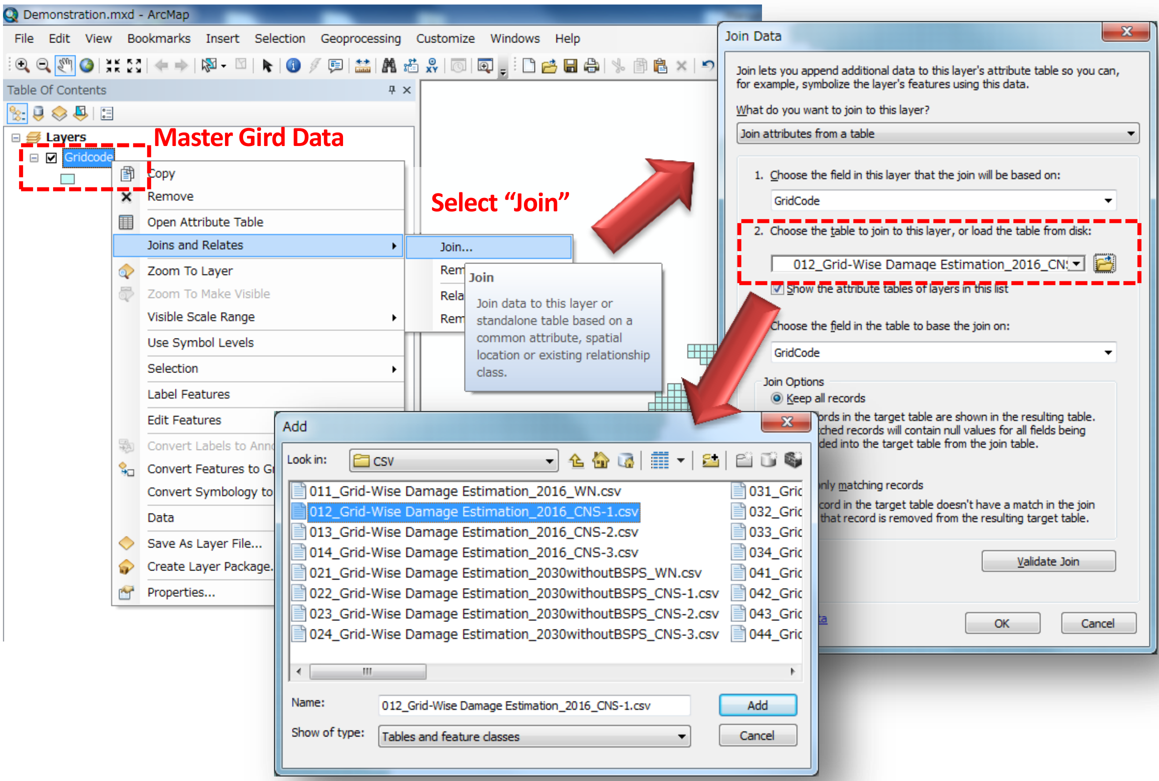
- Number of heavily (DL4+5) damaged masonry buildings;
- Number of heavily (DL4+5) damaged RC buildings;
- Total number of heavily (DL4+5) damaged buildings;;
- Ratio of heavily (DL4+5) damaged buildings;
- Number of moderately (DL3) damaged masonry buildings;
- Number of moderately (DL3) damaged RC buildings;
- Total number of moderately (DL3) damaged buildings;

- Ratio of moderately (DL3) damaged buildings;
- Number of slightly (DL2) damaged masonry buildings;
- Number of slightly (DL2) damaged RC buildings;
- Total number of slightly (DL2) damaged buildings;
- Ratio of slightly (DL2) damaged buildings;

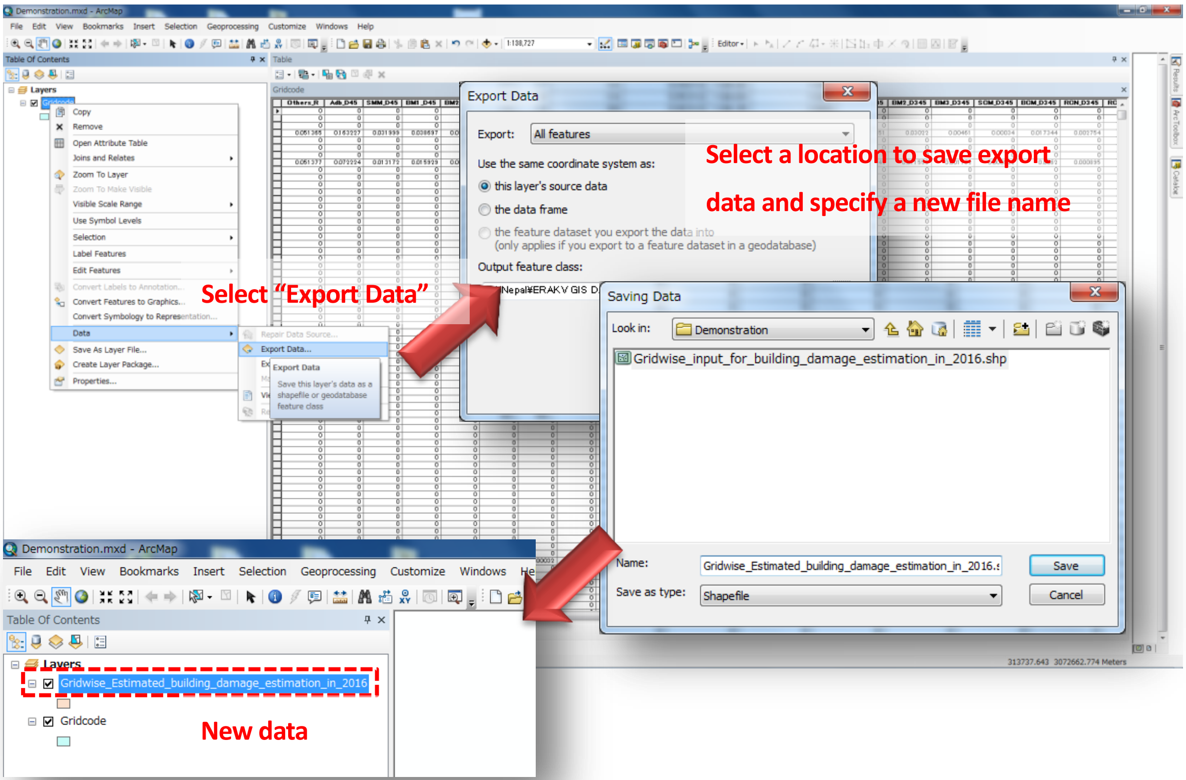
Heavily Damage Building & Ratio | **Moderately Damage Building & Ratio** | **Slightly Damage Building & Ratio**

	A	B	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH
1	OBJECT ID	GridCode	Heavy Damage DL4+5				Moderate Damage DL3				Slight Damage DL2			
2			Masonry 2016	RC 2016	Total Damage Bldg No	Ratio of Damage Bldg	Masonry 2016	RC 2016	Total Damage Bldg No	Ratio of Damage Bldg	Masonry 2016	RC 2016	Total Damage Bldg No	Ratio of Damage Bldg
3	Total		49,723	15,591	65,314	14.7%	24,620	18,320	42,940	9.7%	37,259	30,512	67,771	15.2%
4		GridCode	N_MSRY_HD	N_RC_HD	N_TDB_HD	R_TDB_HD	N_MSRY_MD	N_RC_MD	N_TDB_MD	R_TDB_MD	N_MSRY_SD	N_RC_SD	N_TDB_SD	R_TDB_SD
8315	8311	247236	1.08	0.07	1.16	0.29	0.43	0.09	0.52	0.13	0.59	0.14	0.73	0.18
8316	8312	248236	0.54	0.04	0.57	0.29	0.22	0.04	0.26	0.13	0.30	0.07	0.37	0.18
8317	8313	249236	0.27	0.02	0.29	0.29	0.11	0.02	0.13	0.13	0.15	0.03	0.18	0.18
8318	8314	250236	7.80	2.23	10.03	0.20	3.33	2.60	5.93	0.12	4.64	4.07	8.71	0.18
8319	8315	251236	83.25	20.20	103.45	0.23	36.24	22.45	58.69	0.13	49.65	34.17	83.83	0.18
8320	8316	252236	6.33	6.10	12.43	0.16	2.99	6.49	9.48	0.12	4.29	9.57	13.86	0.18
8321	8317	253236	3.66	0.63	4.29	0.29	1.38	0.64	2.02	0.13	1.83	0.93	2.76	0.18
8322	8318	254236	3.02	2.26	5.29	0.12	1.59	2.88	4.46	0.10	2.45	4.78	7.22	0.16
8323	8319	255236	5.86	4.13	9.99	0.11	3.16	5.47	8.63	0.10	4.96	9.34	14.31	0.16
8324	8320	256236	5.03	4.77	9.80	0.16	2.39	5.14	7.52	0.12	3.44	7.62	11.06	0.18
8325	8321	257236	4.39	3.90	8.29	0.15	2.17	4.44	6.61	0.12	3.22	6.84	10.05	0.18

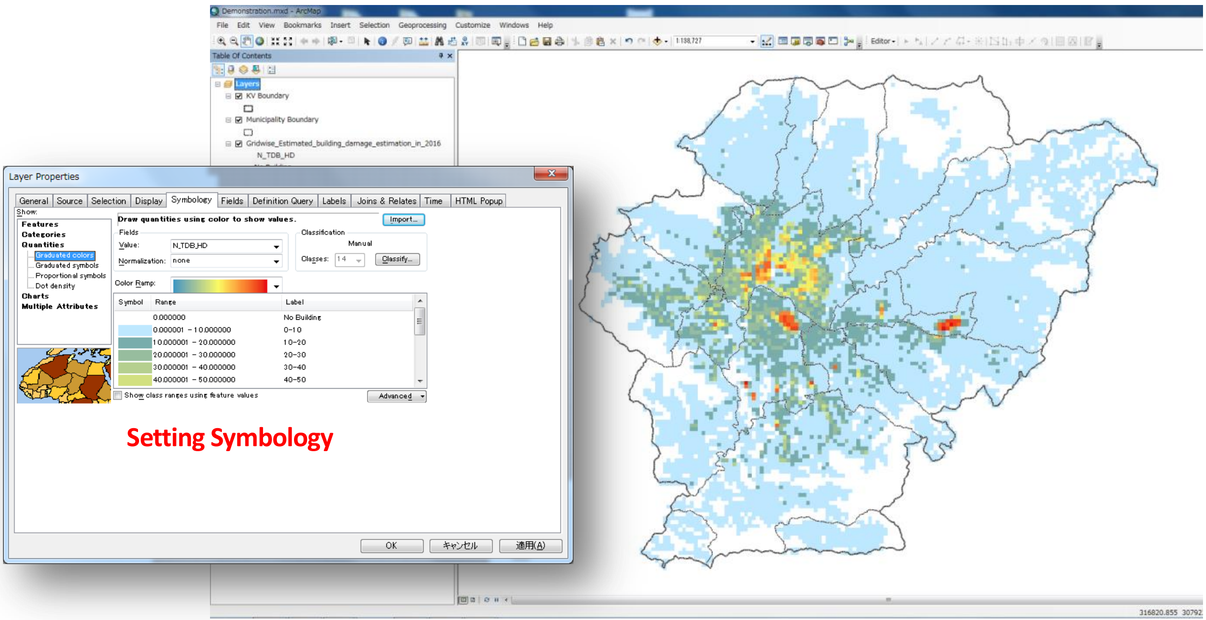
STEP 9: After calculation of grid-wise damaged building number using the calculation form, the sheet including all outputs is saved as CSV file. And then CSV file is imported to the master gird data using the Join Tool of GIS software. Following open the window of Join Tool, Choose "Grid Code" that the join is based on and select the CSV file as the table to join to the master grid data.



STEP 10: After the processing, Export integrated data as a new spatial data. Following open the window of Export Data, select a location to save export data and specify a new file name (e.g. Gridwise_Estimated_building_damage_estimation_in_2016), a new spatial data and its attribute can be shown as a new layer.



STEP 11: By setting the symbology from the layer properties, a map of estimated damage building distribution is created as one of final outcome.



3.1.2. School building, Health facility building and Government building

(1) Method

The damage of school, hospital and government building are estimated for each individual building by its damage probability as shown in Figure 3.3. The probability provides the information of relative vulnerability among buildings, but not which building will be damaged in the future earthquake. The number of damaged building is calculated by Σ Pi, meaning the expected number of building damage.

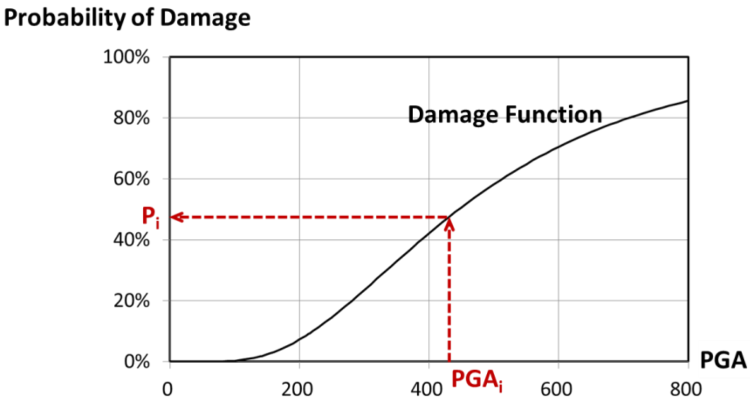


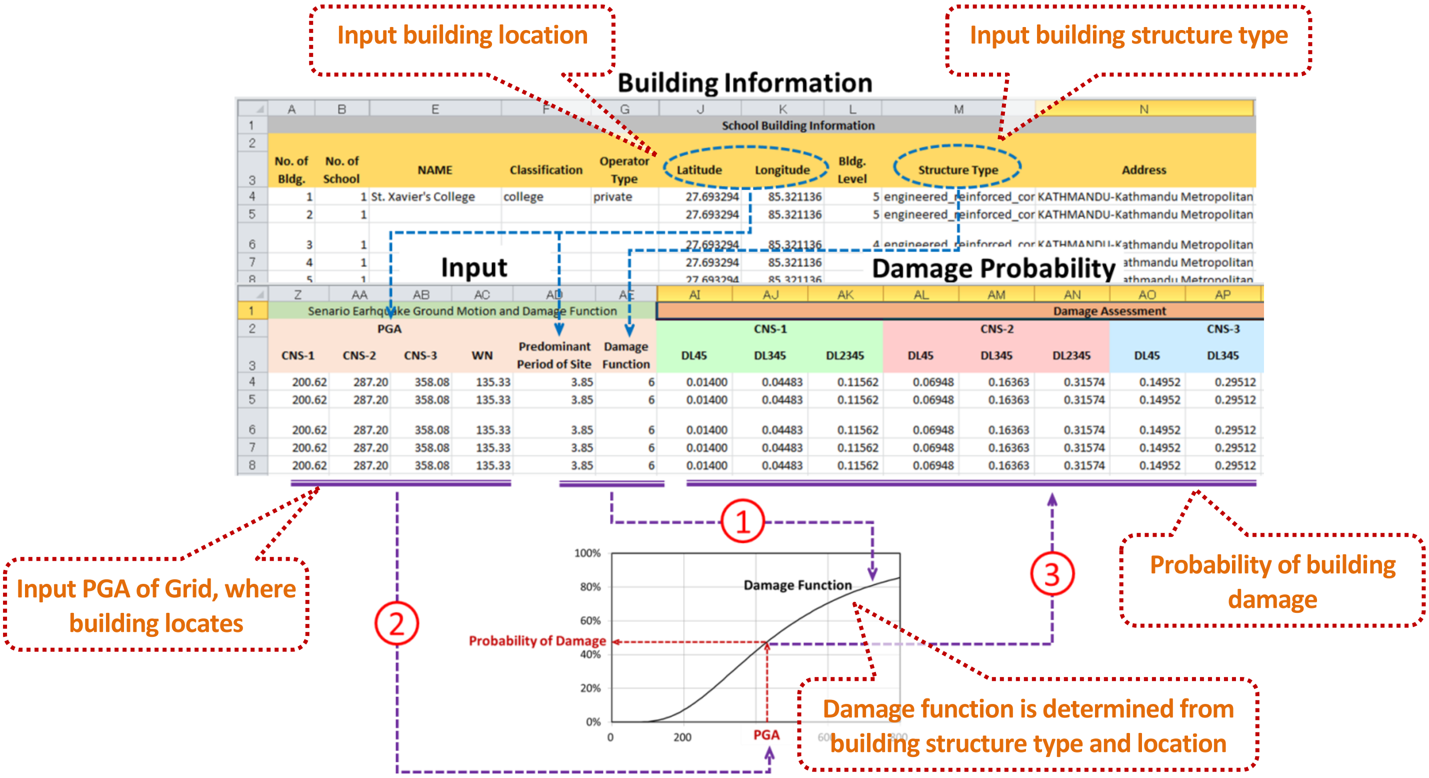
Figure 3.3 Calculation of building damage probability

(2) Calculation Form

The damage probability for each individual building was calculated using following table form.

(i) Input data

- Coordinate of building
- Structure type of building
- Predominant period of ground at the location of building
- PGA at the location of building



(ii) Output

- Damage probability of building (Damage Level 4+5, 3+4+5 and 2+3+4+5)

3.2. Road Damage Assessment

(1) Method

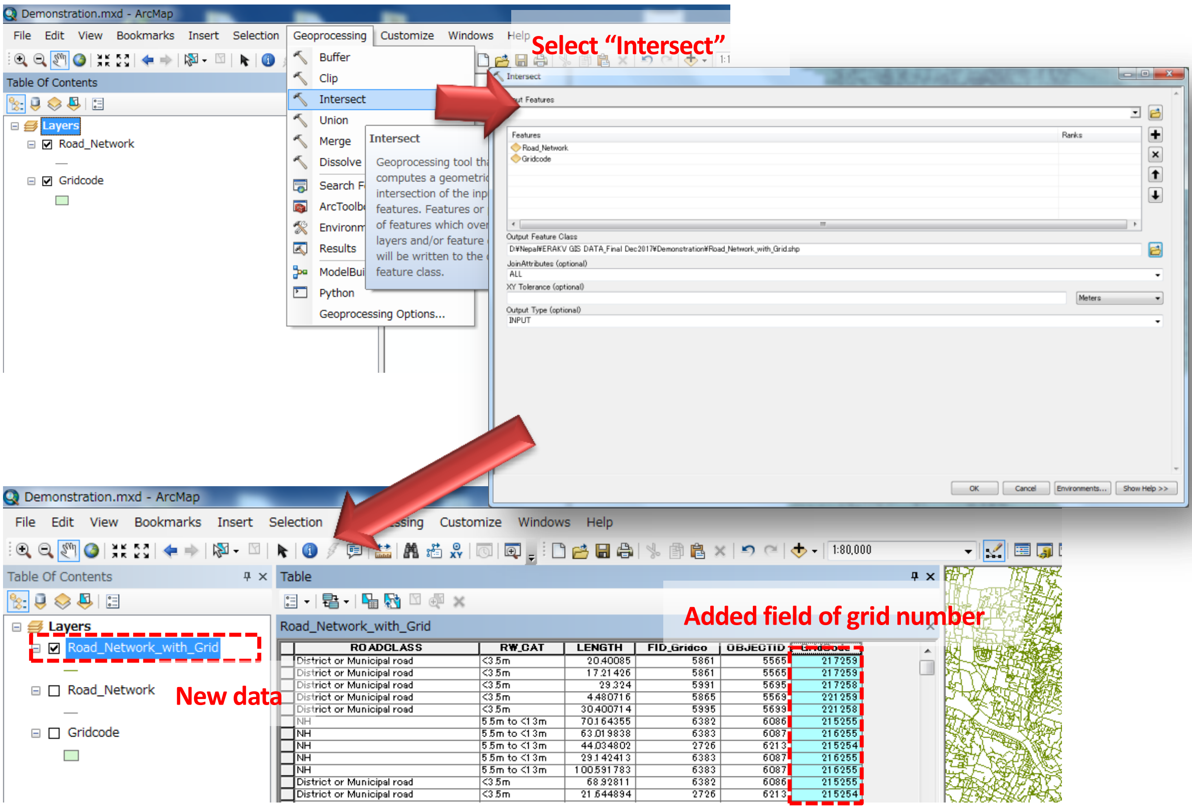
The risk assessment of road network aims to identify the degree of traffic disturbance induced by earthquake. In this project, the traffic disturbance has been examined with reference to two different causes. One is caused by slope failure and liquefaction that can occur due to seismic ground motion and the other is link blockage of road network caused by collapsed building debris.

(2) Data Processing using Calculation Form

1) Slope failure / Liquefaction:

The road located on a high potential area of slope failure and liquefaction is at risk of traffic disturbance by severed roads due to sediment, subsidence of road base and fluctuation of road structures. In this project, possible damaged roads due to slope failure and liquefaction were identified by spatially comparing the grid wise potentials of slope failure and liquefaction estimated based on the scenario seismic ground motion and existing road network for each grid. The procedure of calculating the total length of road network that are located in a high potential area of slope failure and liquefaction by scenario earthquake ground motion is explained in this section.

STEP 1: Put spatially appropriate grid number into each segment of road network. First open road network and master grid data from spatial database using GIS software. Next, select Intersect Tool from the pulldown menu of Geoprocessing and select both layer names as input features. And then, click "OK" and start processing.



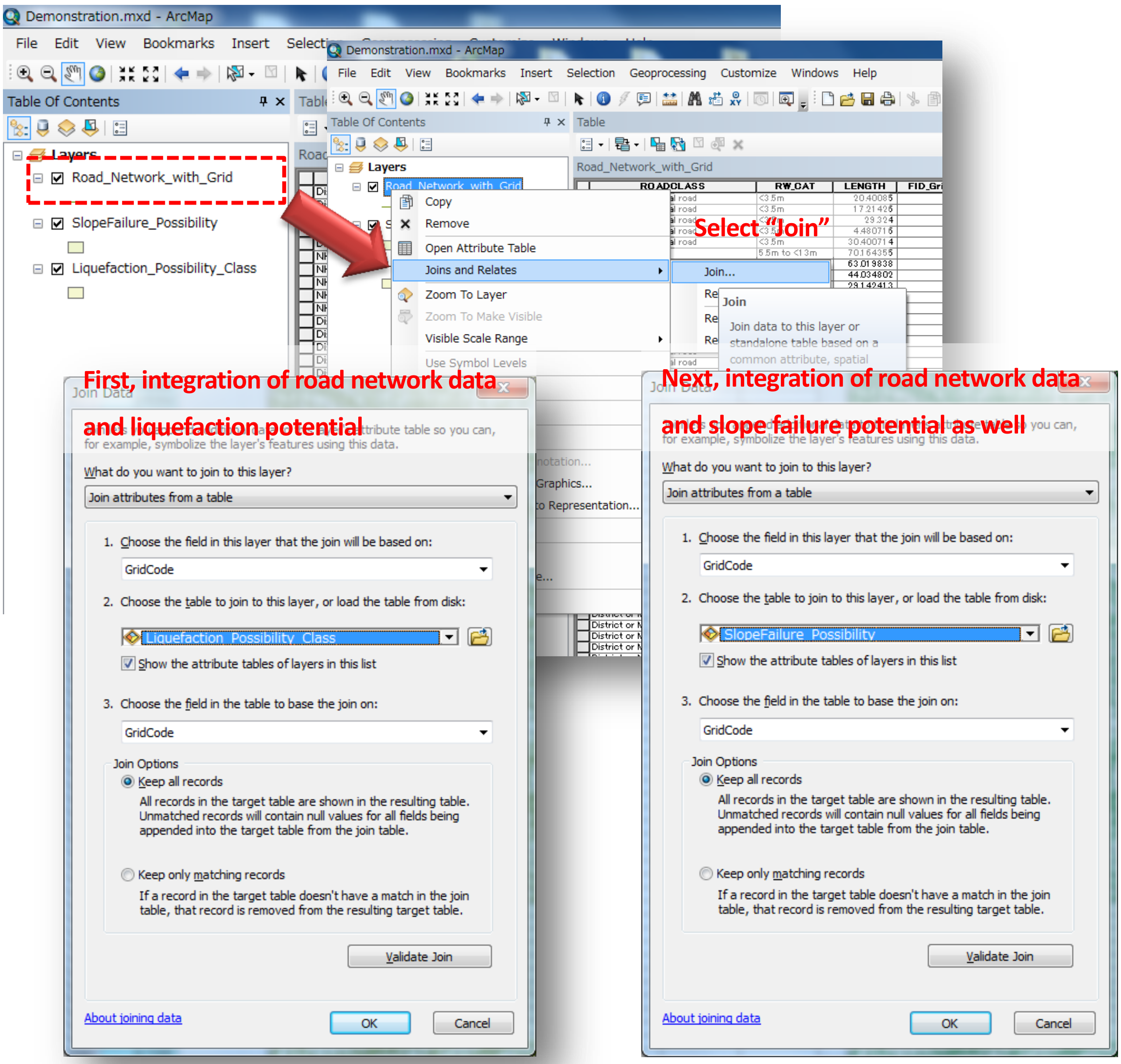
STEP 2: Start integration of road network data and grid-wise potentials of slope failure and liquefaction based on the gird number for each road segment.

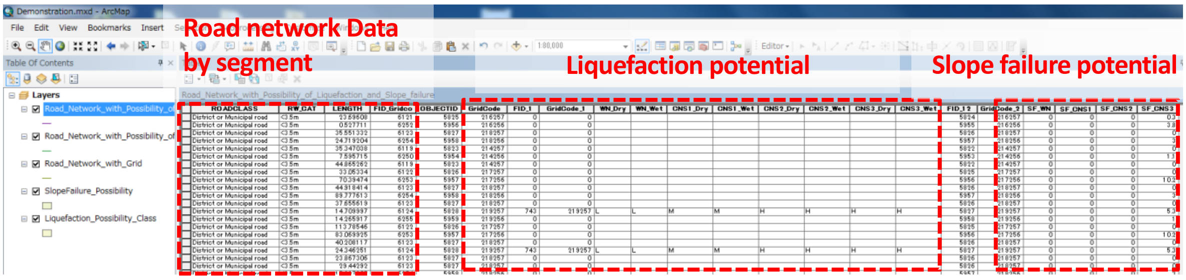
(i) Input data

- Road network data including grid number, surface type, road width, length and road classes as attribute of road segment;
- Potential of slope failure (Potential level: High, Moderate, Low and none);
- Potential of liquefaction (Potential level: High, Moderate, Low and none);

First, open above three spatial data from spatial database using GIS software, and right click on the layer of road network data and select “Join”. Next, choose “Grid Code” that the join is based on and select the layer of liquefaction potential that is joined as “Table name”. After that, click “OK” and start processing.

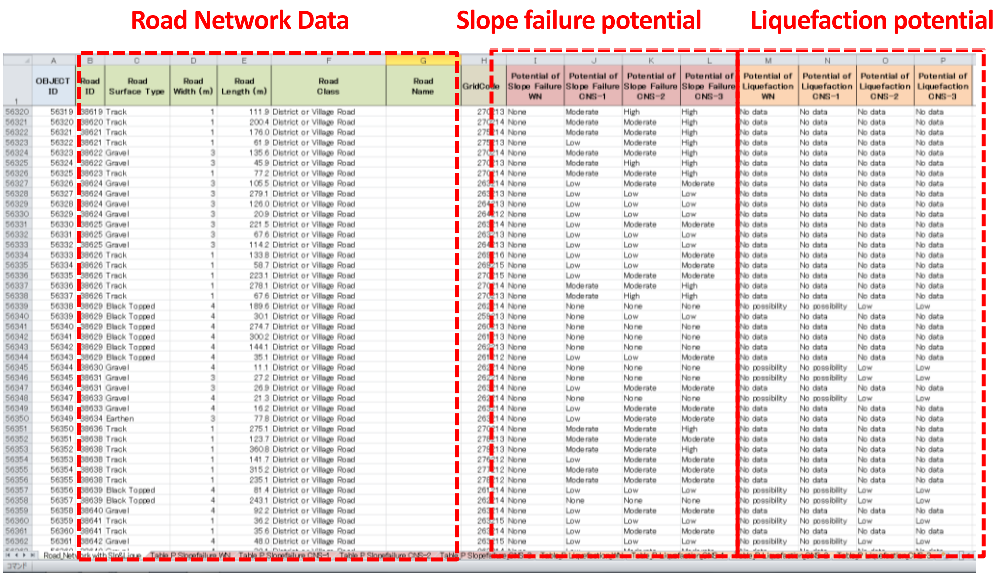
After integration of road network data and liquefaction potential, continue the process to integrate slope failure potential using Join Tool as well. Finally, attribute data of liquefaction potential and slope failure potential are transfered to road network data as shown in below.



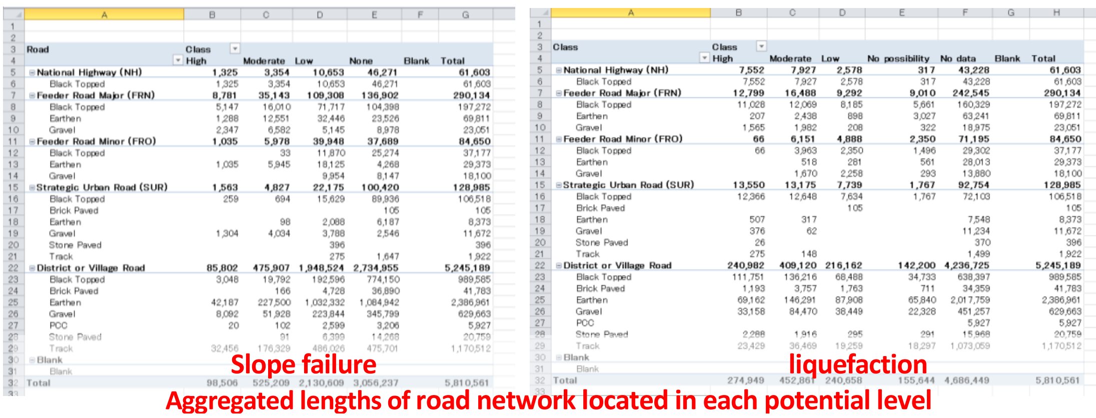


STEP 3: Export this joined layer as a new spatial data. Right click on the layer, and then select "Expert Data". And then, select a location to save export data and specify a new file name (e.g. Road_Network_with_Possibility_of_Liquefaction_and_Slope_failure), finally, a new spatial data is processed.

STEP 4: Open a dbf file of the new spatial data by MS Excel and copy and paste all data used for road damage assessment into appropriate columns of calculation from as following,



STEP 5: Using the function of pivot table in MS Excel, the length of road network that is located on each potential level of slope failure and liquefaction is summarized by road class.



Based on those aggregated data, the total length of road network located in high potential area of slope failure and liquefaction by scenario earthquake ground motion is extracted as the length of possible damaged road.

(ii) Output

- Total length of road network located on high potential area of slope failure and liquefactions by scenario earthquake ground motion;

Road Class	Slope Failure: High				Liquefaction: High				Total Length (Km)
	WN	CNS-1	CNS-2	CNS-3	WN	CNS-1	CNS-2	CNS-3	
NH: National Highway (DOR)	0.0	0.0	1.3	2.8	0.0	1.8	7.6	11.2	61.6
FRN: Feeder Roads Major (DOR)	0.0	0.9	8.8	25.1	0.0	5.6	12.8	19.3	290.1
FRO:Feeder Roads Minor (DOR)	0.0	0.0	1.0	2.4	0.0	0.0	0.1	0.9	84.7
SUR: Strategic Urban Road (DOR)	0.0	0.0	1.6	4.6	0.0	4.3	13.6	18.3	129.0
District or Village Road	0.0	5.7	85.8	355.6	0.0	64.3	241.0	405.6	5,245.2
Total	0.0	6.6	98.5	390.6	0.0	76.1	274.9	455.3	5,810.6

Remark: There is no Mid-Hill Road (MH) and Postal Road (PR) in the study area based on the annual statistic document preparead by DOR

2) Road blockage of the narrow street:

There is a risk of road blockage due to the debris of collapsed buildings by earthquake ground motion in the relatively narrow streets. In this project, the risk of traffic disturbance after the earthquake due to the collapse of adjacent buildings was estimated to calculate the road link blockage rate for each grid targeting the central city where narrow streets are concentrated. First, the road link blockage rate by road segment was calculated based on a typical road width of objective road and a building damage rate of the grid where the road segment is located. Then, the average of road link blockage rates weighted by length of road segments was calculated in each grid. The building damage rate is the sum of half of the complete destruction rate (DL4+5) and half of partial destruction rate (DL3) for each grid.

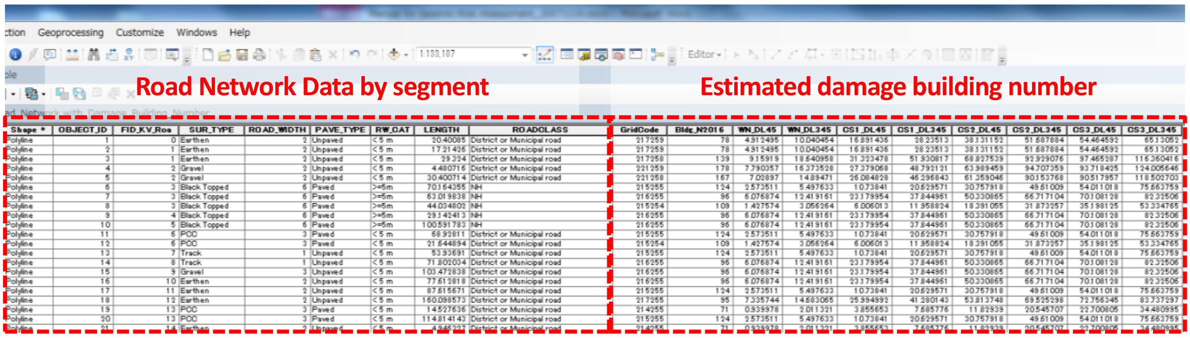
STEP1: Start integration of road network data and grid-wise estimated damage building number (DL4+5 and DL3+4+5).

(i) Input data

- Road network data including grid number, surface type, road width, length and road classes as attribute of road segment;
- Grid-wise estimated damaged building number (DL4+5, DL3+4+5);

The processing procedure of spatial data integration using GIS software is same as a case of slope failure and liquefaction potential. First, open above two spatial data from spatial database using GIS software, and right click on the layer of road network data and select “Join”. Next, choose “Grid Code” that the join is based on and select the layer of grid-wise estimated damage building distribution that is joined as "Table name". After that, click "OK" and start processing.

After this processing, attribute data of grid-wise estimated damage building distribution is transfered to road network data based on a grid number of road segment as shown in below.



STEP 2: Export this joined layer as a new spatial data. Right click on the layer, and then select "Expert Data". And then, select a location to save export data and specify a new file name (e.g. Road_Network with_Damage_Building_Number), finally, a new spatial data is processed.

STEP 3: Open a dbf file of the new spatial data by MS Excel and copy and paste all data used for road damage assessment into appropriate columns of calculation from.

The form has several types of calculation fields in order to calculate a rate of Road Link Blockage based on inputted data. All formula necessary for those calculations were already built based on the evaluation method.

STEP 4: Classify road width using calculation form. The road width for each segment of road is classified into 4 levels such as "Less than 3.5m", "3.5m to < 5.5m", "5.5m to < 13m" and "13m and over" in order to select equations and explanatory variables for calculating "Road link blockage rate".

Classification of Road width using Calculation Form

	A	B	C	D	E	F	G	H	I	J	
1	OBJECT ID	Road ID	Road Surface Type	Road Class	Road Name	Road Width (m)	Class of Road Width	Road Length (m)	GridCode	Bldg No 2016	Dan Bld DL CNS-
2	1	0	Earthen	District or Village Road		2	<3.5m	20.4	217259	78	
3	2	1	Earthen	District or Village Road		2	<3.5m	17.2	217259	78	
4	3	1	Earthen	District or Village Road		2	<3.5m	29.3	217258	139	
5	4	2	Gravel	District or Village Road		2	<3.5m	4.5	221259	178	
6	5	2	Gravel	District or Village Road		2	<3.5m	30.4	221258	167	
7	6	3	Black Topped	National Highway (NH)	Tribhuvan	6	5.5m to <13m	70.2	215255	124	
8	7	3	Black Topped	National Highway (NH)	Tribhuvan	6	5.5m to <13m	63.0	216255	96	

STEP 5: Calculate rate of damaged building using calculation form. Rate of damaged building is calculated using following formula.

Rate of damaged bldg = (Rate of total damage + ½×Rate of partial damage)

Rate of total damage = Damaged Bldg No (DL4+5) / Bldg No

Rate of partial damage = {Damaged Bldg No (DL3+4+5) - Damaged Bldg No (DL4+5)} / Bldg No

STEP 6: Calculate rate of road-link blockage (Rate of RLB) by selecting equations as below based on the level of road width for each road segment.

① **Width of representative road: Less than 3.5m**

Rate of road-link blockage (%)＝0.9009×Rate of damaged building(%)＋19.845

② **Width of representative road: 3.5m to < 5.5m**

Rate of road-link blockage (%)＝0.3514×Rate of damaged building(%)＋13.189

③ **Width of representative road: 5.5m to < 13m**

Rate of road-link blockage (%)＝ 0.2229 ×Rate of damaged building(%)－1.5026

STEP5: Calculation of rate of damaged building based on above formula

OBJECT ID	Road ID	Road Surface Type	Road Class	Road Name	Road Width (m)	Class of Road Width	Road Length (m)	GridCode	Bldg No 2016	Damage Bldg No DL 4+5 CNS-2 2016	Damage Bldg No DL 3+4+5 CNS-2 2016	Rate of Damaged Bldg CNS-2 2016	Rate of Road-Link Blockage (%) CNS-2 2016
1	0	Earthen	District or Village Road		2	<3.5m	20.4	217259	78	38	52	0.576	71.7
2	1	Earthen	District or Village Road		2	<3.5m	17.2	217259	78	38	52	0.576	71.7
3	1	Earthen	District or Village Road		2	<3.5m	29.3	217258	139	69	93	0.582	72.3
4	2	Gravel	District or Village Road		2	<3.5m	4.5	221259	178	64	95	0.446	60.0
5	2	Gravel	District or Village Road		2	<3.5m	30.4	221258	167	61	90	0.454	60.7
6	3	Black Topped	National Highway (NH)	Tribhuvan	6	5.5m to <13m	70.2	215255	124	31	50	0.324	5.7
7	3	Black Topped	National Highway (NH)	Tribhuvan	6	5.5m to <13m	63.0	216255	96	50	67	0.610	12.1

STEP6: Calculation of road-link blockage based on equations

STEP 7: As preparation of calculating gird-wise Rate of RLB by weighted average of road length, Rate of RLB by road segment is multiplied by the length of road segment.

Rate of RLB * length of road segment (m)

OBJECT ID	Road ID	Road Surface Type	Road Class	Road Name	Road Width (m)	Class of Road Width	Road Length (m)	GridCode	Bldg No 2016	(Rate of RLB)* (Road Length) CNS-1 2016	(Rate of RLB)* (Road Length) CNS-2 2016	(Rate of RLB)* (Road Length) CNS-3 2016	(Rate of RLB)* (Road Length) WN 2016
1	0	Earthen	District or Village Road		2	<3.5m	20.4	217259	78	936.5	1,463.1	1,813.9	581.0
2	1	Earthen	District or Village Road		2	<3.5m	17.2	217259	78	790.2	1,234.5	1,530.5	[illegible]
3	1	Earthen	District or Village Road		2	<3.5m	29.3	217258	139	1,373.1	2,119.1	2,613.9	846.1
4	2	Gravel	District or Village Road		2	<3.5m	4.5	221259	178	175.3	268.9	335.8	116.3
5	2	Gravel	District or Village Road		2	<3.5m	30.4	221258	167	1,196.8	1,845.7	2,317.3	783.1
6	3	Black Topped	National Highway (NH)	Tribhuvan	6	5.5m to <13m	70.2	215255	124	92.4	401.4	712.3	0.0
7	3	Black Topped	National Highway (NH)	Tribhuvan	6	5.5m to <13m	63.0	216255	96	351.8	761.7	1,020.5	40.6

STEP 8: Using the function of pivot table in MS Excel, the road length and Rate of RLB by road segment is summed up by gird.

Grid Code	Total Road Length	Total / Rate*Length_CNS-1	Total / Rate*Length_CNS-2	Total / Rate*Length_CNS-3	Total / Rate*Length_WN
187261	101.382818 8	0	0	0	0
188252	122.4658759	0	0	0	0
188253	59.75166924	0	0	0	0
188261	351.3318329	15048.86448	26442.80199	10741.83444	21239.38942
188264	278.7396415	1121.035529	3336.627881	326.3095787	2318.225842
188265	182.9235742	722.5869761	2170.204496	215.0528823	1502.860337
189251	8.22587976	0	0	0	0
189252	862.9860465	0	0	0	0
189253	138.7943605	0	0	0	0
189261	102.1664649	4369.16368	7679.45049	3118.699616	6166.761725
189262	221.3825045	9427.91693	16583.35309	6761.929955	13307.60359
189264	188.4722842	753.0775412	2248.794167	218.3501125	1560.565079

STEP 9: Rate of RLB summed up by gird is divided by the total road length by gird in order to calculate the grid wise Rate of RLB by weighted average of road length.

(ii) Output

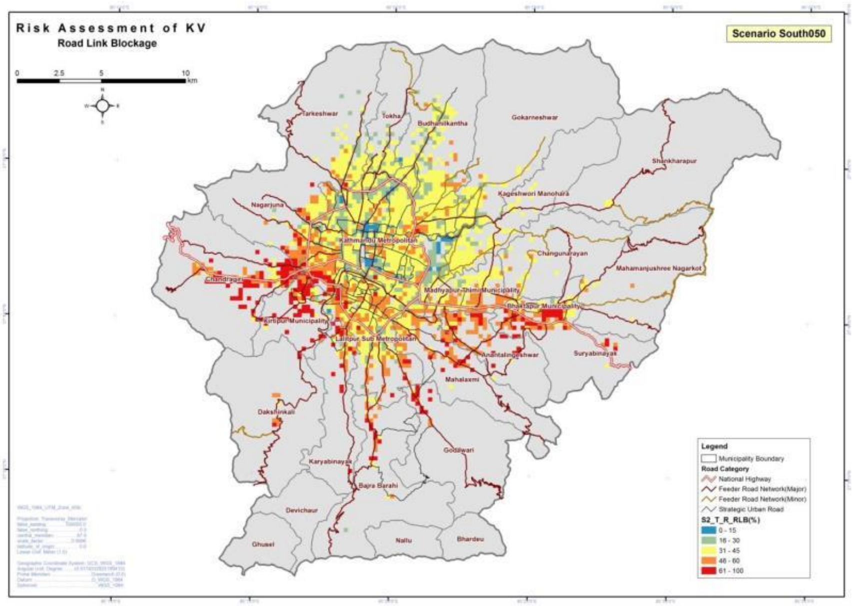
- Grid-wise Rate of Road Link Blockage (RLB);

Grid Number | **Grid-wise Rate of Road Link Blockage (RLB)**

GridCode	Total Road Length	Total / Rate*Length_CNS-1	Total / Rate*Length_CNS-2	Total / Rate*Length_CNS-3	Total / Rate*Length_WN		Grid Wise Rate of Road-Link Blockage (%) CNS-1 2016	CNS-2 2016	CNS-3 2016	WN 2016
187261	101.3828188	0	0	0	0		0.0	0.0	0.0	0.0
188252	122.4658759	0	0	0	0		0.0	0.0	0.0	0.0
188253	59.75166924	0	0	0	0		0.0	0.0	0.0	0.0
188261	351.3318329	15048.86448	26442.80199	10741.83444	21239.38942		42.8	75.3	30.6	60.5
188264	278.7396415	1121.035529	3336.627881	326.3095787	2318.225842		4.0	12.0	1.2	8.3
188265	182.9235742	722.5869761	2170.204496	215.0528823	1502.860337		4.0	11.9	1.2	8.2
189251	8.22587976	0	0	0	0		0.0	0.0	0.0	0.0
189252	862.9860465	0	0	0	0		0.0	0.0	0.0	0.0
189253	138.7943605	0	0	0	0		0.0	0.0	0.0	0.0
189261	102.1664649	4369.16368	7679.45049	3118.699616	6166.761725		42.8	75.2	30.5	60.4
189262	221.3825045	9427.91693	16583.35309	6761.929955	13307.60359		42.6	74.9	30.5	60.1
189264	188.4722842	753.0775412	2248.794167	218.3501125	1560.565079		[illegible]	[illegible]	[illegible]	[illegible]

STEP 10: After calculation of grid-wise Rate of RLB using the calculation form, the sheet including fields of grid number and grid-wise rate of RLB by scenario earthquake is saved as CSV file. And then CSV file is imported to the master gird data using the Join Tool of GIS software.

This data processing procedure is same as the procedure of damaged building distribution that was explained at STEP 9 to 11 of Section 3.1 in this document. Please refer corresponding parts.



3.3. Bridge Damage Assessment

Damage of pier is one of the crucial factors which affects the function of bridge after an earthquake. Response ductility factor of the pier due to seismic load was taken as an index for evaluating the damage degree of pier. A statistical empirical method is applied to calculate the response ductility factor. The calculation procedure is given as below, followed by EXCEL calculation form.

(1) Procedure of Ductility Factor Calculation

1. Collection/preparation of drawing
2. Extraction of dimensions of bridge
3. Calculation of superstructure weight W_u
4. Calculation of substructure weight W_p
5. Calculate moment of inertia:

   $I = \frac{\pi r^4}{4}$ for circular pier section and $I = \frac{bh^3}{12}$ for rectangular pier section

6. Calculate initial stiffness, $K_0 = \frac{3EI}{h^3}$,

   where h = height of pier from top of bottom cap to top of pier top cap.
7. Calculate stiffness under yielding process $K_y = \alpha\, K_0$,

   where α= regression coefficient (See Note: Regression Coefficient below)
8. Calculate equivalent natural period, $T_y = 2.01 \times \left(\frac{W_u+0.3W_p}{Ky}\right)^{1/2}$
9. Calculate yield seismic intensity, $K_{hy} = \beta \times {T_y}^{\gamma}$

   where β, γ= regression coefficient (See Note: Regression Coefficient below)
10. Kathmandu Valley is divided into 250 m x 250 m grid and response spectrum is generated for each grid for each scenario earthquake. Response acceleration (Sa) at period of Ty, calculated in 9, is interpolated using the response spectrum of the grid in which the bridge lies.
11. Calculate response ductility factor $\mu_r = \frac{1}{2}\left(\left(\frac{S_a}{G \times K_{hy}}\right)^2 + 1\right)$
12. Compare threshold value of response ductility factor for damage classification by following judgment

S.N.	Response Ductility Factor (μ_r)	Classification
1	Less than 1.0	No Visible Damage
2	1.0 - 1.5	Slight Damage
3	1.5 - 3.0	Moderate Damage
4	Larger than 3.0	Heavy Damage

Bridge damage calculation is divided into two sheets: one for calculation of superstructure and substructure weight and another for calculation of ductility factor. Please note that the calculation of superstructure and substructure depends on the shape of the structure. For example, there are rectangular, circle and combination of rectangular and semicircle piers.

(2) Ductility Factor Calculation Form

In this sheet, grid code is used to find the response acceleration of grid where the bridge locates. Construction year is used for determination of regression coefficient, which reflected the bridge strength due to different design concept.

Grid code to determine response Acc.

Construction year to determine regression coefficient

Bridge No	Yield Intensity Calculation Form			
19	⇦ Select bridge No. here			
Grid Code			Date :	
240256	Checked by :		Date :	
Construction Year	Name of Bridge :		SN 19 - Dhobi Khola	
A	Weight of super structure Wu (kN)			4,372.50
	Weight of substructure Wp (kN)			797.80
	Pier	Pier section	----	0.00
	Pier	Pier section	----	0.00
	Pier	Pier section	r (m)	0.40
	Pier	Pier section	No. ()	5.00
	Pier	Height	h (m)	3.08
	Pier	I (m^4) for all piers		0.1005
	Pier	Young's modulus of RC pier E (N/mm^2)		20,000
	Pier	Initial stiffness Ky0 (kN/m), only consider that above pilecap		207,249
	Regression coefficient α			0.390
	Yield stiffness ky (kN/m)			80,827
	δ (m) (Displacement subjecting to horizontal acceleration of 1g)			0.057058
	Ty (s)			0.480126
	Regression coefficient β			0.230
	Regression coefficient γ			-0.463
	Yield Intensity Khy (dimensionless)			0.323
	CNS-1	Sa (gal) Acceleration response spectrum		438.150
	CNS-1	μr Response ductility factor		1.458
	CNS-2	Sa (gal) Acceleration response spectrum		620.951
	CNS-2	μr Response ductility factor		2.424
	CNS-3	Sa (gal) Acceleration response spectrum		762.215
	CNS-3	μr Response ductility factor		3.398
	WN	Sa (gal) Acceleration response spectrum		293.894
	WN	μr Response ductility factor		0.928

(3) Superstructure and substructure weight calculation Form

Calculation of substructure weight has basically two templets, one for rectangular shape pier and another for circle. The following is the form for circle pier.

	Calculation Form for Superstructure and Substructure Weight							
19								
	Calculated by :					Date :	3-May-16	
	Checked by :					Date :		
	Name of Bridge :	SN 19 - Dhobi Khola						
	Superstructure weight							
	Element	Width (m)	Thickness (m)	Length (m)	Volume (m^3)	Unit Weight (kN/m^3)	Number	Weight (kN)
	Floor slab	20.520	0.300	16.925	104.190	24	1	2,500.567
	Side walk	3.260	0.350	16.925	19.311	24	2	926.948
	Longitudinal girder	0.180	0.980	16.925	2.986	24	12	859.844
	Transvers beam	0.140	0.810	1.422	0.161	24	22	85.143
	Total							4,372.502
	Substructure weight							
	Element	Width (m)	Thickness (m)	Length (m)	Volume (m^3)	Unit Weight (kN/m^3)	Number	Weight (kN)
	Upper half of pier cap	1.200	0.350	19.100	8.022	24	1	192.528
	Lower half of pier cap	1.000	0.450	18.100	8.145	24	1	195.480
	Pier	0.629	0.800	2.276	1.145	24	5	137.340
	Pilecap	1.200	0.550	17.200	11.352	24	1	272.448
	Total							797.796

Note: Regression Coefficient

	Design concept of corresponding Japanese code	Time period	Regression coefficient		
			α	β	γ
A	Linear analysis utilizing response spectra	Before 1980	0.39	0.23	-0.463
B	Non-linear analysis was applied to consider ductile behavior of pier	1980~1990	0.39	0.25	-0.328
C	Considering large scale earthquake ground motion (about 400 years of return period) in design	1990~1995	0.39	0.25	-0.277
D	Special code utilizing the experience of Kobe earthquake	After 1995	0.41	0.33	-0.484

3.4. Water Supply Network Damage Assessment

(1) Method

A flow diagram of damage assessment of water supply network is shown in Figure 3.4. The damage rate of water supply network is expressed in terms of the number of damage spot per unit length (1 km). There are two ways for calculating the damage rate depending on the presence or absence of liquefaction potential. If there is no liquefaction potential, the PGV (Peak Ground Velocity of ground surface (cm/s)) is used as the explanatory variable for calculating the standard damage rate, R(v), that is given by the empirical formula. On the other hand, if there is the potential of liquefaction, the constant value is inputted as the standard damage rate, RL. The empirical formula and the constant value for setting the standard damage rate were estimated based on the recent findings of earthquake damage of pipelines in Japan. Furthermore, three types of factors are adopted to modify the standard damage rate in consideration of pipe material and joint type, pipe diameter and ground condition.

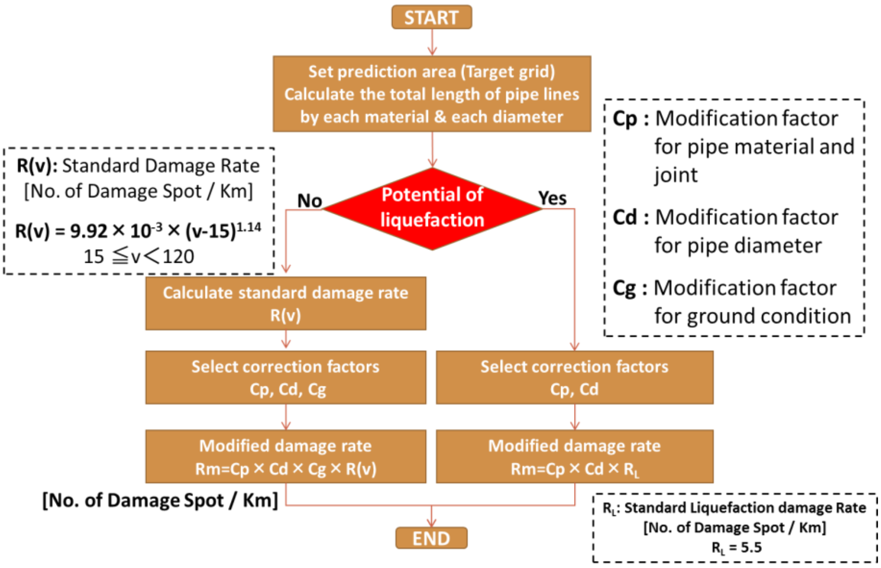
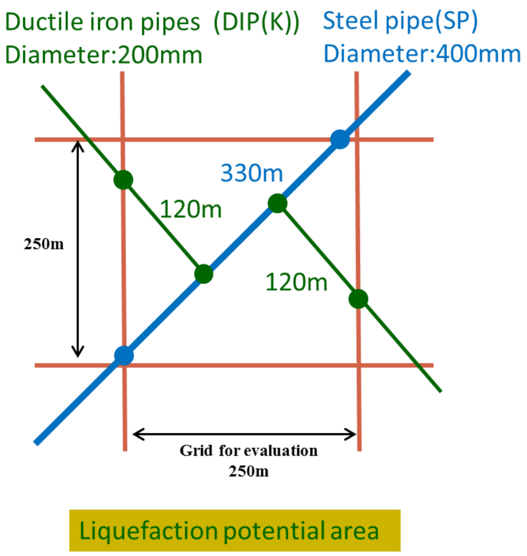


Figure 3.4 Flow diagram of risk assessment of water supply network

In this project, the grid-based analysis was adopted as the damage assessment method of water supply network using GIS software. 250m-mesh grids were set as the minimum units, and the damage rate was estimated for each grid. There were several kinds of pipe segments in a grid as shown in Figure 3.5. First, the damage rate per pipe segment was calculated based on the flow of damage estimation. Then, the damage rate in a grid was obtained by weighted average of damage rates of each pipe segment based on the length of each pipe segment.



Damage Prediction Formula for Pipe line

$Rm = Cp \times Cd \times R_L$

Rm: Estimated Damage Rate [No. of Damage Spot / Km]
Cp: Correction Factor due to type of pipeline material
Cd: Correction Factor due to pipeline diameter
R_L :(=5.5) Standard Liquefaction Damage Rate [No. of Damage Spot / Km]

In case of Steel pipe(SP), Cp = 0.5
In case of Diameter:400mm, Cd = 0.2

In case of Ductile iron pipes (DIP(K)): Cp = 0.5
In case of Diameter:200mm, Cd = 0.4

$$Rm = 5.5 \times \{(2.5 \times 0.2) \times 330 + (0.5 \times 0.4) \times 240\} / 570$$
$$= 5.5 \times (33+48) / 570$$
$$= \underline{0.78\ [\text{No. of Damage Spot / Km}]}$$

Figure 3.5 An example of schematic drawing for pipe damage rate summary of each grid

(2) Data Processing using Calculation Form

STEP 1: Put a grid number into each segment of water supply network. First open water network and master grid data from spatial database using GIS software. Next, select Intersect Tool from the pulldown menu of Geoprocessing and select both layer names as input features. And then, click "OK" and start processing.

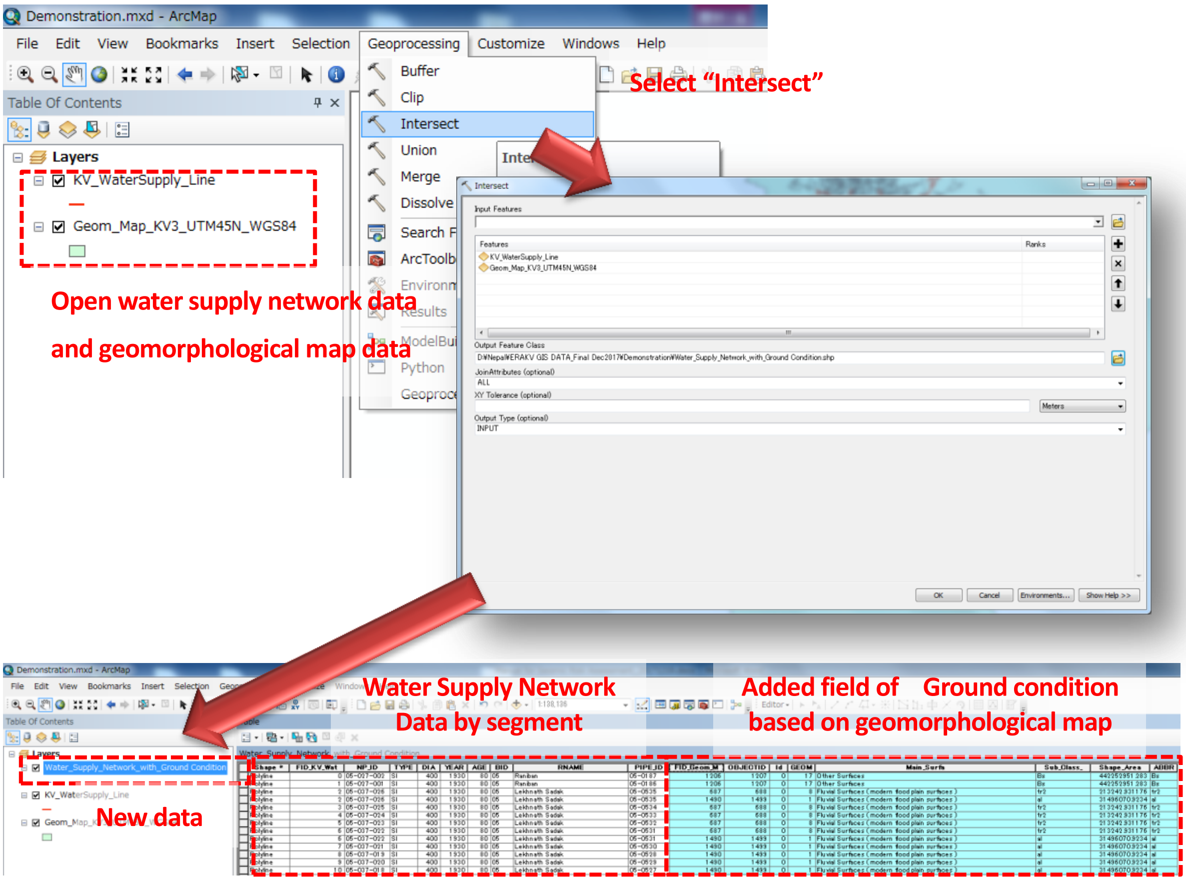
This data processing procedure is same as the procedure of joining road network and master grid data that was explained at STEP 1 of Section 3.2 in this document. Please refer corresponding parts.

STEP2: Start integration of water supply network data, grid-wise PGV and ground condition based on geomorphological map using GIS software in order to put spatially appropriate PGV value and ground condition into each pipe segment of water supply network based on a grid number.

(i) Input data

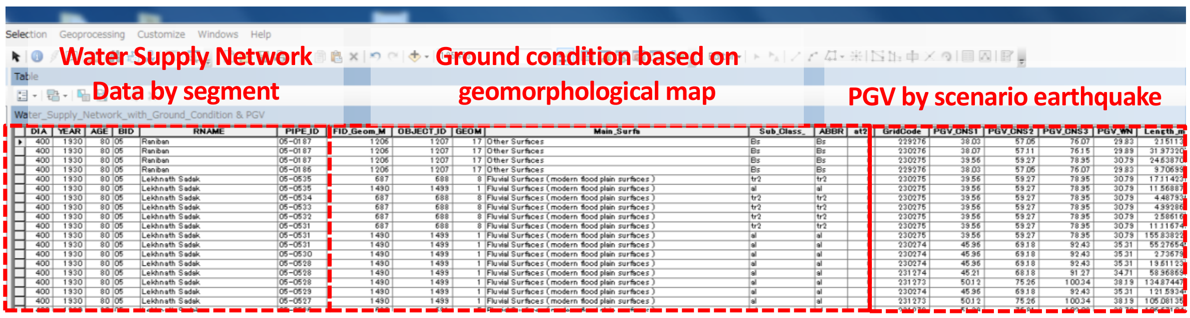
- Water supply network data including gird number, pipe material and diameter as attribute of pipe segment;
- Gird-wise PGV;
- Ground condition based on geomorphological map;

For putting ground condition based on geomorphological map into each segment of water supply network, Intersect Tool is used again.



For putting grid-wise PGV into each segment of water supply network, this data processing procedure is same as the procedure of spatial data integration of road network and grid-wise slope failure and liquefaction potential that was explained at STEP 2 of Section 3.2 in this document. Please refer corresponding parts.

After this processing, attribute data of grid-wise PGV is transferred to water supply network data based on a grid number of pipe segment as shown in below.



STEP 3: Export this joined layer as a new spatial data. After that, open a dbf file of the new spatial data by MS Excel and copy and paste all data used for pipeline damage assessment into appropriate columns of calculation from.

STEP4: The form has several types of calculation fields in order to calculate grid-wise damage rate of water supply network (Rm: Number of damage spot / km) based on inputted data. All formula necessary for those calculations were already built based on the evaluation method.

Identify coefficients for pipe material by pipe segment (Cp), pipe diameter pipe segment (Cd) and ground condition (Dg) by pipe segment.

(Cp) (Cd) (Cg) PGV by scenario earthquake | Standard damage rate by segment

	A	B	C	D	E	F	G	H	I	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1	NP_ID	PIPE_ID	GridCode	TYPE	Cp	DIA	Cd	YEAR	AGE	Class	ABBR	Cg	Length (m)	PGV CNS-1	PGV CNS-2	PGV CNS-3	PGV WN	Rv CNS-1	Rv CNS-2	Rv CNS-3	Rv WN	Rm CNS-1	Rm CNS-2	Rm CNS-3	Rm WN
2	05-027-002	05-0187	229276	SI	0.5	400	0.2	1,930	80	Bs	Bs	0.4	2.2	38.03	57.05	76.07	29.8	0.354	0.704	1.077	0.215	0.0142	0.0282	0.0431	0.0086
3	05-027-002	05-0187	230276	SI	0.5	400	0.2	1,930	80	Bs	Bs	0.4	32.0	38.07	57.11	76.15	29.8	0.355	0.705	1.079	0.216	0.0142	0.0282	0.0432	0.0086
4	05-027-002	05-0187	230275	SI	0.5	400	0.2	1,930	80	Bs	Bs	0.4	24.6	39.56	59.27	78.95	30.7	0.381	0.747	1.135	0.230	0.0153	0.0299	0.0454	0.0092
5	05-027-001	05-0186	229276	SI	0.5	400	0.2	1,930	80	Bs	Bs	0.4	9.7	38.03	57.05	76.07	29.8	0.354	0.704	1.077	0.215	0.0142	0.0282	0.0431	0.0086
6	05-037-026	05-0535	230275	SI	0.5	400	0.2	1,930	80	tr2	tr2	1.0	17.1	39.56	59.27	78.95	30.7	0.381	0.747	1.135	0.230	0.0381	0.0747	0.1135	0.0230
7	05-037-026	05-0535	230275	SI	0.5	400	0.2	1,930	80	al	al	1.0	11.6	39.56	59.27	78.95	30.7	0.381	0.747	1.135	0.230	0.0381	0.0747	0.1135	0.0230
8	05-037-025	05-0534	230275	SI	0.5	400	0.2	1,930	80	tr2	tr2	1.0	4.5	39.56	59.27	78.95	30.7	0.381	0.747	1.135	0.230	0.0381	0.0747	0.1135	0.0230
9	05-037-024	05-0533	230275	SI	0.5	400	0.2	1,930	80	tr2	tr2	1.0	5.0	39.56	59.27	78.95	30.7	0.381	0.747	1.135	0.230	0.0381	0.0747	0.1135	0.0230
10	05-037-023	05-0532	230275	SI	0.5	400	0.2	1,930	80	tr2	tr2	1.0	2.6	39.56	59.27	78.95	30.7	0.381	0.747	1.135	0.230	0.0381	0.0747	0.1135	0.0230
11	05-037-022	05-0531	230275	SI	0.5	400	0.2	1,930	80	tr2	tr2	1.0	11.1	39.56	59.27	78.95	30.7	0.381	0.747	1.135	0.230	0.0381	0.0747	0.1135	0.0230
12	05-037-022	05-0531	230275	SI	0.5	400	0.2	1,930	80	al	al	1.0	155.8	39.56	59.27	78.95	30.7	0.381	0.747	1.135	0.230	0.0381	0.0747	0.1135	0.0230

As preparation of calculating gird-wise damage rate (Rm) by weighted average of damage rates of each pipe segment, the damage rate per pipe segment is multiplied by the length of segment.

Damage rate * length of pipe segment (m)

M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
g	Length (m)	PGV CNS-1	PGV CNS-2	PGV CNS-3	PGV WN	Rv CNS-1	Rv CNS-2	Rv CNS-3	Rv WN	Rm CNS-1	Rm CNS-2	Rm CNS-3	Rm WN	Rm*Length CNS-1	Rm*Length CNS-2	Rm*Length CNS-3	Rm*Length WN	
0.4	2.2	38.03	57.05	76.07	29.83	0.354	0.704	1.077	0.215	0.0142	0.0282	0.0431	0.0086	0.0000	0.0001	0.0001	0.0000	
0.4	32.0	38.07	57.11	76.15	29.89	0.355	0.705	1.079	0.216	0.0142	0.0282	0.0432	0.0086	0.0005	0.0009	0.0014	0.0003	
0.4	24.6	39.56	59.27	78.95	30.79	0.381	0.747	1.135	0.230	0.0153	0.0299	0.0454	0.0092	0.0004	0.0007	0.0011	0.0002	
0.4	9.7	38.03	57.05	76.07	29.83	0.354	0.704	1.077	0.215	0.0142	0.0282	0.0431	0.0086	0.0001	0.0003	0.0004	0.0001	
1.0	17.1	39.56	59.27	78.95	30.79	0.381	0.747	1.135	0.230	0.0381	0.0747	0.1135	0.0230	0.0007	0.0013	0.0019	0.0004	
1.0	11.6	39.56	59.27	78.95	30.79	0.381	0.747	1.135	0.230	0.0381	0.0747	0.1135	0.0230	0.0004	0.0009	0.0013	0.0003	
1.0	4.5	39.56	59.27	78.95	30.79	0.381	0.747	1.135	0.230	0.0381	0.0747	0.1135	0.0230	0.0002	0.0003	0.0005	0.0001	
1.0	5.0	39.56	59.27	78.95	30.79	0.381	0.747	1.135	0.230	0.0381	0.0747	0.1135	0.0230	0.0002	0.0004	0.0006	0.0001	
1.0	2.6	39.56	59.27	78.95	30.79	0.381	0.747	1.135	0.230	0.0381	0.0747	0.1135	0.0230	0.0001	0.0002	0.0003	0.0001	
1.0	11.1	39.56	59.27	78.95	30.79	0.381	0.747	1.135	0.230	0.0381	0.0747	0.1135	0.0230	0.0004	0.0008	0.0013	0.0003	
1.0	155.8	39.56	59.27	78.95	30.79	0.381	0.747	1.135	0.230	0.0381	0.0747	0.1135	0.0230	0.0059	0.0116	0.0177	0.0036	

STEP5: Using the function of pivot table in MS Excel, the length of pipe segment and the calculation result by multiplying the damage rate by the length of pipe segment (the result of Rm*Length) is summed up by gird. Then, the sum total of results of Rm*Length is divided by the total length for each grid in order to calculate grid wise damage rate by weighted average of damage rates based on the length of pipe segment.

(ii) Output

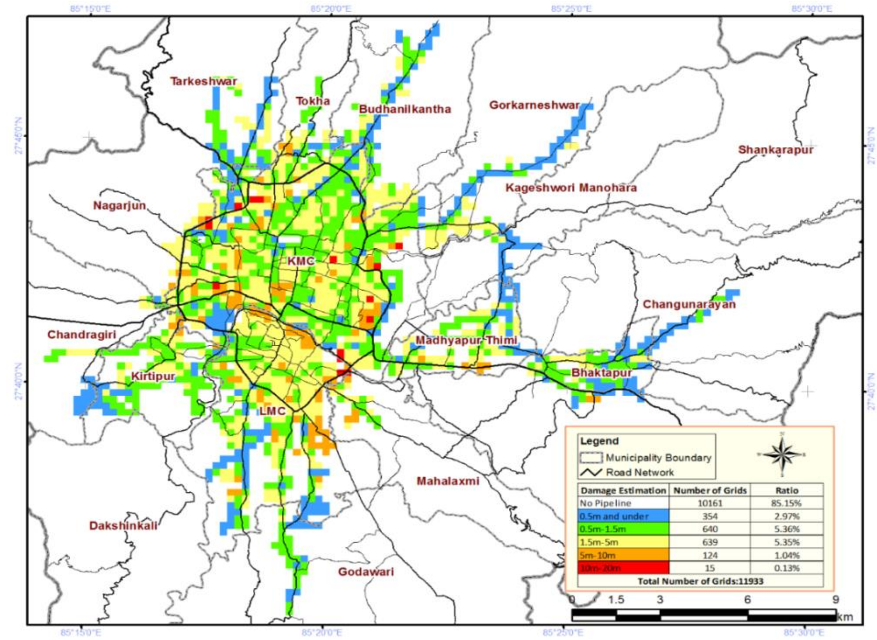
- Grid-wise damage rate of water supply network (Number of damage spot / km);

Grid Number | Grid-wise damage rate

	A	B	C	D	E	F	G	H	I	J	K
1	GridCode	Length (m)	Total / Rm*Length CNS-1	Total / Rm*Length CNS-2	Total / Rm*Length CNS-3	Total / Rm*Length WN		Grid wise Rm CNS-1	Grid wise Rm CNS-2	Grid wise Rm CNS-3	Grid wise Rm WN
2	204249	133.2	0.2104	0.3832	0.5658	0.0859		1.58	2.88	4.25	0.65
3	205249	187.1	0.2921	0.5352	0.7939	0.1177		1.56	2.86	4.24	0.63
4	205250	120.9	0.1859	0.3401	0.5034	0.0749		1.54	2.81	4.16	0.62
5	206250	278.4	0.4545	0.8310	1.2312	0.1849		1.63	2.98	4.42	0.66
6	207250	251.7	0.4546	0.8226	1.2142	0.1897		1.81	3.27	4.82	0.75
7	208241	644.2	0.1415	0.2608	0.3873	0.0535		0.22	0.40	0.60	0.08

STEP 6: After calculation of damage rate of water supply network using the calculation form, the sheet including fields of grid number and grid-wise damage rate is saved as CSV file. And then CSV file is imported to the master gird data using the Join Tool of GIS software.

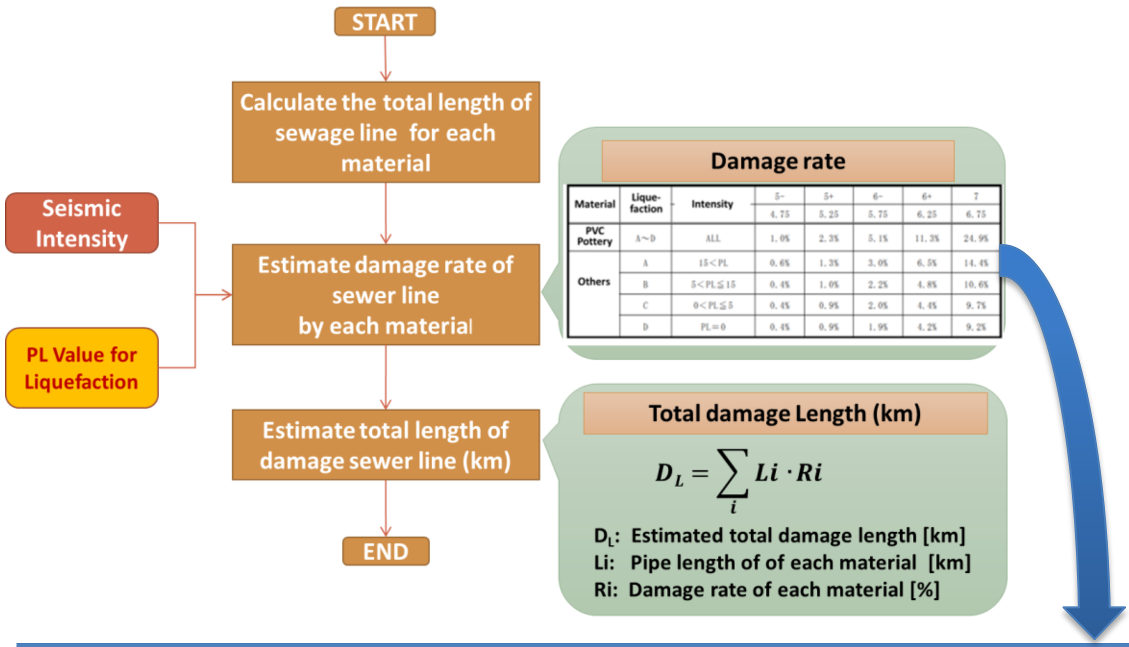
This data processing procedure is same as the procedure of damaged building distribution that was explained at STEP 9 to 11 of Section 3.1 in this document. Please refer corresponding parts.



3.5. Sewage Network Damage Assessment

(1) Method

A flow diagram of damage assessment of sewage network is shown in Figure 3.6. Estimated damage is expressed in terms of the total length of damaged pipeline. The relation between the damage rate of sewage pipeline and explanatory valuable such as liquefaction potential, intensity scale of ground motion and pipe type is shown in Figure 5.1, too. The intensity scale of ground motion was converted from PGA value by the formula proposed by Midorikawa. Liquefaction potential was referred to the PL value.



Pipe type	Liquefaction potential	JMA intensity scale / Instrumental value	5 - / 4.75	5 + / 5.25	6 - / 5.75	6 + / 6.25	7 / 6.75
PVC polyvinyl chloride・Ceramic Work Pipe	A - D	ALL	1.0%	2.3%	5.1%	11.3%	24.9%
Other than above	A	15<PL	0.6%	1.3%	3.0%	6.5%	14.4%
Other than above	B	5<PL≦15	0.4%	1.0%	2.2%	4.8%	10.6%
Other than above	C	0<PL≦5	0.4%	0.9%	2.0%	4.4%	9.7%
Other than above	D	PL=0	0.4%	0.9%	1.9%	4.2%	9.2%

Figure 3.6 Flow diagram of risk assessment of sewage network

(2) Data Processing using Calculation Form

STEP 1: Put a grid number into each segment of sewer network. First open sewer network and master grid data from spatial database using GIS software. Next, select Intersect Tool from the pulldown menu of Geoprocessing and select both layer names as input features. And then, click "OK" and start processing.

This data processing procedure is same as the procedure of joining road network and master grid data that was explained at STEP 1 of Section 3.2 in this document. Please refer corresponding parts.

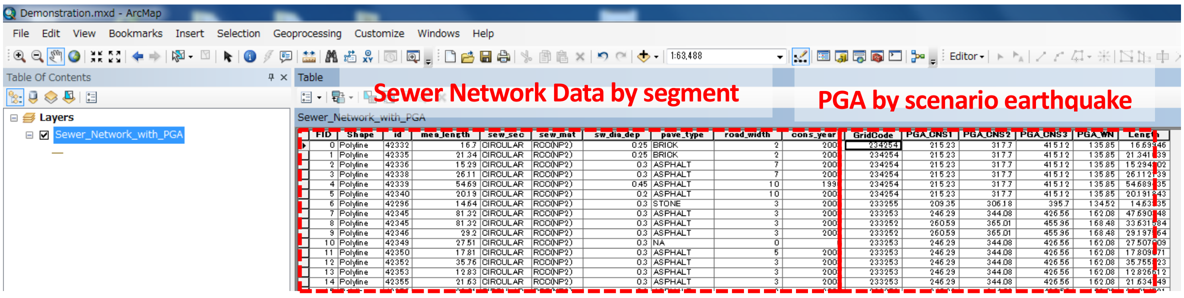
STEP2: Start integration of sewer network data and grid-wise PGA using GIS software in order to put spatially appropriate PGA value into each pipe segment of sewer network based on a grid number.

(i) Input data

- Sewer network including pipe material as attribute of pipe segment;
- Grid-wise PGA;

This data processing procedure is same as the procedure of spatial data integration of road network and grid-wise slope failure and liquefaction potential that was explained at STEP 2 of Section 3.2 in this document. Please refer corresponding parts.

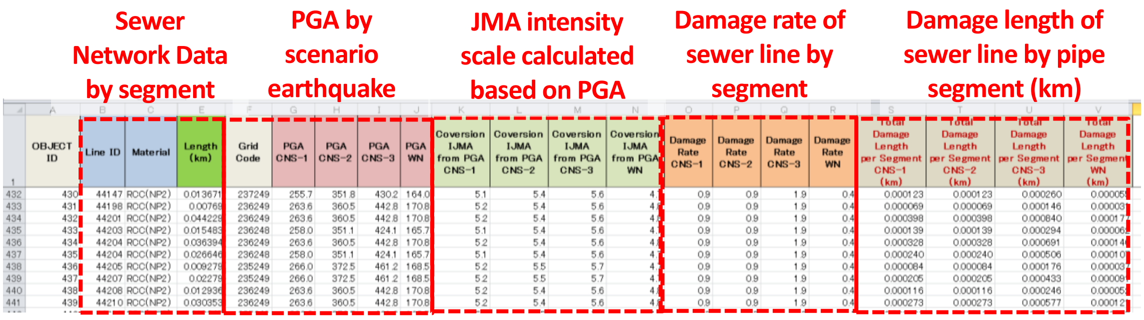
After this processing, attribute data of grid-wise PGA is transferred to sewer network data based on a grid number of pipe segment as shown in below.



STEP 3: Export this joined layer as a new spatial data. After that, open a dbf file of the new spatial data by MS Excel and copy and paste all data used for pipeline damage assessment into appropriate columns of calculation from.

STEP4: The form has several types of calculation fields in order to calculate Gird-wise damage length of sewage network (km) based on inputted data. All formula necessary for those calculations were already built based on the evaluation method.

Using following calculation form, the length of damaged sewer line (km) per pipe segment is calculated for each scenario earthquake ground motion.



STEP5: Using the function of pivot table in MS Excel, the total damage length of sewer network per grid is obtained by adding damage lengths of sewer line per pipe segment in the same grid.

(ii) Output

- Gird-wise damage length of sewage network (km);

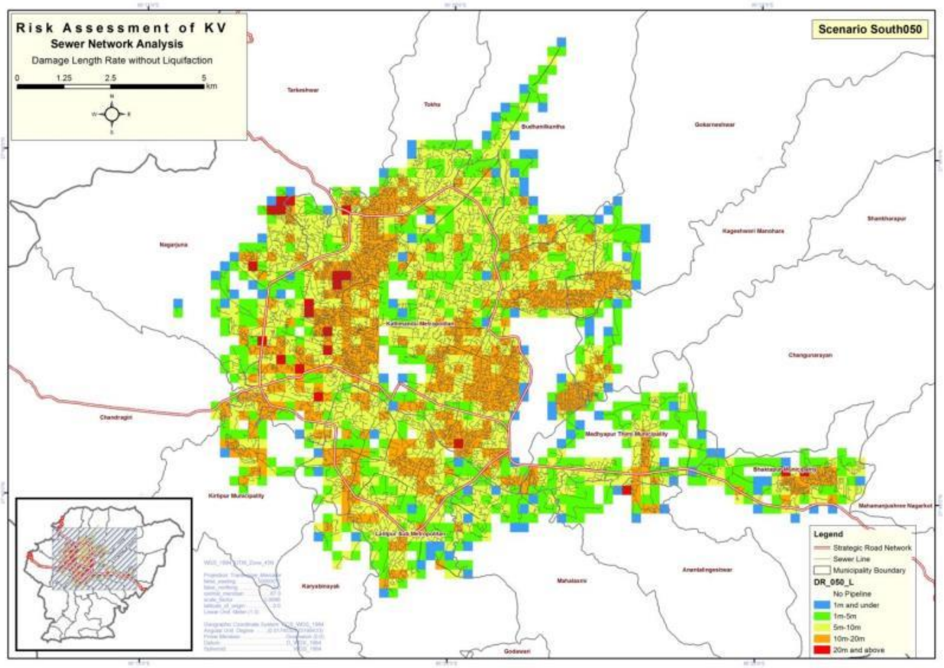
Grid Number

Grid-wise total damage length (km)

	A	B	C	D	E	F
1	Grid Code	Total Length (km)	Total Damage Length per Grid CNS-1 (km)	Total Damage Length per Grid CNS-2 (km)	Total Damage Length per Grid CNS-3 (km)	Total Damage Length per Grid WN (km)
608	237249	1.594	0.014	0.014	0.030	0.006
609	237250	0.995	0.009	0.019	0.019	0.004
610	237251	0.529	0.005	0.010	0.010	0.002
611	237252	0.235	0.002	0.004	0.004	0.001
612	237253	0.240	0.001	0.002	0.005	0.001
613	237254	0.761	0.007	0.007	0.014	0.003
614	237255	0.540	0.005	0.010	0.010	0.002
615	237256	0.280	0.003	0.003	0.005	0.001
616	237258	0.068	0.000	0.001	0.001	0.000
617	237260	0.263	0.001	0.002	0.002	0.001

STEP 6: After calculation of total damage length of sewer network per grid using the calculation form, the sheet including fields of grid number and grid-wise total damage length is saved as CSV file. And then CSV file is imported to the master gird data using the Join Tool of GIS software.

This data processing procedure is same as the procedure of damaged building distribution that was explained at STEP 9 to 11 of Section 3.1 in this document. Please refer corresponding parts.



3.6. Power Distribution Network Damage Assessment

(1) Method

A flow diagram of damage assessment of power distribution network is shown in Figure 3.7. Estimated damage is expressed in terms of the number of failure poles. Poles broken by the earthquake is divided as, the case due to ground motion and the collateral case due to the collapse of buildings in the proximity. The pole failure rate due to seismic shaking (Rs) is applied by referring to the value from a report of Japan. Regarding the intensity of ground motion (JMA intensity scale), PGA value has been referred utilizing the formula proposed by Midorikawa. Regarding the pole failure rate setting by building damage (Rb), this element means the damage due to the fact that the building is leaning against pole. This is calculated by applying the building damage rate of the relevant area of the (DL4+5) as an explanatory variable.

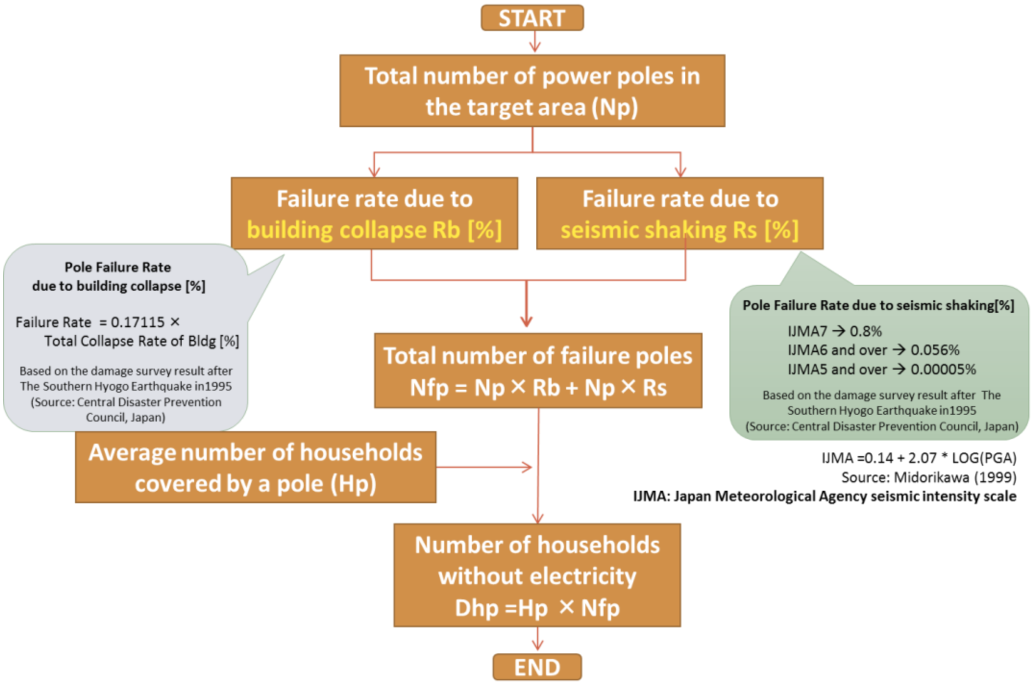


Figure 3.7 Flow diagram of risk assessment of power distribution network

(2) Data Processing using Calculation Form

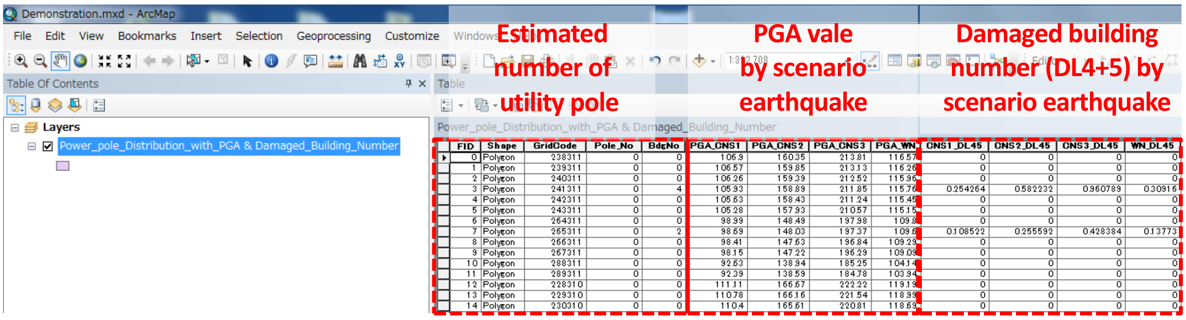
STEP1: The number of failure poles was calculated by grid that has unique Gird-Code. For preparation of input data of the table calculation using MS Excel, following spatial data should be integrated using GIS software.

(i) Input data

- Grid-wise estimated number of utility pole;
- Grid-wise PGA;
- Grid-wise estimated damaged building number (DL4+5);

This data processing procedure is same as the procedure of spatial data integration of gird-wise general building number, grid-wise predominant period and grid-wise PGA that was explained at STEP 1 to 6 of Section 3.1 in this document. Please refer corresponding parts.

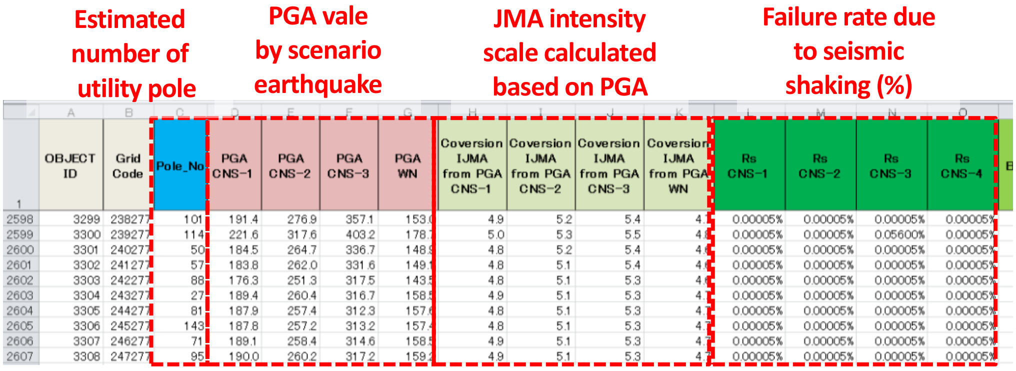
After this processing, attribute data of PGA value and estimated damaged building number (DL4+5) are transferred to grid-wise estimated number of utility pole based on a grid number as shown in below.



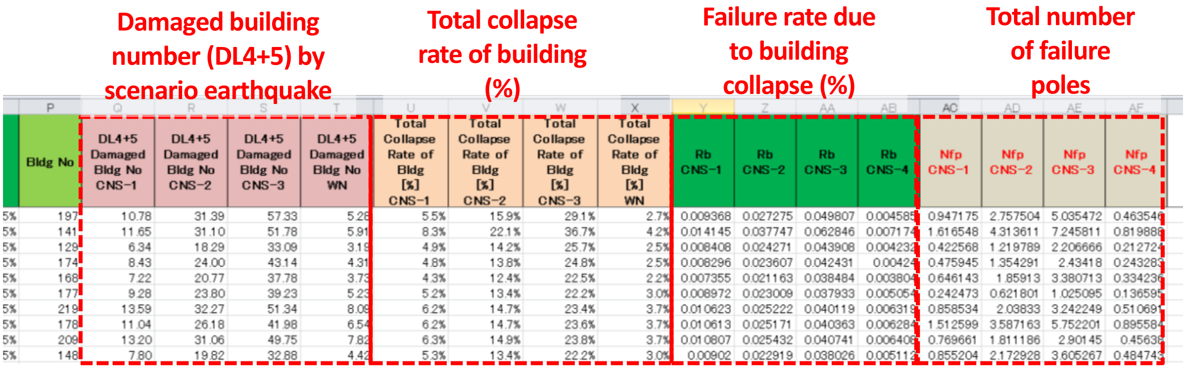
STEP 2: Export this joined layer as a new spatial data. After that, open a dbf file of the new spatial data by MS Excel and copy and paste all data used for pipeline damage assessment into appropriate columns of calculation from.

STEP3: The form has several types of calculation fields in order to calculate Gird-wise number of failure poles based on inputted data. All formula necessary for those calculations were already built based on the evaluation method.

Using following calculation form, the total number of failure poles per grid was calculated.



	OBJECT ID	Grid Code	Pole_No	PGA CNS-1	PGA CNS-2	PGA CNS-3	PGA WN	Coversion IJMA from PGA CNS-1	Coversion IJMA from PGA CNS-2	Coversion IJMA from PGA CNS-3	Coversion IJMA from PGA WN	Rs CNS-1	Rs CNS-2	Rs CNS-3	Rs CNS-4
2598	3299	238277	101	191.4	276.9	357.1	153.0	4.9	5.2	5.4	4.7	0.00005%	0.00005%	0.00005%	0.00005%
2599	3300	239277	114	221.6	317.6	403.2	178.7	5.0	5.3	5.5	4.8	0.00005%	0.00005%	0.05600%	0.00005%
2600	3301	240277	50	184.5	264.7	336.7	148.9	4.8	5.2	5.4	4.6	0.00005%	0.00005%	0.00005%	0.00005%
2601	3302	241277	57	183.8	262.0	331.6	149.1	4.8	5.1	5.4	4.6	0.00005%	0.00005%	0.00005%	0.00005%
2602	3303	242277	88	176.3	251.3	317.5	143.5	4.8	5.1	5.3	4.6	0.00005%	0.00005%	0.00005%	0.00005%
2603	3304	243277	27	189.4	260.4	316.7	158.5	4.9	5.1	5.3	4.7	0.00005%	0.00005%	0.00005%	0.00005%
2604	3305	244277	81	187.9	257.4	312.3	157.6	4.8	5.1	5.3	4.7	0.00005%	0.00005%	0.00005%	0.00005%
2605	3306	245277	143	187.8	257.2	313.2	157.4	4.8	5.1	5.3	4.7	0.00005%	0.00005%	0.00005%	0.00005%
2606	3307	246277	71	189.1	258.4	314.6	158.5	4.9	5.1	5.3	4.7	0.00005%	0.00005%	0.00005%	0.00005%
2607	3308	247277	95	190.0	260.2	317.2	159.2	4.9	5.1	5.3	4.7	0.00005%	0.00005%	0.00005%	0.00005%



Bldg No	DL4+5 Damaged Bldg No CNS-1	DL4+5 Damaged Bldg No CNS-2	DL4+5 Damaged Bldg No CNS-3	DL4+5 Damaged Bldg No WN	Total Collapse Rate of Bldg [%] CNS-1	Total Collapse Rate of Bldg [%] CNS-2	Total Collapse Rate of Bldg [%] CNS-3	Total Collapse Rate of Bldg [%] WN	Rb CNS-1	Rb CNS-2	Rb CNS-3	Rb CNS-4	Nfp CNS-1	Nfp CNS-2	Nfp CNS-3	Nfp CNS-4
197	10.78	31.39	57.33	5.28	5.5%	15.9%	29.1%	2.7%	0.009368	0.027275	0.049807	0.004585	0.947175	2.757504	5.035472	0.463546
141	11.65	31.10	51.78	5.91	8.3%	22.1%	36.7%	4.2%	0.014145	0.037747	0.062846	0.007174	1.616548	4.313611	7.245811	0.819888
129	6.34	18.29	33.09	3.19	4.9%	14.2%	25.7%	2.5%	0.008408	0.024271	0.043908	0.004232	0.422568	1.219789	2.206666	0.212724
174	8.43	24.00	43.14	4.31	4.8%	13.8%	24.8%	2.5%	0.008296	0.023607	0.042431	0.00424	0.475945	1.354291	2.43418	0.243283
168	7.22	20.77	37.78	3.73	4.3%	12.4%	22.5%	2.2%	0.007355	0.021163	0.038484	0.003804	0.64614 3	1.85913	3.380713	0.334236
177	9.28	23.80	39.23	5.23	5.2%	13.4%	22.2%	3.0%	0.008972	0.023009	0.037933	0.005054	0.242473	0.621801	1.025095	0.136595
219	13.59	32.27	51.34	8.09	6.2%	14.7%	23.4%	3.7%	0.010623	0.025222	0.040119	0.006319	0.858534	2.03833	3.242249	0.510691
178	11.04	26.18	41.98	6.54	6.2%	14.7%	23.6%	3.7%	0.010613	0.025171	0.040363	0.006284	1.512599	3.587163	5.752201	0.895584
209	13.20	31.06	49.75	7.82	6.3%	14.9%	23.8%	3.7%	0.010807	0.025432	0.040741	0.006406	0.769661	1.811186	2.90145	0.45636
148	7.80	19.82	32.88	4.42	5.3%	13.4%	22.2%	3.0%	0.00902	0.022919	0.038026	0.005112	0.855204	2.172928	3.605267	0.484743

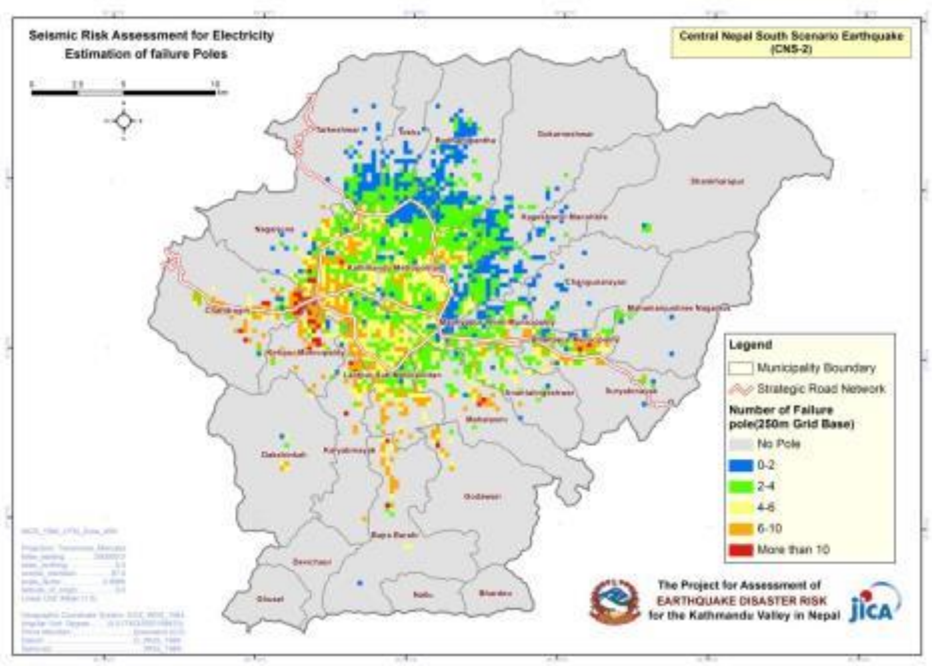
(ii) Output

- Gird-wise number of failure poles

If there is authoritative data for the average number of households covered by a pole (Hp), the number of households without electricity will be estimated by multiplying the number of failure poles by the average number of households covered by a pole.

STEP 4: After calculation of gird-wise number of failure poles using the calculation form, the sheet including fields of grid number and number of failure poles is saved as CSV file. And then CSV file is imported to the master gird data using the Join Tool of GIS software.

This data processing procedure is same as the procedure of damaged building distribution that was explained at STEP 9 to 11 of Section 3.1 in this document. Please refer corresponding parts.



3.7. Mobil Base Transceiver Station (BTS) Damage Assessment

(1) Method

The damage of BTS tower is estimated by its damage function for ground based tower and the combination of building and tower damage for rooftop tower, which means the tower can only maintain its function under the condition that both building and tower are not subjected to damage, illustrated in Figure 3.8.

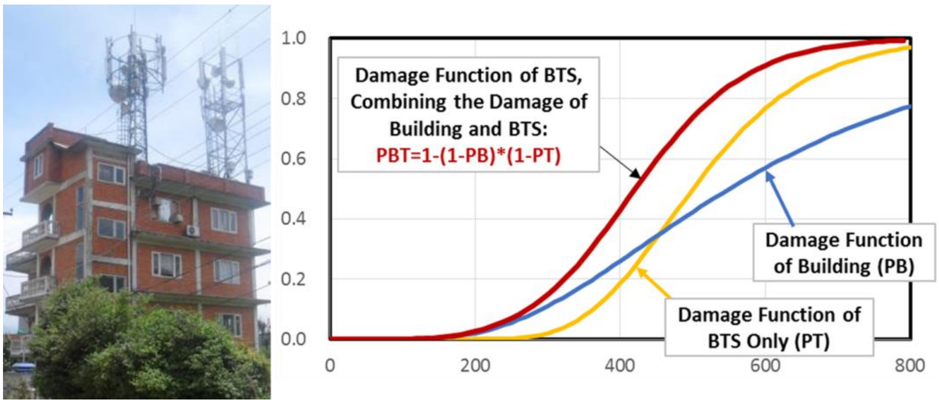


Figure 3.8 Damage function of BTS tower

(2) Calculation Form

(i) Input data

- PGA of each BTS site
- Predominant period of each BTS site
- Tower type
- Building structure type

Input PGA, predominant period of the grid, where BTS locates, and BTS and building type

Input for PGA, predominant period of site, tower type and building structure type									
PGA					Predominant Period of Site			Tower_Type	Bldg_Type
PGA_Gorkha	PGA_WN	PGA_CNS-1	PGA_CNS-2	PGA_CNS-3	Predo_period	Center	Perimeter		
137.2	151.06	291.58	437.36	583.16	0.27	0.27	0	GBT	
113.83	132.88	252.42	381.26	507.9	0.83	0	0.83	GBT	
87.62	109.5	200.54	300.81	401.08	0.03	0.03	0	GBT	
107.03	115.7	215.66	324.15	438.78	0.09	0.09	0	Roof Top	Non-Engineered
111.65	125.83	230.99	349.87	460.39	1.43	0	1.43	GBT	

(ii) Calculation and output

- Probability of BTS damage

Probability of BTS tower damage

Combined probability of BTS facility, including building and tower

Probability of building damage

PGA - CNS-1									
Damage Ratio of Building (Pb)				Damage Ratio of BTS Tower (Pt)	■ Damage Ratio of BTS facility (Pbt = 1-(1-Pb)×(1-Pt))				
Non Engineered		Engineered			Rooftop				Ground
Center	Perimeter	Center	Perimeter		Non Engineered		Engineered		
RC1	RC1	RC2	RC2		Center	Perimeter	Center	Perimeter	
0	0	0	0	0.017919809	0	0	0	0	0.017919809
0	0	0	0	0.00372953	0	0	0	0	0.00372953
0	0	0	0	0.000161608	0	0	0	0	0.000161608
0.1051768	0	0	0	0.000474564	0.1056014	0	0	0	0
0	0	0	0	0.001220737	0	0	0	0	0.001220737

- Expected number of BTS damage

Summation of probabilities of all BTS

PGA-CNS-1									
Damage of Building				Damage of BTS Tower	■ Damage of BTS facility				
Non Engineered		Engineered			Rooftop				Ground
Center	Perimeter	Center	Perimeter		Non Engineered		Engineered		
RC1	RC1	RC2	RC2		Center	Perimeter	Center	Perimeter	
39.77844161	16.00960558	6.247702104	0.742412003	1.878000842	40.43352652	16.43658413	6.441086888	0.781561997	0.067433049

3.8. Human Casualty Assessment

(1) Method

Number of death was estimated in term of the number of heavily damaged building, population per building and the inside building ratio of population when earthquake occurs. The formula for the estimation of death is

Number of death = Death rate * (Number of heavily damaged building
* Population per building
* Ratio of population inside building)

Death rate was calculated for masonry and RC buildings and for damage levels of 4 and 5 (noted as heavy damage), respectively from the building damage data and death number of Gorkha earthquake. However, since building damage function was created for damage level 4 and 5 collectively, it cannot have the direct result of building damage for damage level 4 and 5 separately. For the purpose of easy update in the future, the death will be estimated by means of the total number of building with heavy damage.

Injured was estimated from the relationship between death and injured.

Number of injured = Injured rate * Number of death

The number of evacuee, who need temporary house after an earthquake, was considered as the number of people whose residence suffered moderate (damage level 3) or heavy damage (damage level 4 and 5) due to earthquake.

No. of evacuee = Population of building with moderate and heavy damage - Number of death

(2) Flowchart

Flowchart for the estimation of death, injured and evacuee is illustrated in Figure 3.9.

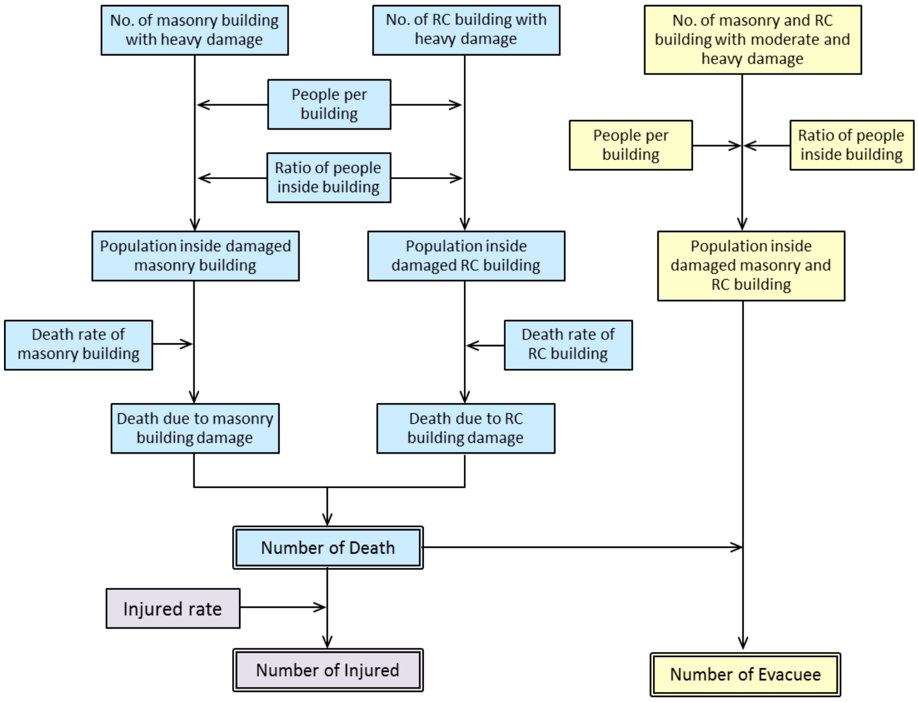


Figure 3.9 Flowchart for the estimation of death, injured and evacuee

(3) Input Data

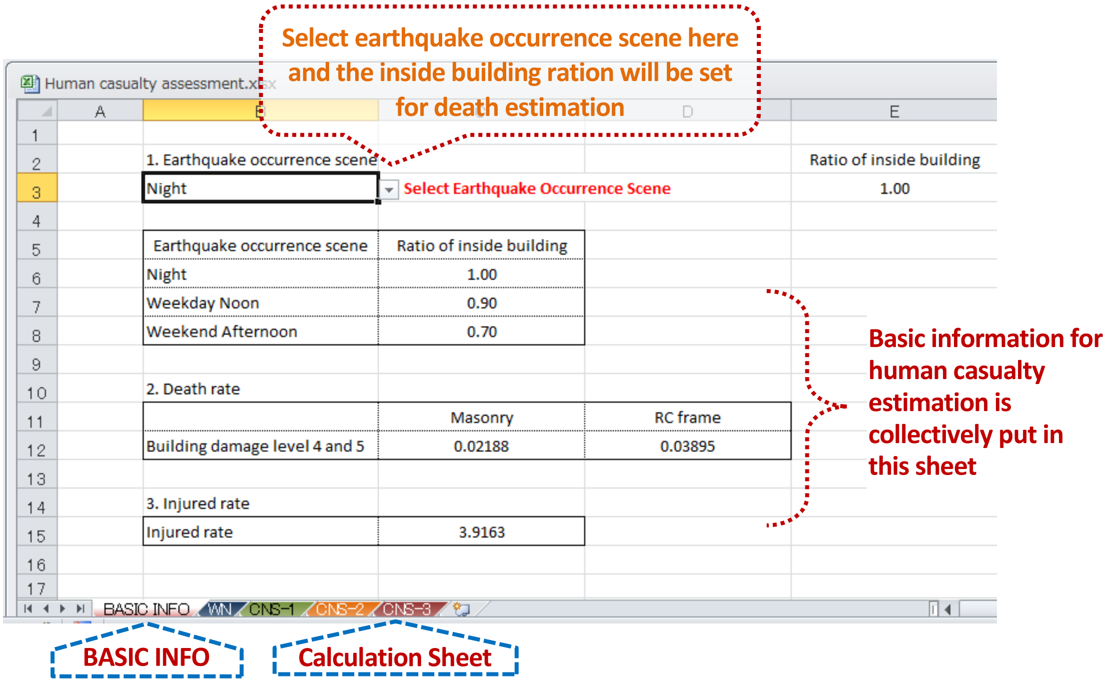
Human casualty is estimated in the unit of ward, the input required for the calculation is:

- Ward-wise population in night time
- Ward-wise population in daytime
- Ward-wise total number of building
- Ward-wise number of building with heavy damage (DL45)
- Ward-wise number of building with moderate and heavy damage (DL345)
- Death rate
- Injured rate
- Earthquake occurrence scene (inside building ratio)

(4) Calculation Form

Calculation form consists of two kinds of sheets: one for basic information and another for calculation.

Basic information sheet: Giving death rate, injured rate, inside building ratio and selection of occurrence scene.



Calculation sheet: Input ward-wise population and building damage data and calculate death, injured and evacuee.

Human casualty assessment.xlsx

Input population of night and daytime and building number here, the population per building will be calculated

Earthquake Occurrence Scene: Night

Municipality / Ward	Municipality / Ward	Population (night)	Population (daytime)	No. of Building	people per building
Anantalingeshwar	1	43,699.05	29,199.34	8,936.26	4.89
1	0	4,490.96	3,000.82	527.19	8.52
2	0	3,425.10	2,288.62	1,002.67	3.42
3	0	3,505.78	2,342.53	988.46	3.55
4	0	2,026.99	1,354.42	330.33	6.14
5	0	5,799.40	3,875.11	747.64	7.76

Human casualty assessment.xlsx

Input building damage of EMS DL345 for each structure type, estimated from building damage assessment

CNS-3: Estimated Dmage Building Number for DL345										
Adobe	SMM	BMM 1	BMM 2	BMM 3	SCM	BCM	RC N Eng	RC Eng	Others	total
260.32	130.05	410.71	299.55	117.58	17.11	1,656.21	2,654.36	427.48	150.62	6,123.99
4.97	2.53	19.46	8.93	5.90	0.49	90.94	179.55	22.73	5.72	341.23
10.10	5.34	32.31	19.05	10.33	1.13	155.50	346.22	54.99	11.95	646.92
9.28	4.81	31.58	17.88	10.12	1.03	154.71	344.56	52.25	11.46	637.67
6.89	3.86	15.66	10.07	4.50	0.65	62.59	97.10	16.03	5.10	222.46
5.75	3.15	22.16	13.46	7.50	0.80	119.25	300.58	52.05	8.81	533.51

Human casualty assessment.xlsx

Input building damage of EMS DL45 for each structure type, estimated from building damage assessment

CNS-3: Estimated Dmage Building Number for DL45									
Adobe	SMM	BMM_1	BMM_2	BMM_3	SCM	BCM	RC_N_Eng	RC_Eng	Others
252.0200	119.8627	380.6567	256.9337	101.4057	13.7615	1339.1722	1903.3062	277.4539	120.9024
4.8620	2.3791	18.0817	7.7144	5.0632	0.3989	72.0697	124.5520	14.1591	4.5521
9.8585	4.9843	29.9494	16.3718	8.8341	0.9015	123.2221	241.3887	34.3865	9.5165
9.0668	4.5080	29.4016	15.4461	8.7227	0.8332	124.0290	243.0318	33.1497	9.1700
6.7387	3.6259	14.5726	8.7584	3.8785	0.5281	50.2744	68.0288	10.0828	4.1369
5.6212	2.9542	20.8478	11.8518	6.6124	0.6545	98.1363	223.8373	35.0366	7.2544

Human casualty assessment.xlsx

Calculation conditions are showing here

	Masonry	RC frame
Death rate	0.02188	0.03895
Injured rate	3.9163	3.9163
Inside ratio	1.0000	1.0000

Estimated results of death, injured and evacuee are expressed here

Total		Death		Injured		Results		
Masonry	RC	Masonry	RC	Masonry	RC	Death	Injured	Evacuee
2,584.71	2,180.76	276.55	415.37	1,083.06	1,626.71	691.92	2,709.77	29,255
115.12	138.71	21.46	46.03	84.03	180.25	67.48	264.28	2,839
203.64	275.78	15.22	36.69	59.61	143.70	51.91	203.31	2,158
201.18	276.18	15.61	38.15	61.14	149.42	53.76	210.56	2,208
92.51	78.11	12.42	18.67	48.64	73.11	31.09	121.76	1,334
153.93	258.87	26.13	78.21	102.32	306.31	104.34	408.63	4,034

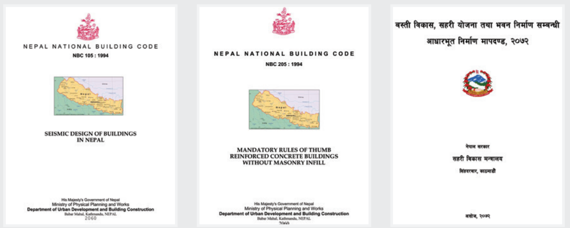
REMARKS: Scenario earthquake is not the prediction of future earthquake. Damage assessment was carried out based on scientific research and investigation results but with inevitable assumptions. Its results might have uncertainties and are not the guarantee of the future damage of scenario earthquake. The purpose of damage assessment is to provide basic information for the development of policy and plan for disaster risk reduction.

DISASTER RISK REDUCTION (DRR)

Are you planning to build a new house?

Follow Building Code and Byelaws:

Construction of buildings following National Building Code, byelaws and proper construction technique ensures minimal damage to houses. It is one of the most affordable intervention for reducing death and injury.



Images of NBC, Byelaw

Images of Retrofitting Guidelines

Is your house strong enough against earthquake?

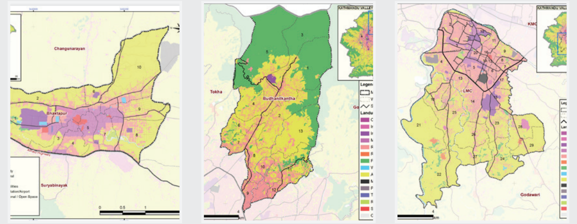
Seismic Strengthening of Existing Building:

Majority of existing buildings are vulnerable to earthquake. Seismic diagnosis and retrofitting of the existing structures should be carried to ensure safety of your house.

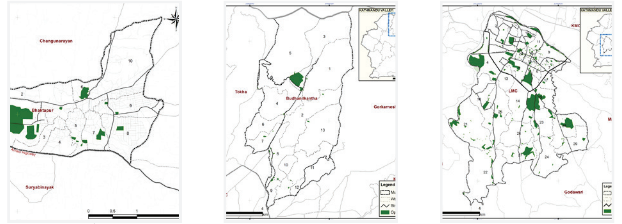
Is your house in appropriate location?

Construct Structures as per Land Use Policy & Zoning:

Construction of any structure in hazard prone areas should be forbidden. Countermeasures should be strictly implemented if unavoidable. Haphazard construction and urbanization without following land use policy and zoning should be strictly prohibited.



Images of Land Use



Images of Open Spaces

Where would you go if an earthquake occurs?

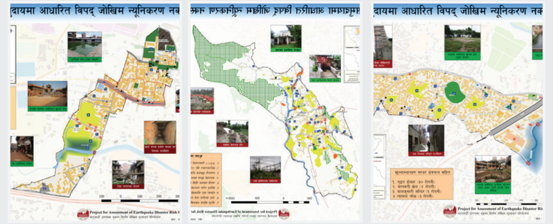
Conservation of Open Spaces:

Open spaces are of great value both during and after earthquake. Conservation of open spaces should be promoted in order to ensure adaptable evacuation spaces.

How will you support your neighborhood in case of a disaster?

Disaster Risk Awareness and Management:

People living in community should be made aware about disaster risk in their neighbourhood and measures of disaster risk reduction and management. Knowledge sharing among communities is important for effective response and use of tools, equipment and skills during before, and after disaster.



Images of DRR Carte

OUTLINE AND ACCOMPLISHMENT OF THE PROJECT

The Project for Assessment of Earthquake Disaster Risk for the Kathmandu Valley is supported by JICA with an overall aim to reduce the earthquake disaster risk through effective and sustainable measures based on the disaster risk assessment. The project is spanned for a duration of three years, commencing in April 2015 and concluding by April 2018.

The main objective of the project is to implement the earthquake risk assessment for future scenario earthquakes considering the effects and situation created after the Gorkha Earthquake, and to develop local disaster and climate resilience plan (LDCRP) for effective promotion on disaster risk management against future earthquakes.

The main counterparts of this project are Ministry of Urban Development (MoUD), Ministry of Home Affairs (MoHA), Ministry of Federal Affairs and Local Development (MoFALD) and Department of Mines and Geology (DMG), while, the three municipalities – Lalitpur Metropolitan City, Bhaktapur Municipality and Budhanilkantha Municipality are the target local governments for the pilot activities of the project.

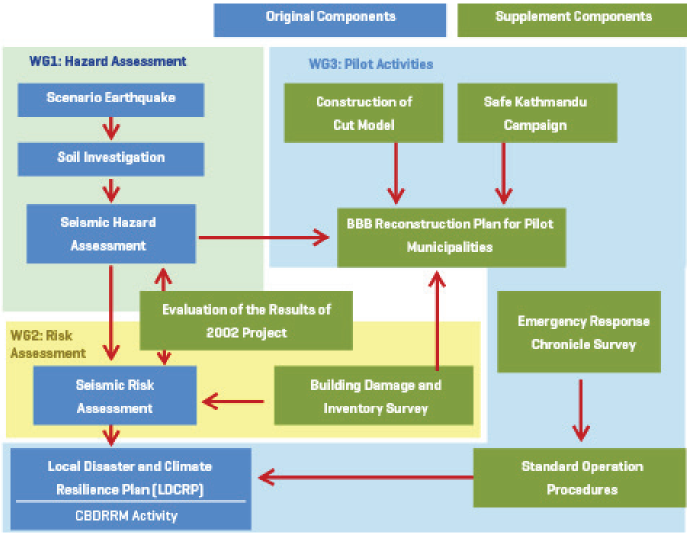
The major accomplishments of this project are:

· Seismic hazard assessment of Kathmandu Valley

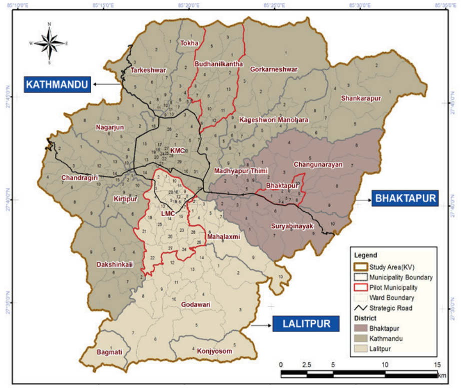
· Seismic risk assessment of Kathmandu Valley

· Development of Build Back Better (BBB) Recovery and Reconstruction Plan, Local Disaster and Climate Resilience Plan (LDCRP), Standard Operation Procedures (SOP) and Community Based Disaster Risk Reduction and Management (CBDRRM) activities for 3 pilot municipalities

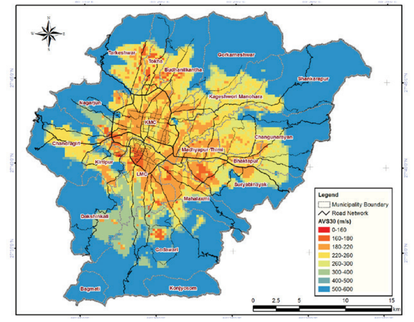
· Development of Technical Guideline for formulation of Local Disaster and Climate Resilience Plan (LDCRP) for all local levels in Nepal,



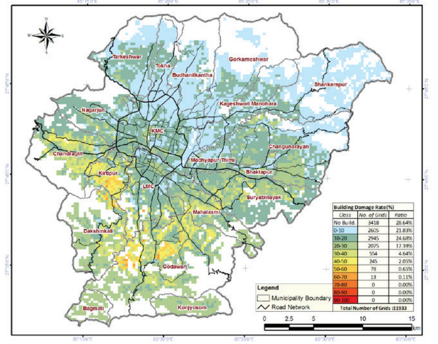
Project Components



Project study area



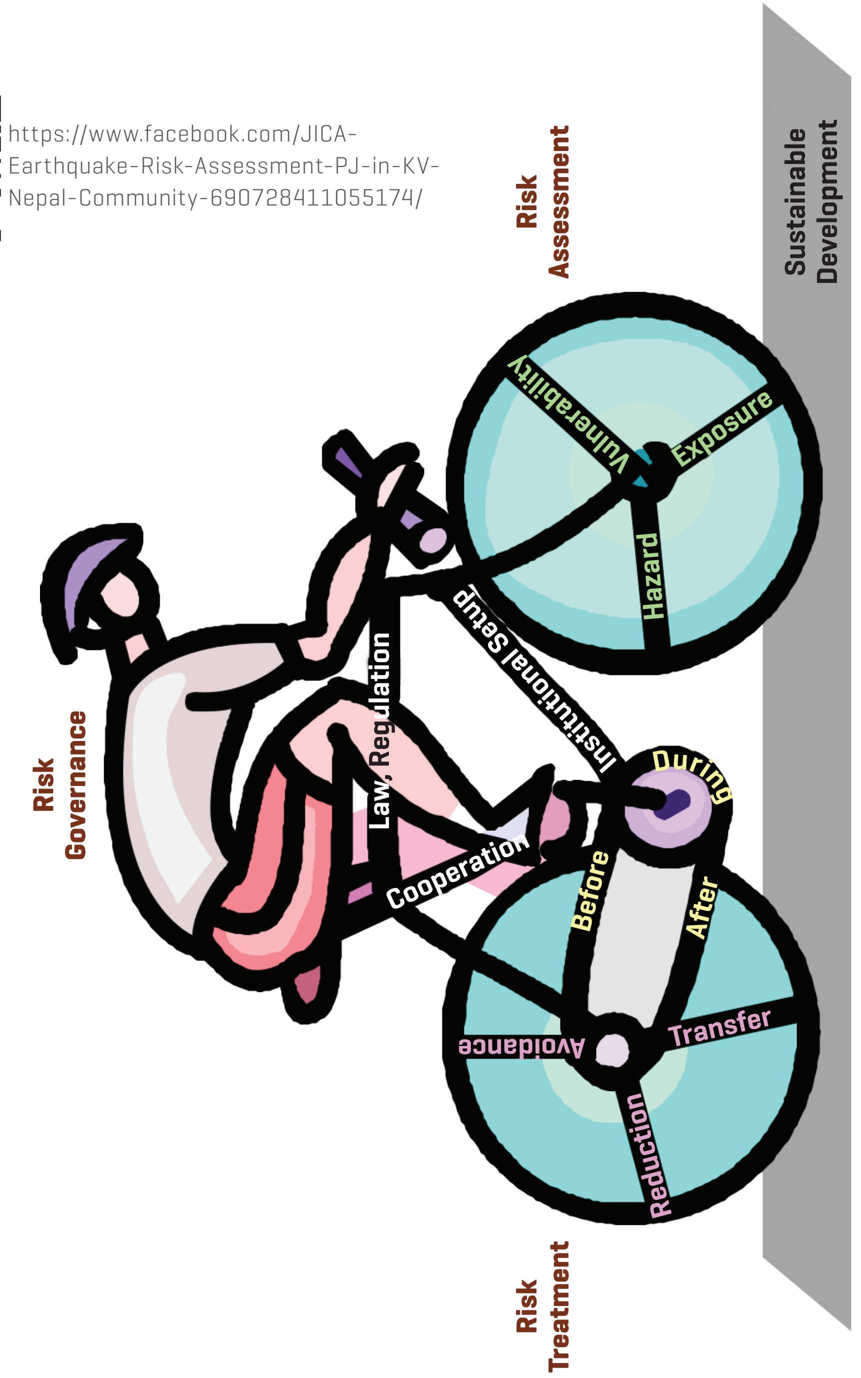
Ground model



Heavily Damaged Building Ratio

LDCRP Technical Guideline and DCR Plan

https://www.facebook.com/JICA-Earthquake-Risk-Assessment-PJ-in-KV-Nepal-Community-690728411055174/



Government of Nepal
Ministry of Urban Development
Ministry of Home Affairs
Ministry of Federal Affairs and Local Development
Department of Mines and Geology

Japan International Cooperation Agency

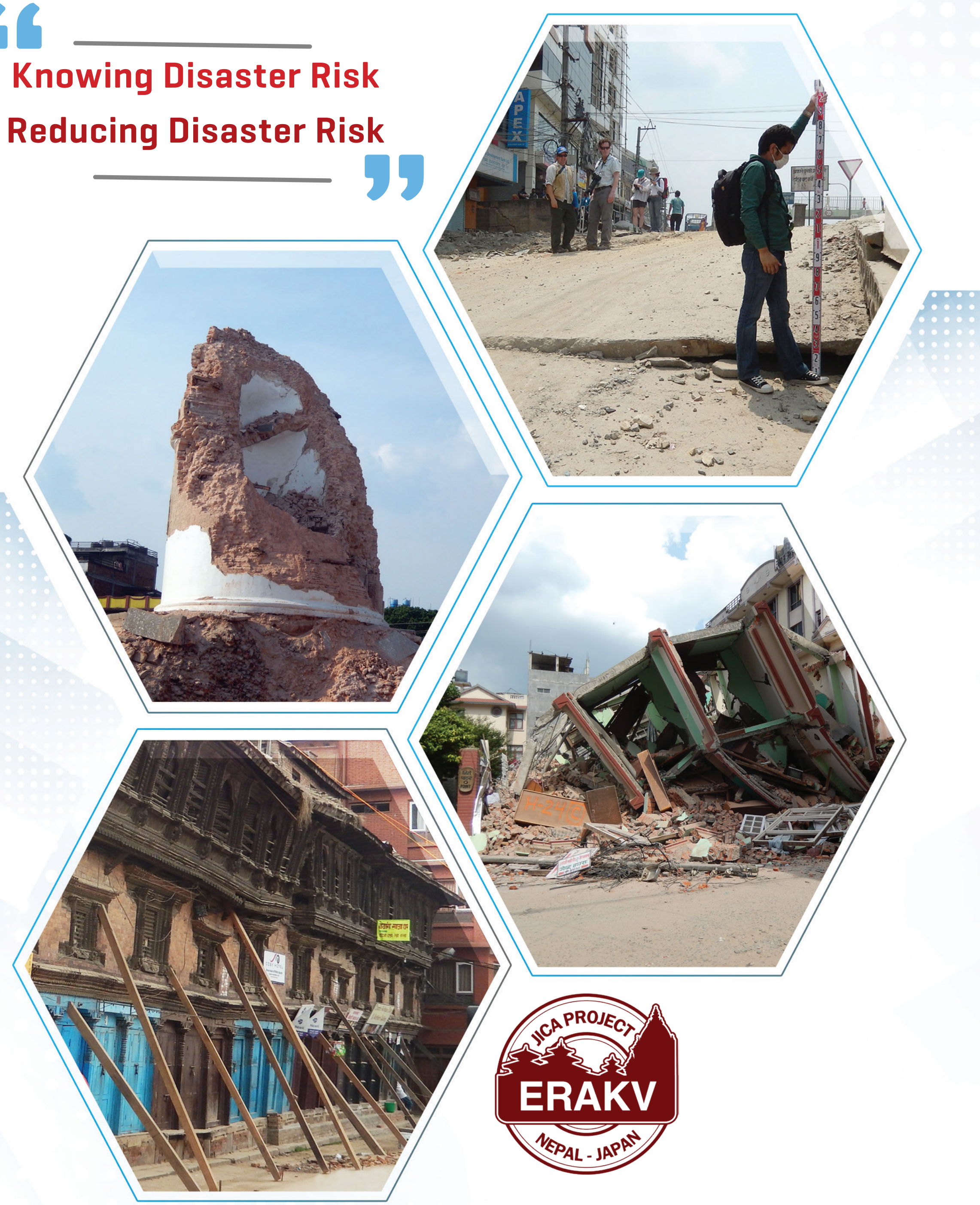
The Project for Assessment of
EARTHQUAKE DISASTER RISK
for the Kathmandu Valley in Nepal

The Project For Assessment of

EARTHQUAKE DISASTER RISK

for the Kathmandu Valley in Nepal

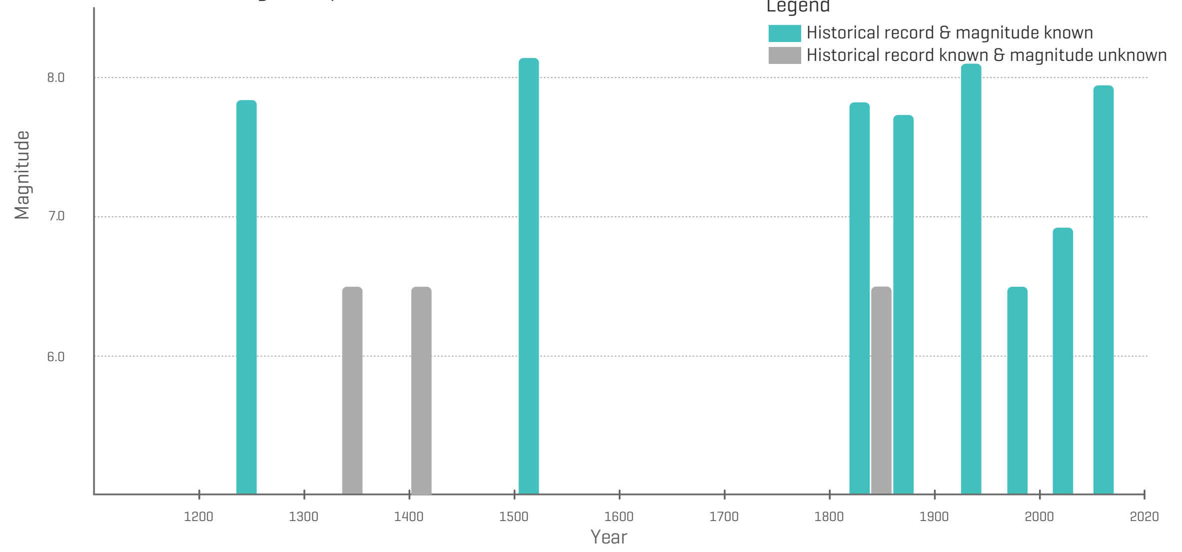
**“Knowing Disaster Risk
Reducing Disaster Risk”**



ERAKV
JICA PROJECT
NEPAL - JAPAN

EARTHQUAKE CAN OCCUR IN FUTURE

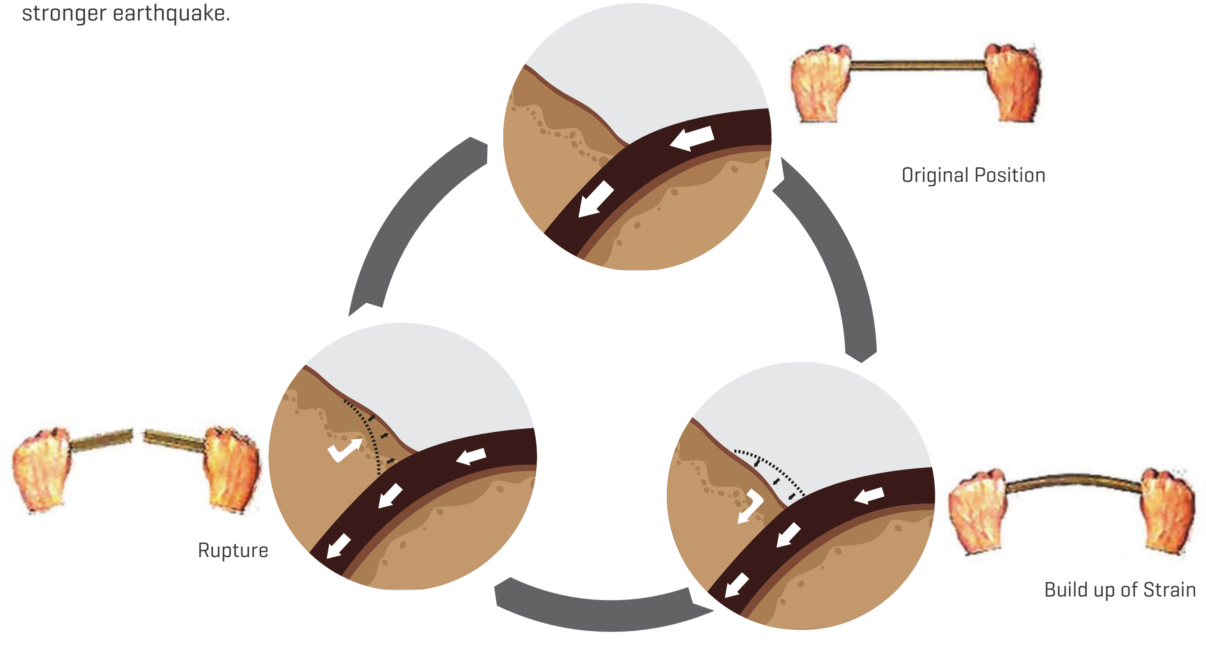
Nepal and its surrounding region are situated on one of the most seismically active zones in the world. Several destructive earthquakes dating back to 13th century have been revealed by the information from historical literatures and trenching survey.



Historical Destructive Earthquakes in Nepal

Source: Ambraseys and Douglas (2004), Bilham and Ambraseys (2005), Bilham et al. (1995), Szeliga et al. (2010), UNDP (2013)

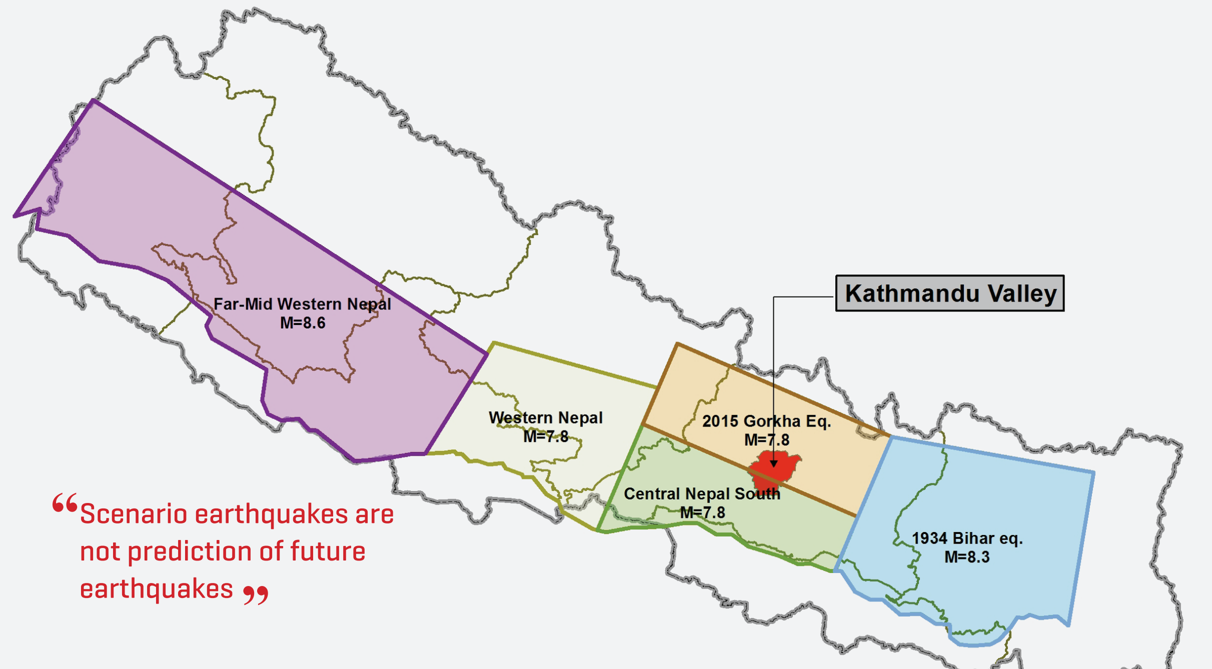
Almost all the territory of Nepal is located above the Main Himalayan Thrust zone, the plate boundary where Indian Plate subducts underneath the Eurasian Plate. Due to the movement of the plates, they deform at the boundary and rebound when deformation reaches its threshold. This phenomenon causes earthquake to occur repeatedly and a longer time gap leads to an increased strain build-up, thus increased amount of energy release in form of a stronger earthquake.



Earthquake Occurrence Mechanism

SCENARIO EARTHQUAKES

Three scenario earthquakes: Far-Mid Western Nepal, Western Nepal and Central Nepal South, are proposed for the purpose of estimation of seismic risk and development of local disaster and climate resilience plan for Kathmandu Valley. Scenario earthquakes are technical assumption of possible earthquakes based on the studies of historical earthquakes, recent seismicity, tectonics and active faults.



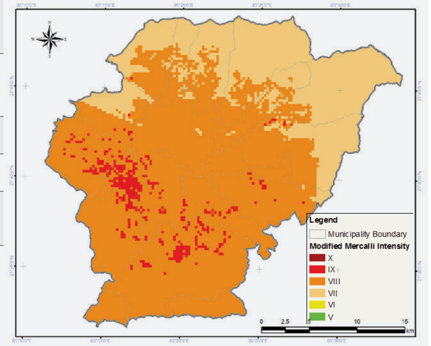
“Scenario earthquakes are not prediction of future earthquakes”

Location Area of Scenario Earthquake

Ground shaking intensity varies with the magnitude of earthquake and the distance from the source to the site. The intensity of Western Nepal Scenario Earthquake is approximately the same as that of Gorkha earthquake, while Central Nepal South Scenario Earthquake causes stronger shaking than Gorkha earthquake. Three possible ground shaking intensities for Central Nepal South Scenario Earthquake (CNS-1, CNS-2 and CNS-3) have been proposed based on the different considerations on the attenuation of Gorkha earthquake. Among them, it is recommended that CNS-1 is applied for disaster risk reduction of general buildings and CNS-2 for critical facilities such as school, hospital, government buildings as well as infrastructure and lifeline.

Scenario Earthquakes		PGA Range (gal)	Strength	Comparison with Gorkha Eq shaking level
Far-Mid Western Nepal (M=8.6)		71-216	weak	Very Small comparing with other scenarios
Western Nepal (WN) (M=7.8)		91-303		Approximately same
Central Nepal South (CNS) (M=7.8)	CNS-1	91-519		Approximately 1.5 times
	CNS-2	136-777		Approximately 2 times
	CNS-3	181-1055	Strong	Approximately 2.75 times

Comparison of Scenario Earthquakes with Gorkha Earthquake



Modified Mercalli Intensity (MMI) distribution-CNS-2

DAMAGE ESTIMATE FOR KATHMANDU VALLEY (Case CNS-2)

BUILDING

General Building Damage

Slight	Moderate	Heavy
77,713 (17.5%)	62,691 (14.1%)	136,060 (30.6%)

Out of 444,554

Health Facility Damage

Slight	Moderate	Heavy
105 (18.0%)	83 (14.2%)	153 (26.2%)

Out of 584

School Building Damage

Slight	Moderate	Heavy
1,057 (18.4%)	810 (14.1%)	1,654 (28.9%)

Out of 5,731

Government Building Damage

Slight	Moderate	Heavy
85 (17.8%)	66 (13.8%)	126 (26.4%)

Out of 478

HUMAN CASUALTY

Case of Earthquake occurrence at midnight

22,180 Dead (0.80%)	86,860 Injured (3.12%)	1,196,080 Evacuees (42.92%)

Out of 2,786,929

LIFE LINE

Water Supply (Existing)

3,496 Damage points
Out of 1,167 km

Water Supply (Planned)

460 Damage points
Out of 699 km

Sewage

11.9 km
Damage length (1.0%)

Out of 1,192 km

Power Distribution

9,156
Broken Electricity Pole (4.8%)

Out of 190,851 Poles

Mobile BTS Tower

372
Tower Damage (35.7%)

Out of 1,043

INFRASTRUCTURE

Bridge Damage
(RC Sub-structure)

Slight: 6 (13.3%)
Moderate: 27 (60 %)
Heavy: 12 (26.7%)

RC= Reinforced Concrete
Out of 45

Road Damage
Susceptibility

By landslide	By Liquefaction
98.5 km (1.7%)	274.9 km (4.7%)

Out of 5,811 km

DIRECT ECONOMIC LOSS

(Million NPR)

Buildings	Infrastructure & life line
761,534	4,144

Total Economic loss = 765,675

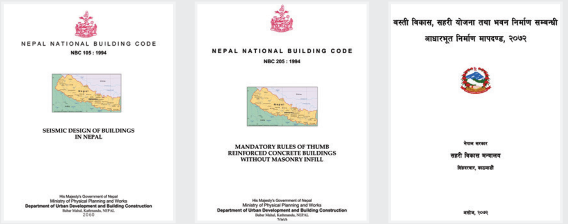
Damage estimation is based on available data with some assumptions, therefore, actual damage might not be exactly as above.

विपद् जोखिम न्यूनीकरण

के तपाई नयाँ घर निर्माण गर्दै हुनुहुन्छ ?

भवन संहिता तथा मापदण्ड पालना गरौं :

राष्ट्रिय भवन संहिता, मापदण्ड तथा उचित निर्माण प्रविधिको पालना गरी भवन निर्माण गर्नाले घरमा न्युनतम क्षति हुन्छ। जीवन रक्षा र मानवीय क्षति न्यूनीकरणको लागि यो सबैभन्दा कम खर्चमा गर्न सकिने उपाय हो।

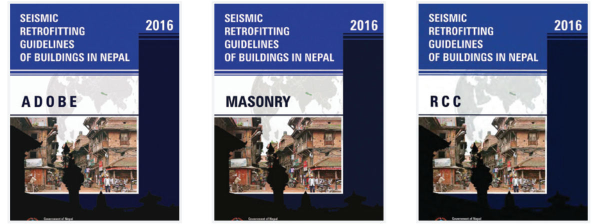


राष्ट्रिय भवन संहिता र मापदण्ड

के तपाईंको घर भूकम्प प्रतिरोधी छ ?

विद्यमान घरहरूको भूकम्पीय प्रबलीकरण गर्नै :

अधिकांश निर्मित भवनहरू भूकम्प सङ्कटासन्न रहेको अवस्था छ। विद्यमान भवन संरचनाहरूको नियमित भूकम्पीय विश्लेषण र प्रबलीकरण गरी हाम्रो जीवनको सुरक्षा सुनिश्चित गर्न अपरिहार्य छ।

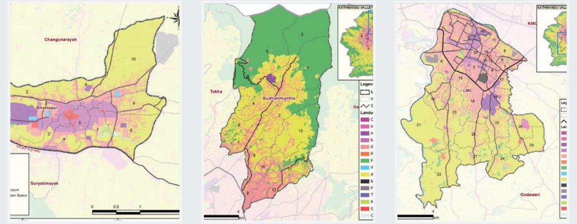


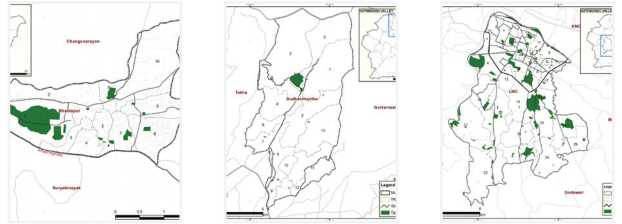
भूकम्पीय प्रबलीकरण निर्देशिका

के तपाईले घर उचित स्थानमा बनाउनु भएको छ ?

भू-उपयोग नीति तथा योजना अनुसार संरचना निर्माण गरौं :

प्रकोपोन्मुख क्षेत्रमा कुनै पनि संरचना निर्माण गर्न निषेध गर्नुपर्दछ। अपरिहार्य अवस्थामा प्रत्युपायहरू कडा रूपमा पालना गरी निर्माण गर्नुपर्दछ। भू-उपयोग नीति र योजनाको पालना नगरी अव्यवस्थित निर्माण तथा सहरीकरणमा प्रतिबन्ध लगाउनु पर्दछ।


भू-उपयोग नमूना नक्सा


खुला स्थलहरुको नमूना नक्सा

भूकम्प गएको अवस्थामा तपाई कहाँ जानुहुन्छ ?

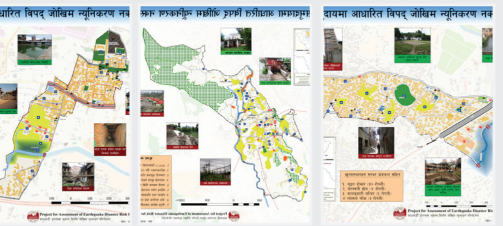
खुला स्थलहरुको संरक्षण :

भूकम्प गएको समय र भूकम्प पश्चातको समय दुवैमा खुला स्थलहरुको धेरै महत्व हुन्छ। अनुकूलित आश्रय स्थलको सुनिश्चितताको लागि खुला स्थलहरुको संरक्षण तथा संवर्द्धनलाई प्रोत्साहन गर्नुपर्दछ।

विपद्को अवस्थामा तपाईले आफ्नो समुदायलाई कसरी सहयोग पुऱ्याउनु हुन्छ ?

विपद् जोखिम जनचेतना र व्यवस्थापन :

कुनै पनि समुदायमा त्यहाँका बासिन्दा विपद् जोखिम र त्यसको न्यूनीकरण तथा व्यवस्थापनका तरिकाहरुको बारेमा सचेत रहनु पर्दछ। विपद् पूर्व, विपद्को समयमा र विपद् पश्चात् प्रभावकारी प्रतिकार्य र स्रोतसाधन तथा सीपको उचित प्रयोग गर्नको लागि समुदायहरू बीच ज्ञान र जानकारीको आदानप्रदान हुनु अत्यावश्यक हुन्छ।


DRR Carte

परियोजनाको रूपरेखा र उपलब्धि

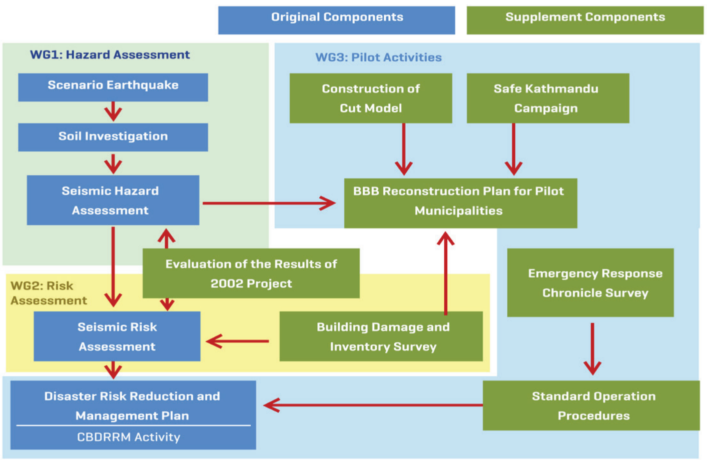
"काठमाडौं उपत्यका भूकम्प विपत्ति जोखिम मूल्याङ्कन परियोजना" JICA को सहयोगमा कार्यान्वयन भएको परियोजना हो। विपद् जोखिम विश्लेषणको आधारमा प्रभावकारी तथा दिगो उपायहरू प्रयोग गरी विपद् जोखिम न्यूनीकरण गर्नु यसको मुख्य उद्देश्य रहेको छ। ३ वर्ष समयावधि रहेको यस परियोजनाको प्रारम्भ २०७२ वैशाखमा भएको थियो भने २०७५ वैशाखमा समापन हुनेछ।

गोरखा भूकम्पको प्रभाव र त्यसबाट श्रृजित अवस्थालाई ध्यानमा राखी भविष्यमा आउन सक्ने परिदृश्य भूकम्पहरूको लागि भूकम्पीय जोखिम विश्लेषण गर्ने र विपद् जोखिम व्यवस्थापनका प्रभावकारी संर्वधनको लागि स्थानीय विपद् तथा जलवायु उत्थानशील योजना तर्जुमा गर्ने यस परियोजनाको मुख्य लक्ष्य रहेको छ।

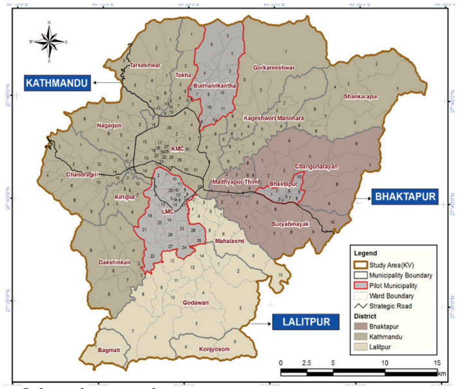
यस परियोजनाको नेपाल सरकारका तर्फबाट प्रमुख समकक्षीको रूपमा सहरी विकास मन्त्रालय, गृह मन्त्रालय , संघीय मामिला तथा स्थानीय विकास मन्त्रालय र खानी तथा भूगर्भ विभाग रहेका छन् भने ललितपुर महानगरपालिका , भक्तपुर नगरपालिका र बुढानिलकण्ठ नगरपालिका परियोजनाको पाइलट गतिविधिका लागि लक्षित ३ वटा पाइलट नगरपालिका हुन्।

यस परियोजनाका मूख्य उपलब्धिहरू निम्नानुसार छन् :

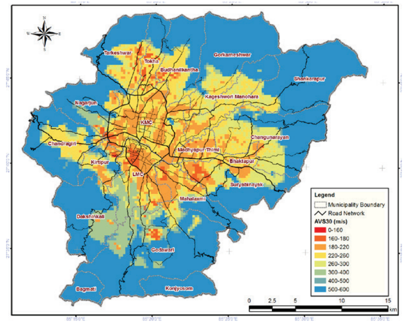
- काठमाडौं उपत्यकाको भूकम्पीय प्रकोप मूल्याङ्कन
- काठमाडौं उपत्यकाको भूकम्पीय जोखिम मूल्याङ्कन
- ३ वटा पाइलट नगरपालिकाहरूको लागि "अझ राम्रो र बलियो (Build Back Better – BBB) पुनर्निर्माण योजना" , "स्थानीय विपद् तथा जलवायु उत्थानशील योजना", "आधारभूत कार्यसञ्चालन विधि" को तर्जुमा र "समुदायमा आधारित विपद् जोखिम न्यूनीकरण तथा व्यवस्थापन गतिविधिहरु" सञ्चालन
- नेपालको सम्पूर्ण स्थानीय निकायहरुको लागि स्थानीय विपद् तथा जलवायु उत्थानशील योजनाको प्राविधिक निर्देशिकाको तर्जुमा

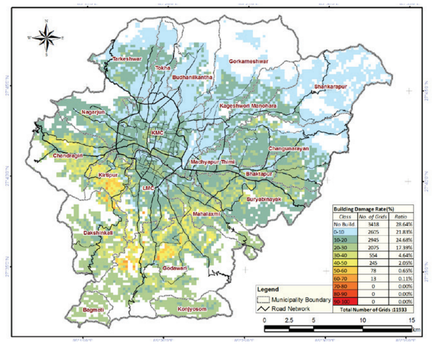


परियोजनाका बिषयबस्तुहरु



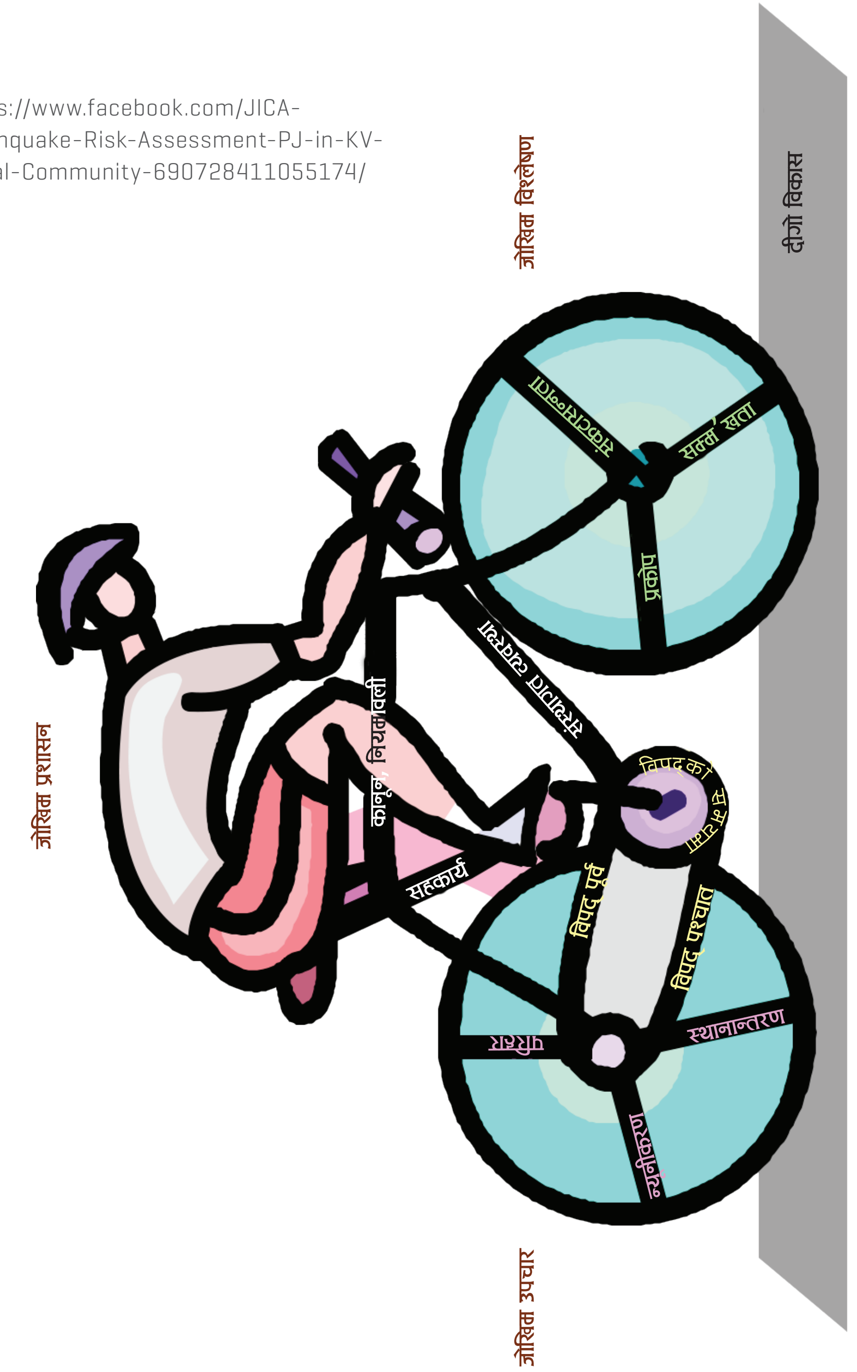
परियोजनाको अध्ययन क्षेत्र


भू-नमूना


अत्यधिक भवन क्षतिको अनुपात

स्थानीय विपद् तथा जलवायु उत्थानशील योजना तथा प्राविधिक निर्देशिका

https://www.facebook.com/JICA-Earthquake-Risk-Assessment-PJ-in-KV-Nepal-Community-690728411055174/



नेपाल सरकार
सहरी विकास मन्त्रालय
गृह मन्त्रालय
संघीय मामिला तथा स्थानीय विकास मन्त्रालय
खानी तथा भूगर्भ विभाग

जापान अन्तर्राष्ट्रिय सहयोग नियोग (जाइका)

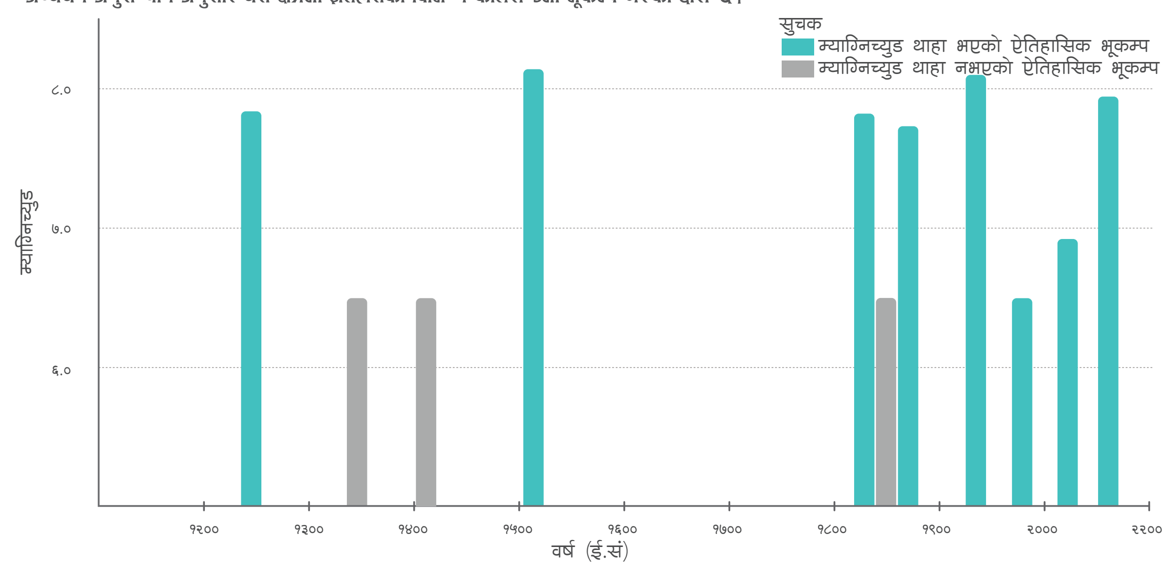
काठमाण्डौ उपत्यका भूकम्प विपत्ति जोखिम मूल्याङ्कन परियोजना

काठमाण्डौ उपत्यका भूकम्प विपत्ति जोखिम मूल्याङ्कन परियोजना

"विपद् जोखिमबारे बुझाइ,
दिगो विकासका लागि विपद् जोखिम न्यूनीकरण"

भूकम्प : इतिहास, वर्तमान र भविष्य

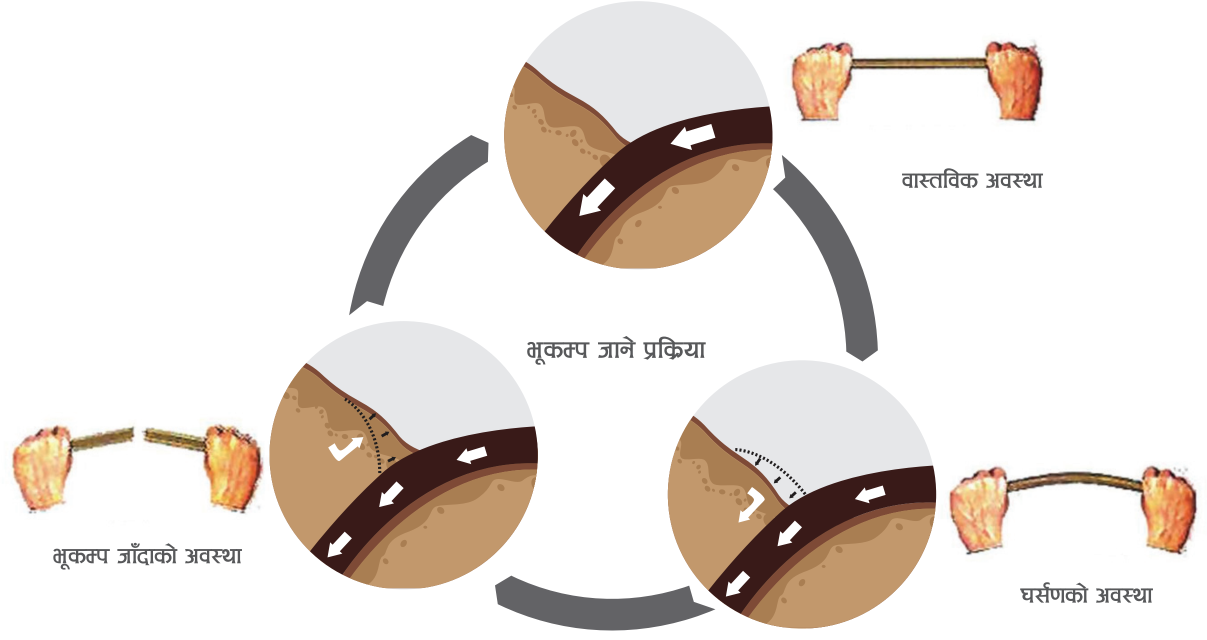
हिमालय श्रृंखलाको आसपासमा रहेको नेपालको अधिकांश भूभाग भूकम्प प्रकोपजन्य क्षेत्रमा पर्दछ। ऐतिहासिक लेख, शिलापत्र र पछिल्लो समयको विभिन्न अध्ययन अनुसन्धान अनुसार यस क्षेत्रमा इतिहासको विभिन्न कालखण्डमा भूकम्प गएको देखिन्छ।



नेपालमा गएका ऐतिहासिक विनाशकारी भूकम्प

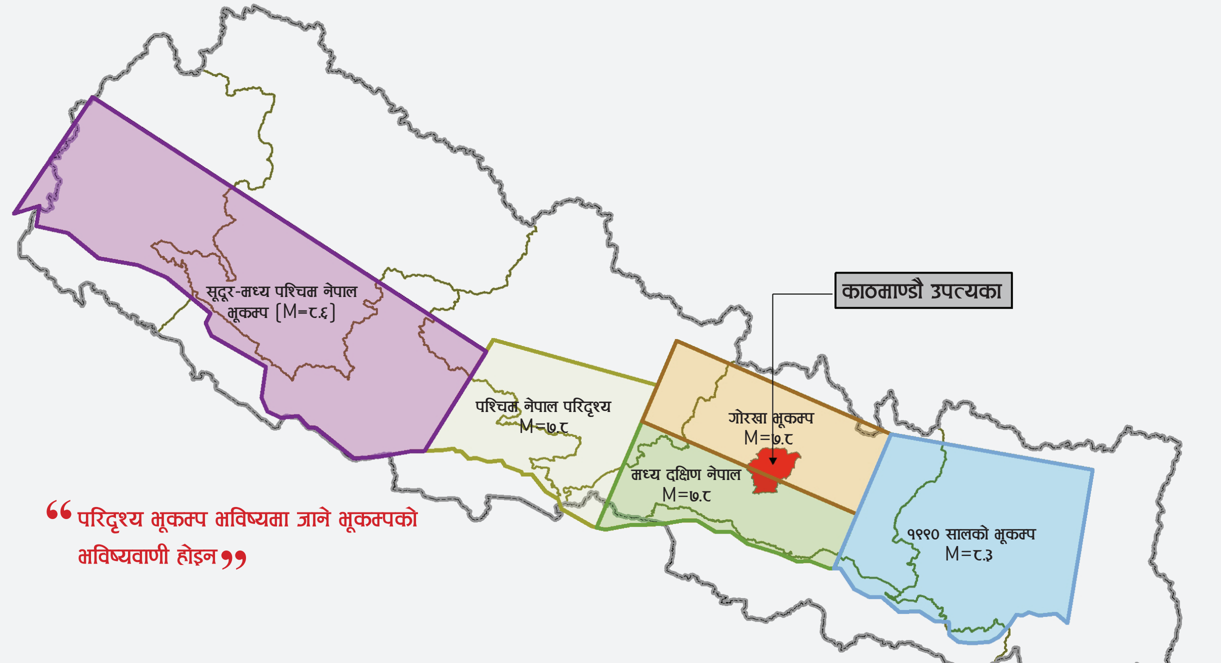
श्रोत : *Ambraseys and Douglas (2004), Bilham and Ambraseys (2005), Bilham et al. (1995), Szeliga et al. (2010), UNDP (2013)*

नेपालको भूभाग दक्षिणमा इण्डियन प्लेट र उत्तरतर्फ तिब्बतीय प्लेट माथि अवस्थित छ। इन्डियन प्लेट क्रमिक रुपमा तिव्वीय प्लेटमा घुस्रिदै जाँदा सञ्चित हुने शक्ति उत्सर्ग हुँदा यस भूभागमा भूकम्प जान्छ। यसरी शक्ति सञ्चयको अवधि जति लामो समयसम्म हुन्छ त्यति नै ठूलो म्याग्निच्युडको र विनाशकारी भूकम्प जान्छ।



परिदृश्य भूकम्पहरू

ऐतिहासिक भूकम्प, भूकम्पीय अवस्था, चलायमान प्लेटका गतिविधि र सक्रिय दरारहरुको अध्ययनबाट गरिने सम्भावित भूकम्पहरुको प्राविधिक अनुमान नै परिदृश्य भूकम्प हो। काठमाडौं उपत्यकाको भूकम्पीय जोखिम अनुमानका साथसाथै स्थानीय विपद् तथा जलवायु उत्थानशील योजना तर्जुमाका लागि सुदूर-मध्य पश्चिम नेपाल, पश्चिम नेपाल र मध्य दक्षिण नेपाल नामका तीन परिदृश्य भूकम्पहरू प्रस्ताव गरिएको छ।



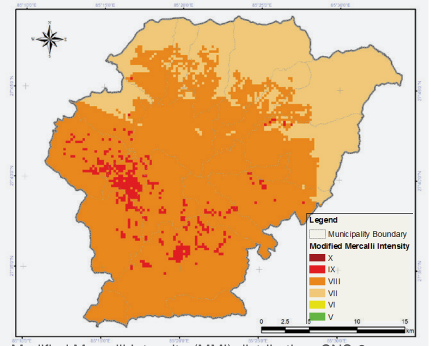
"परिदृश्य भूकम्प भविष्यमा जाने भूकम्पको भविष्यवाणी होइन"

परिदृश्य भूकम्पको उत्पति क्षेत्र

भूकम्पको म्याग्निच्युड र श्रोतबाट स्थलको दूरी अनुसार जमीनको हल्लाइमा फरक पर्दछ। पश्चिम नेपाल परिदृश्य भूकम्पको मात्रा गोरखा भूकम्पको मात्रा जतिकै रहेको छ भने मध्य दक्षिण नेपाल परिदृश्य भूकम्पले गोरखा भूकम्पको भन्दा बढी हल्लाइ निम्त्याउँदछ। काठमाण्डौ उपत्यकाबाट सबैभन्दा नजिक रहेको मध्य दक्षिण नेपाल परिदृश्य भूकम्पको सम्भावित हल्लाइलाई तीन किसिमको [CNS-1, CNS-2 and CNS-3] अनुमान गरिएको छ। गोरखा भूकम्पको हल्लाइलाई वैज्ञानिक विश्लेषण गरी आएको नतिजाका आधारमा उक्त किसिमहरु तय गरिएको हो। सामान्य भवनहरूको विपद् जोखिम न्यूनीकरणको लागि CNS-1 को अनुमान प्रयोग गर्ने सुझाव गरिएको छ भने अत्यावश्यक पूर्वाधार जस्तै विद्यालय, अस्पताल, सरकारी भवनहरू र दैनिक जीविकोपार्जनका लागि आवश्यक सुविधाहरूको विपद् जोखिम न्यूनीकरणको लागि CNS-2 को अनुमान प्रयोग गर्ने सल्लाह दिइएको छ।

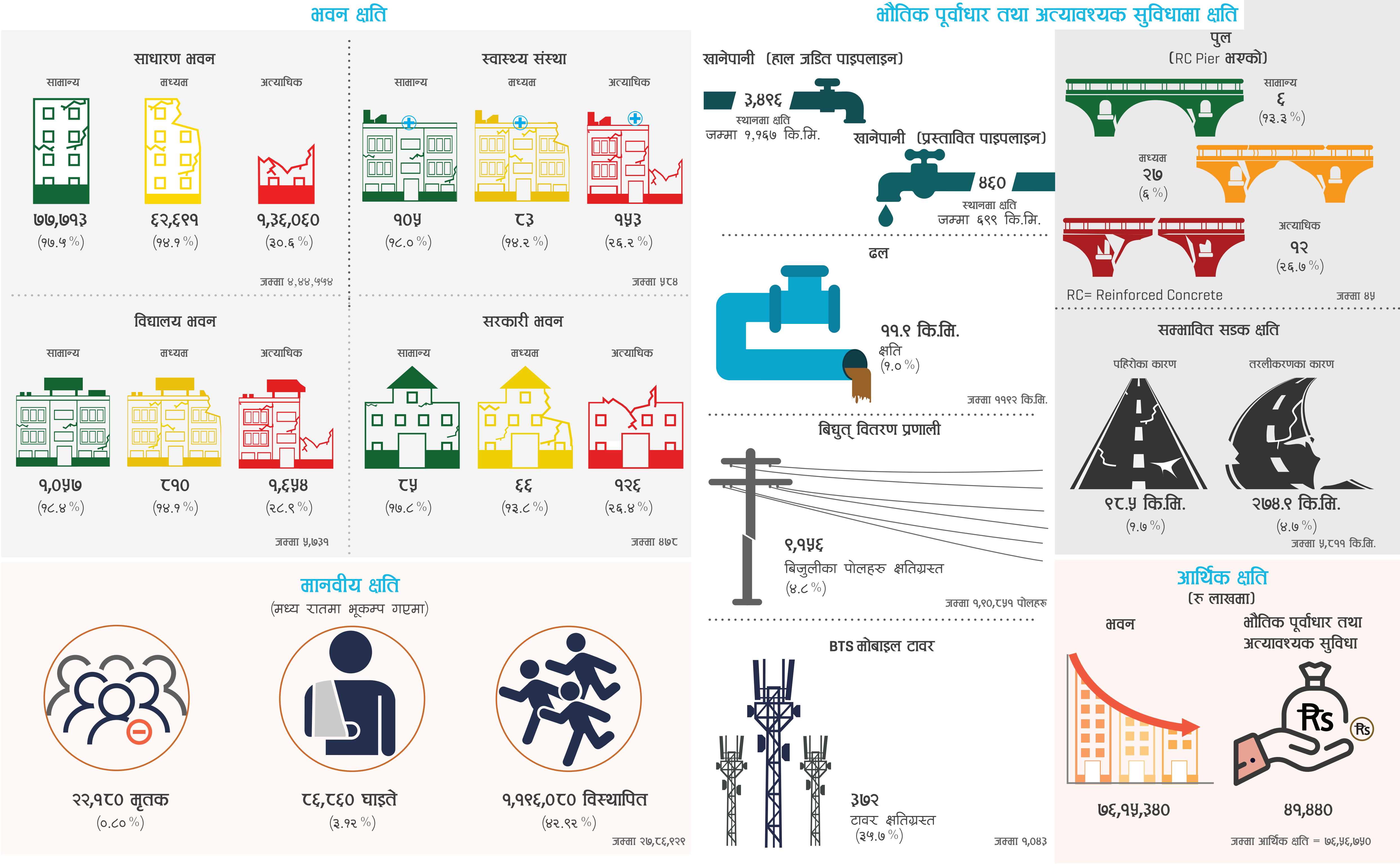
परिदृश्य भूकम्पहरू		PGA वितरण (gal)	हल्लाइको अवस्था	गोरखा भूकम्पको तूलनामा जमीनको हल्लाइको तह
सूदूर-मध्य पश्चिम नेपाल परिदृश्य भूकम्प [M=८.६]		७२-२१३	कमजोर	अन्य परिदृश्यहरु भन्दा निकै सानो
पश्चिम नेपाल परिदृश्य [WN] [M=७.८]		९१-३०३		लगभग उतिकै
मध्य दक्षिण नेपाल [CNS] [M=७.८]	CNS-1	९१-५१९		लगभग १.५ गुणा बढी
	CNS-2	१३६-७७७		लगभग २ गुणा बढी
	CNS-3	१८१-१०५५	शक्तिशाली	लगभग २.७५ गुणा बढी

गोरखा भूकम्पसँग परिदृश्य भूकम्पको तुलना



Modified Mercalli Intensity. (MMI) distribution- CNS-2;

काठमाण्डौ उपत्यकाको अनुमानित क्षति [CNS-2]



उपलब्ध तथ्याङ्कहरु र पूर्वधारणाका आधारमा अनुमानित क्षति प्रस्तुत गरिएको छ। तसर्थ, यथार्थ क्षति अनुमानित क्षतिबमोजिम नहुन सक्छ।