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	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





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



[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	f fault origin
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160.8, 60.0, 10.0	: Length,	Width,	Depth	(km)
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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	Х	Y	1505_fault	1505_JB	West_fault	West_JB	Gorkha_fau	Gorkha_JE	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	C	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

- : data
 - : program



File format

a) Distance.csv

Grid	Х	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: C	rid Cod	e												

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)

$$\begin{split} &\ln Sa(g) = f_1(M, R_{rap}) + a_{12}F_{RV} + a_{13}F_{NM} + a_{15}F_{AS} + f_5(P\hat{G}A_{1100}, V_{530}) \\ &+ F_{IIW}f_4(R_{jb}, R_{rap}, R_x, W, \delta, Z_{T_{OR}}, M) + f_6(Z_{TOR}) + f_8(R_{rap}, M) + f_{10}(Z_{1.0}, V_{530}) \\ &f_1(M, R_{rap}) = \begin{cases} a_1 + a_4(M - c_1) + a_8(8.5 - M)^2 + [a_2 + a_3(M - c_1)]\ln(R) & \text{for } M \le c_1 \\ a_1 + a_5(M - c_1) + a_8(8.5 - M)^2 + [a_2 + a_3(M - c_1)]\ln(R) & \text{for } M \le c_1 \\ R = \sqrt{R_{rap}^2 + c_4^2} \\ &f_5(P\hat{G}A_{1100}, V_{530}^*) = \begin{cases} a_{10} \ln\left(\frac{V_{530}}{V_{LN}}\right) - b \ln(P\hat{G}A_{1100} + c) + b \ln\left(P\hat{G}A_{1100} + c\left(\frac{V_{530}}{V_{LN}}\right)^n\right) & \text{for } V_{530} < V_{LN} \\ (a_{10} + bn) \ln\left(\frac{V_{530}}{V_{LN}}\right) & \text{for } V_{530} \ge V_{LN} \\ &f_5(P\hat{G}A_{1100}, V_{530}^*) = \begin{cases} V_{530} & \text{for } V_{530} < V_1 \\ (a_{10} + bn) \ln\left(\frac{V_{530}}{V_{LN}}\right) & \text{for } V_{530} \ge V_{LN} \\ &f_{530} = \begin{cases} V_{530} & \text{for } V_{530} < V_1 \\ V_1 & \text{for } V_{530} \ge V_1 \\ \end{bmatrix} & \text{for } V_{530} \ge V_1 \\ &f_{530} = V_1 \\ &f_{530} = (c_1 - c_1 -$$

$$T_{4}(M) = \begin{cases} 0 & \text{for } M \le 6 \\ M - 6 & \text{for } 6 < M < 7 \\ 1 & \text{for } M \ge 7 \end{cases}$$
$$T_{5}(\delta) = \begin{cases} 1 - \frac{\delta - 70}{20} & \text{for } \delta \ge 70 \\ 1 & \text{for } \delta < 70 \end{cases}$$

$$f_{6}(Z_{TOR}) = \begin{cases} \frac{a_{16}Z_{TOR}}{10} & \text{for } Z_{TOR} < 10 \text{ km} \\ a_{16} & \text{for } Z_{TOR} \ge 10 \text{ km} \end{cases}$$

$$f_{8}(R_{rup}, M) = \begin{cases} 0 & \text{for } R_{rup} < 100 \text{ km} \\ a_{18}(R_{rup} - 100)T_{6}(M) & \text{for } R_{rup} \ge 100 \text{ km} \end{cases}$$

$$T_{6}(M) = \begin{cases} 1 & \text{for } M < 5.5 \\ 0.5(6.5 - M) + 0.5 & \text{for } 5.5 \le M \le 6.5 \\ 0.5 & \text{for } M > 6.5 \end{cases}$$

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

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

$$\ln(\hat{Z}_{1.0}(V_{530})) = \begin{cases} 6.745 & \text{for } V_{530} < 180 \text{ m/s} \\ 6.745 - 1.35 \ln\left(\frac{V_{530}}{180}\right) & \text{for } 180 \le V_{530} \le 500 \text{ m/s} \\ 5.394 - 4.48 \ln\left(\frac{V_{530}}{500}\right) & \text{for } V_{530} > 500 \text{ m/s} \end{cases}$$

$$\begin{aligned} a_{21} &= \begin{cases} 0 & \text{for } V_{s30} \ge 1000 \\ -(a_{10} + bn) \ln\left(\frac{V_{s30}^*}{\min(V_1, 1000)}\right) & \text{for } (a_{10} + bn) \ln\left(\frac{V_{s30}^*}{\min(V_1, 1000)}\right) + e_2 \ln\left(\frac{Z_{10} + c_2}{\hat{Z}_{10} + c_2}\right) < 0 \\ e_2 & \text{otherwise} \end{cases} \\ e_2 & \text{otherwise} \end{cases} \\ e_2 & e_$$

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 totop of rupture(km)

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

 F_{NM} : Flag for normal faulting earthquake: 1 for -120° $\leq \lambda \leq$ -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 toVs = 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 $M \leq M_h$ $F_M(M) = e_1U + e_2SS + e_3NS + e_4RS + e_5(M - M_h) + e_6(M - M_h)^2$ For $M > M_h$ $F_M(M) = e_1U + e_2SS + e_3NS + e_4RS + e_7(M - M_h)$ mechanism unspecified : U = 1, SS = NS = RS = 0strike slip : SS = 1, U = NS = RS = 0normal : NS = 1, U = SS = RS = 0reverse : RS = 1, U = NS = SS = 0

$$F_{D}(R_{JB}, M) = \left[c_{1} + c_{2}\left(M - M_{ref}\right)\right] \ln\left(R/R_{ref}\right) + c_{3}\left(R - R_{ref}\right)$$
$$R = \sqrt{R_{JB}^{2} + h^{2}}$$

$$\begin{split} F_{S} &= F_{LIN} + F_{NL} \\ F_{LIN} &= b_{lin} \cdot \ln(V_{S30}/V_{ref}) \end{split}$$

For
$$pga4nl \le a_1$$

 $F_{NL} = b_{nl} \cdot \ln(pga_low/0.1)$
For $a_1 < pga4nl \le a_2$
 $F_{NL} = b_{nl} \cdot \ln(pga_low/0.1) + c[\ln(pga4nl/a_1)]^2 + d[\ln(pga4nl/a_1)^3]$
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 $V_{ref} \le V_{s30}$ $b_{nl} = 0.0$

 $Y : PGA(g), Sa_{h=5\%}(g) \text{ or } PGV(cm/sec)$ M : moment magnitude $R_{JB} : closest horizontal distance to the vertical projection of the rupture(km)$ $V_{S30} : average shear - wave velocity to a depth of 30m (m/sec)$ $b_1, b_2, b_{lin} : period - dependent coefficien t$ $b_{nl} : function of period as well as V_{S30}$ $V_{ref} : specified reference velocity (= 760m/sec)$ $pga_low := 0.06g$ $pga4nl : predicted PGA in g for V_{ref} = 760m/sec$ $V_1 : 180m/sec$ $V_2 : 300m/sec$

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

$$\begin{aligned} \ln Y &= f_{mag} + f_{dis} + f_{flt} + f_{hng} + f_{site} + f_{sed} + \varepsilon \\ f_{mag} &= \begin{cases} c_0 + c_1 M & M \leq 5.5 \\ c_0 + c_1 M + c_2 (M - 5.5) & 5.5 < M \leq 6.5 \\ c_0 + c_1 M + c_2 (M - 5.5) + c_3 (M - 6.5) & 6.5 < M \end{cases} \\ f_{dis} &= (c_4 + c_5 M) \ln \sqrt{R_{rup}^2 + c_6^2} \\ f_{flt} &= c_7 F_{RV} f_{flt,Z} + c_8 F_{NM} \\ f_{flt,Z} &= \begin{cases} Z_{TOR} & ; Z_{TOR} < 1 \\ 1 & ; Z_{TOR} \geq 1 \end{cases} \end{aligned}$$

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

$$\begin{split} f_{hng} &= c_9 f_{hng,R} f_{hng,M} f_{hng,z} f_{hng,\delta} \\ f_{hng,R} &= \begin{cases} 1 & ; R_{JB} = 0 \\ [\max(R_{RUP}, \sqrt{R_{JB}^2 + 1}) - R_{JB}] / \max(R_{RUP}, \sqrt{R_{JB}^2 + 1}) & ; R_{JB} > 0, Z_{TOR} < 1 \\ (R_{RUP} - R_{JB}) / R_{RUP} & ; R_{JB} > 0, Z_{TOR} > 1 \\ (R_{IU} - 6.0) & ; 6.0 < M < 6.5 \\ 1 & : M \ge 6.5 \\ 1 & : M \ge 6.5 \\ \end{cases} \\ f_{hng,Z} &= \begin{cases} 0 & ; Z_{TOR} \ge 20 \\ (20 - Z_{TOR}) / 20 & ; 0 \le Z_{TOR} < 20 \\ (90 - \delta) / 20 & ; \delta > 70 \end{cases}$$

$$f_{site} = \begin{cases} c_{10} \ln\left(\frac{V_{s30}}{k_1}\right) + k_2 \left\{ \ln\left[A_{1100} + c\left(\frac{V_{s30}}{k_1}\right)^n\right] - \ln\left[A_{1100} + c\right] \right\} & ;V_{s30} < k_1 \\ (C_{10} + k_2 n) \ln\left(\frac{V_{s30}}{k_1}\right) & ;k_1 \le V_{s30} < 1100 \\ (c_{10} + k_2 n) \ln\left(\frac{1100}{k_1}\right) & ;V_{s30} \ge 1100 \end{cases}$$

$$f_{sed} = \begin{cases} c_{11}(Z_{2.5} - 1) & ; Z_{2.5} < 1\\ 0 & ; 1 \le Z_{2.5} \le 3\\ c_{12}k_3e^{-0.75} \left[1 - e^{-0.25(Z_{2.5} - 3)} \right] & ; Z_{2.5} > 3 \end{cases}$$

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

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)

$$\begin{split} &\ln(y_{ref_{ij}}) = c_{1} + c_{1a}F_{RV_{i}} + c_{1b}F_{NM_{i}} + c_{7}(Z_{TOR} - 4)(1 - AS_{i}) + \left[c_{10} + c_{7a}(Z_{TOR_{i}} - 4)\right]AS_{i} \\ &+ c_{2}(M_{i} - 6) + \frac{c_{2} - c_{3}}{c_{n}}\ln\left(1 + e^{c_{n}(c_{M} - M_{i})}\right) \\ &+ c_{4}\ln\left[R_{RUPij} + c_{5}\cosh\left\{c_{6}\max\left(M_{i} - c_{HM}, 0\right)\right\}\right] \\ &+ \left(c_{4a} - c_{4}\right)\ln\left(\sqrt{R_{RUPij}^{2} + c_{RB}^{2}}\right) \\ &+ \left\{c_{r1} + \frac{c_{r2}}{\cosh\left[\max\left(M - c_{r3}, 0\right)\right]}\right\}R_{RUPij} \\ &+ c_{9}F_{HW_{i}} \tanh\left(\frac{R_{X_{ij}}\cos^{2}\delta_{i}}{c_{9a}}\right)\left\{1 - \frac{\sqrt{R_{JB_{ij}}^{2} + Z_{TOR_{i}}^{2}}}{R_{RUPij} + 0.001}\right\} \\ &\ln(y_{ij}) = \ln(y_{ref_{ij}}) + \Phi_{1} \cdot \min\left[\ln\left(\frac{V_{30_{j}}}{1130}\right), 0\right] \\ &+ \Phi_{2}\left\{e^{\Phi_{3}\left(\min\left(V_{30_{j}}, 1130\right) - 360\right)} - e^{\Phi_{3}\left(1130 - 360\right)}\right\}\ln\left(\frac{y_{ref_{ij}} + \Phi_{4}}{\Phi_{4}}\right) \\ &+ \Phi_{5}\left(1 - \frac{1}{\cosh\left[\Phi_{6} \cdot \max\left(0, Z_{1.0} - \Phi_{7}\right)\right]}\right) + \frac{\Phi_{8}}{\cosh\left[0.15 \cdot \max\left(0, Z_{1.0} - 15\right)\right]} \end{split}$$

$$+\eta_i + \varepsilon_{ij}$$

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

M: Moment magnitude

 R_{RUP} : Closest distance to the rupture plane (km)

 R_{IB} : Joy ner - Boore distance to the rup ture 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 $R_X \ge 0$ and 0 for $R_X < 0$

 δ : Fault dip angle

 Z_{TOR} : Depth totop of rupture(km)

 $F_{_{RV}}$: Reverse faulting flag :1 for $30^\circ \le \lambda \le 150^\circ$ (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

 $V_{\rm S30}$: Average shear - wave velocity for top 30 m (m/sec)

 $Z_{1,0}$: Depth toshear 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

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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.





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.

Notes:

- 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 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.







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.

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

 Table 2.1
 Category of Fundamental Data

Category of Inventory Data	Types of Data	Sources of Data
Water Supply Network (Planned)	Network Data	KUKL,2016
Total length of pipelines: 699km	(Line Data)	
Sewage Network (Existing)	Network Data	KUKL,2015
Total length of pipelines: 1,192km	(Line Data)	
Estimated Power Pole Distribution	Grid-wise Data	NEA, 2016
• 190,851 poles	(Polygon Data)	JICA ERAKV, 2017
Base Transceiver Station (BTS)	Individual BTS	NTA, NTC, Ncell, 2015
• 1,043 stations	Data (Point Data)	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.

Types of Data	Sources of Data
Polygon Data	JICA ERAKV, 2016
Raster Data	UNDP/KVDA, 2013
Grid-wise Data	JICA ERAKV, 2016
(Polygon Data)	
Grid-wise Data	JICA ERAKV, 2016
(Polygon Data)	
Grid-wise Data	JICA ERAKV, 2016
(Polygon Data)	
Grid-wise Data	JICA ERAKV, 2016
(Polygon Data)	
Grid-wise Data	JICA ERAKV, 2016
(Polygon Data)	
Grid-wise Data	JICA ERAKV, 2016
(Polygon Data)	
Grid-wise Data	JICA ERAKV, 2016
(Polygon Data)	
Grid-wise Data	JICA ERAKV, 2016
(Polygon Data)	
Polygon Data	JICA ERAKV, 2016
Polygon Data	JICA ERAKV, 2016
Polygon Data	JICA ERAKV, 2016
	Types of DataPolygon DataRaster DataGrid-wise Data(Polygon Data)Grid-wise Data(Polygon Data)Polygon DataPolygon DataPolygon DataPolygon Data

Table 2.2Category of Hazard Assessment Relevant Data

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.

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

Table 2.3	Category of Risk Assessment Relevant Data
1 4010 2.5	Cutegory of Risk Tissessment Relevant Data

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



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.

Evaluation	Input1:	Input2:	Output of Risk Assessment
Target	Exposures to hazard	External forces	Names and units estimated based
	Necessary Attribute Data	Necessary Attribute Data	on exposures and external forces
General Buildings	· Grid-wise building number	· Predominant period	\cdot Gird-wise damaged building
	· Grid-wise building structure	\cdot PGA (gal)	number
	component ratio		· Grid-wise damaged building
			ratio (%)
School Buildings	· Coordinate of building	· Predominant period	· Damage probability of
Health Facilities	· Building structure type	· PGA (gal)	building (%)
Government			
Buildings	Der Lerter en	<u>C1</u> (
Road Network	· Koad category	· Slope failure potential	· lotal road length on high
	· Road width (m) by segment	· Liqueraction potentiai	potential area (km)
	· Pavement type by segment	· Gird-wise damaged	· Gird-wise rate of road-link
	51 5 6	building number	blockage (%)
Bridges	· Coordinate of bridge	· Acceleration response	· Damage Degree based on
-	· Dimension data of bridge	spectrum (Sa: gal)	response ductility factor (μ_r)
Water Supply	· Length (m) by segment	· PGV (kine)	· Grid-wise damage rate of
Pipeline Network	· Type of material by segment	· Liquefaction Potential	water supply network (No.
	· Diameter (mm) by segment		of damage spot / km)
	· Ground condition by segment		
Sewage Pipeline	· Length (m) by segment	· PGA (gal)	· Grid-wise damage length of
Network	• Type of material by segment	 Liquefaction Potential 	sewage network (Km)
	• Diameter (mm) by segment		
Pole Distribution	· Grid-wise number of utility	· PGA (gal)	• Grid-wise number of failure
for Power Supply	pole		poles
BTS Tower	· Coordinate of tower	· Predominant period	· Damage Probability of BTS
for Mobile	· Tower type	· PGA (gal)	tower
Communication	· Building structure type	i ori (gui)	
Human Casualty	· Population for Daytime and	· Building number with	· Number and ratio of Death,
5	Nighttime	heavy and moderate	Injured and Evacuee
	· Death and Injured rate	damage	2
	Earthquake occurrence scene	-	
	(inside building ratio)		
Direct Economic	\cdot Unit cost of construction for	· Estimated damage of	· Direct loss due to building
Losses	building and infrastructure	building and	and infrastructure damage
	· Economic statistical data	Infrastructure	

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

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


(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



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.

pin Data
Join lets you append additional data to this layer's attribute table so you can, for example, symbolize the layer's features using this data.
What do you want to join to this layer?
Join attributes from a table
 <u>Choose the field in this layer that the join will be based on:</u>
GridCode 👻
2. Choose the table to join to this layer, or load the table from disk:
PGA CNS1
Show the attribute tables of layers in this list
3. Choose the field in the table to base the join on:
GridCode 👻
Join Options
Keep all records
All records in the target table are shown in the resulting table. Unmatched records will contain null values for all fields being appended into the target table from the join table.
Keep only matching records
If a record in the target table doesn't have a match in the join table, that record is removed from the resulting target table.
Validate Join
About joining data OK Cancel

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.

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P P PGA CNS1			2	Polycon	240311	99.99	0.03	2	2	3	240311	105.26	1000	62500.00000	1
			3	Polygon	241311	99.99	0.03	3	3	4	241311	105.93	1 0 0 0	6250	
			4	Polyson	242311	99,99	0.03	4	4	5	242311	105.53	1000	62500.00000	
			5	Polycon	243311	99.99	0.03	5	5	6	243311	105.28	1000	6250	
Gridwise_Building_Distri	bution_2016		6	Polygon	264311	99,99	0.03	6	6	7	264311	98.99	1000	6250	
			7	Polycon	265311	99.99	0.03	7	7	8	265311	98.59	1000	62500.000001	
			8	Polygon	266311	99,99	0.03	8	8	9	266311	98.41	1000	6250	
			9	Polycon	267311	99.99	0.03	9	9	10	267311	9815	1000	62500.00000	
			10	Polycon	288311	99.99	0.03	10	10	11.	288311	92.63	1000	62500	1
			11	Poheron -	000211	99.99		11	11	12	209211	99.29	1000	62500.00000	

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.

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	11 Polygon	289311	99.99	0.03	11 11	12	289311 91	39 10	00 62500.000001	11	12	289311	0 0	0	0	0	
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	15 Polygon	231310	99.99	0.00	15 15	16	231310 111	07 10	62500	15	16	231310	0 0	Ŭ Ö	0	ő	
1	16 Polygon	233310	25.95	0.00	16 10		222210 10	35 10	60 <u>60500</u>	16	17	933310		P	0	-	

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.

Demonstration.mxd	- ArcMap		Export Data
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D D DCA CNS1	× Remove	1 Polyton 239311 99.93 0.03 2 Polyton 240311 99.93 0.03	the feature dataset you export the data into
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		4 Polyson 242311 8939 0.00 4 4 5 5 Polyson 243311 8939 0.00 5 5 6	242311 105.83 1000 69500.000001 4 5 242311 0 0 0 0 0 0 0 0 243311 10528 1000 62500 5 5 243311 0 0 0 0 0 0 0 0
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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,

		(1)	(2)	(3)	(4)					- (!	5)																
		<u> </u>							_																		
	A	В	С	D	E	F	G	Н	1	J.	K Dida I	L	M	N	0	P	Q	R	S	T	U	V	W	Х	Y	Z	дд
1			Predominant			_		00	mponen	t Ratio o	r Didg i	structu	ne Type							Dama	ge Lev	11175					_
	OBJECT ID	GridCode	Period of Ground	PGA CNS-2	Bldg No 2016	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	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 Bidg No	Adol 201
2	0550	010035	0.00			0.01		0.74		1.00		00.4 5	01.01	2.01					0.50	0.50	0.01	6.30	2.00	0.10		Diag res	
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%	1.22	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	200.48	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	7.00	1.11	0.36	027	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	1
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	1
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	1
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. All outputs of damage buildings are

																	calc	ulate	ed a	utor	nat	icall	ly.				
4	A	в	с	D	E	F	G	н	I	J	К	L	м	N	0	P	Q	R	S	т	U	V	W	X	Y	Z	A
1								C	omponen	t Ratio o	f Bldg S	Structu	re Type			-				Dama	ge Lev	14+5					
0	OBJECT ID	GridCode	Predominant Period of Ground	PGA CNS-2	Bldg No 2016	Adobe 2016	SMM 2016	BMM 2016	BMM_2 2016	BMM_3 2016	SCM 2016	ВСМ 2016	RC_N_Eng 2016	RC_Eng 2016	Others 2016	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	Ado 201
3555	3553	243275	3.85	262.32	138	0.3%	01%	3.7%	1.2%	1.2%	0.0%	23.1%	61.8%	7.3%	1.25	0.37	010	3.09	0.56	0.56	0.01	5.78	7.68	0.49	0.29	19	
3556	3554	244275	357	263.95	154	0.3%	0.1%	3.7%	1.2%	1.2%	0.0%	231%	61.8%	7.3%	1.25	0.42	011	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%	1.25	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%	1.01	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%	1.71	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	227	201.07	195	0.0%	0.0%	0.3%	0.5%	0.5%	0.0%	21.0%	01.5%	13.1%	2.0%	0.00	- 0.00	0.40	- 0.75	0.75	0.00	10.19	10.69	2.04	0.95		



(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

Total Damaged

	A	в	P	Q	R	S	Т	U	V	W	Х	Y	Z
1							Dar	nage Leve	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 Bidg 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	80.0	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

					b	uilding	g struc	ture t	ype			buildi	ng Nun
	A	В	AA	AB	AC	AD	AE	AF	AG	AH	A	AJ	AK
1			- to be to be				Dama	age 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 Bidg 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_D34	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
3316	8312	248236	0.15	80.0	0.10	0.13	0.02	0.00	0.23	0.07	0.01	0.08	1
3317	8313	249236	0.07	0.04	0.05	0.07	0.01	0.00	0.12	0.04	0.00	0.0	0
3318	8314	250236	1.17	0.59	2.88	1.04	0.55	0.06	4.54	4.27	0.56	0.30	16
3319	8315	251236	1.16	0.31	50.34	2.88	10.34	0.30	53.24	41.30	1.36	0.8	162
3320	8316	252236	0.38	0.19	1.64	0.78	0.45	0.03	5.44	11.11	1.48	0.40	22
3321	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	0.36	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	0.28	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]; ٠

					t	ouildin	g struc	ture t	ype	cuen	I	ouildi	ng Nun
	A	В	A	A8.4					- 4B			ومقاضر مع	AX
1							Damag	e 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	Other: 2016	Total Damage Bidg No
3	Total		7,745	3,291	31,481	8,057	5,969	336	51,805	58,337	6,086	2,51	176,02
4		GridCode	Adb_D2345	SMM_D2345	BM1_D2345	BM2_D2345	BM3_D2345	SCM_D2345	BCM_D2345	RON_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	O n (
8316	8312	248236	0.16	0.10	0.12	0.20	0.03	0.01	0.39	0.13	0.02	005	
8317	8313	249236	80.0	0.05	0.06	0.10	0.02	0.00	0.20	0.07	0.01	002	
8318	8314	250236	1.22	0.70	3.39	1.52	0.80	0.09	7.54	7.76	1.15	049	2
8319	8315	251236	1.21	0.36	58.91	4.17	14.97	0.49	87.51	74.09	2.74	163	24
8320	8316	252236	0.40	0.22	1.89	1.10	0.63	0.05	8.67	19.29	2.88	064	3
8321	8317	253236	0.83	0.42	0.89	0.75	0.25	0.05	3.30	1.91	0.29	0.40	
8322	8318	254236	0.30	0.14	1.26	0.63	0.36	0.03	4.01	8.78	1.14	03	17
8323	8319	255236	0.62	0.30	2.60	1.26	0.73	0.05	7.79	16.81	2.13	06	3:
8324	8320	256236	0.33	0.18	1.55	0.89	0.51	0.04	6.85	15.29	2.24	06	2.
8325	8321	257236	0.32	017	1.47	082	0.47	0.04	6.05	13.28	1.89	046	2

Number of damaged buildings for each

Total Damaged ıber

Number of heavily (DL4+5) damaged masonry buildings; ٠

Number of heavily (DL4+5) damaged RC buildings; ٠

- ٠ Total number of heavily (DL4+5) damaged buildings;;
- Ratio of heavily (DL4+5) damaged buildings; ٠

- Number of moderately (DL3) damaged masonry buildings; ٠
- Number of moderately (DL3) damaged RC buildings; ٠
- Total number of moderately (DL3) damaged buildings; ٠

- 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;

			He Bu	avily l ilding	Damag & Rati	e 0	Moo Bu	derate uilding	ly Dam ; & Rati	age O	Sli Bu	ghtly Iilding	Damag & Rati	e o
	A	в	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH
1			H	eavy Dam	age DL4+5		M	oderate D	amage DL3			Slight Dai	nage DL2	لمتعلمات
2	OBJECT ID	GridCode	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 Bidg 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	NJMSRYJHD	N,RC,HD	N_TDB_HD	R_TDB_HD	NJMSRYJMD	N,RC,MD	N_TDB_MD	R_TDB_MD	N_MSRY_SD	N_RO_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.

Probability of 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.

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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.



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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,

			Ro	ad Ne	etwo	rk Data		Slop	e fail	ure po	otenti	ial	Liqu	efact	ion p	otent
	A	в	0	D	E		G	н	I	J	К	L	м	N	0	р
1	OBJECT ID	Road ID	Road Surface Type	Road Width (m)	Road Length (m)	Road Class	Road Name	GridCode	Potential of Slope Failure WN	Potential of Slope Failure CNS-1	Potential of Slope Failure CNS-2	Potential of Slope Failure CNS-3	Potential of Liquefaction WN	Potential of Liquefaction CNS-1	Potential of Liquefaction CNS-2	Potential of Liquefaction CNS-3
320	56319	38619	Track	1	111.9	District or Village Ros	d	270113	None	Moderate	High	High	No data	No data	No data	No data
321	56320	88620	Track	1	200.4	District or Village Roa	d	270214	None	Moderate	Moderate	High	No data	No data	No data	No data
22	56321	39621	Track	1	176.0	District or Village Ros	d	275 14	None	Moderate	Moderate	High	No data	No data	No data	No data
123	56322	38621	Track	1	61.9	District or Village Roa	d	275 13	None	Low	Moderate	High	No data	No data	No data	No data
24	56323	88622	Gravel	3	135.6	District or Village Roa	d	270214	None	Moderate	Moderate	High	No data	No data	No data	No data
25	56324	38622	Gravel	3	45.9	District or Village Ros	d	270 13	None	Moderate	High	High	No data	No data	No data	No data
26	56325	38623	Track	1	77.2	District or Village Roa	d	270214	None	Moderate	Moderate	High	No data	No data	No data	No data
27	56326	88624	Gravel	3	105.5	District or Village Roa	d	263214	None	Low	Moderate	Moderate	No data	No data	No data	No data
28	56327	38624	Gravel	3	279.1	District or Village Roa	d	263 13	None	Low	Low	Low	No data	No data	No data	No data
29_	56328	38624	Gravel	3	126.0	District or Village Roa	d	264213	None	Low	Low	Low	No data	No data	No data	No data
30	56329	38624	Grave	3	20.9	District or Village Ros	d	264212	None	Low	Low	Low	No data	No data	No data	No data
31	56330	38625	Gravel	3	221.5	District or Village Roa	d	263 14	None	Low	Moderate	Moderate	No data	No data	No data	No data
32_	56331	88625	Gravel	3	67.6	District or Village Roa	d	263213	None	Low	Low	Low	No data	No data	No data	No data
13	56332	38625	Gravel	3	114.2	District or Village Ros	d	264 13	None	Low	Low	Low	No data	No data	No data	No data
14.	56333	38626	Track	1	133.B	District or Village Roa	d	269210	None	Low	Low	Moderate	No data	No data	No data	No data
15	56334	88626	Track	1	58.7	District or Village Ros	d	269215	None	Low	Low	Moderate	No data	No data	No data	No data
16	56335	38626	Track	1	223.1	District or Village Roa	d	270 15	None	Low	Moderate	Moderate	No data	No data	No data	No data
37	56336	38626	Track	1	278.1	District or Village Roa	d	270214	None	Moderate	Moderate	High	No data	No data	No data	No data
38	56337	88626	Track	1	67.6	District or Village Ros	d	270213	None	Moderate	High	High	No data	No data	No data	No data
39	56338	38629	Black Topped	4	189.6	District or Village Ros	d	262 14	None	None	None	None	No possibility	No possibility	Low	Low
40	56339	38629	Black Topped	4	30.1	District or Village Roa	d	259213	None	None	Low	Low	No data	No data	No data	No data
11	56340	38629	Black Topped	4	274.7	District or Village Roa	d	260213	None	None	None	None	No data	No data	No data	No data
12	56341	88629	Black Topped	4	300.2	District or Village Roa	d	261 13	None	None	None	None	No data	No data	No data	No data
13	56342	38629	Black Topped	4	144.1	District or Village Ros	d	262213	None	None	None	None	No data	No data	No data	No data
44	56343	38629	Black Topped	4	35.1	District or Village Roa	d	261 12	None	Low	Low	Moderate	No data	No data	No data	No data
15	56344	88630	Gravel	4	11.1	District or Village Ros	d	262 14	None	None	None	None	No possibility	No possibility	Low	Low
6	56345	08631	Gravel	3	27.2	District or Village Ros	d	262214	None	None	None	None	No possibility	No possibility	Low	Low
47	56346	38631	Gravel	3	26.9	District or Village Ros	d	263 14	None	Low	Moderate	Moderate	No data	No data	No data	No data
48	56347	39633	Gravel	4	21.3	District or Village Ros	d	26214	None	None	None	None	No possibility	No possibility	Low	Low
49	56348	88633	Gravel	4	16.2	District or Village Roa	d	263214	None	Low	Moderate	Moderate	No data	No data	No data	No data
0	56349	38634	Earthen	3	77.8	District or Village Ros	d	263 14	None	Low	Moderate	Moderate	No data	No data	No data	No data
51	56350	38636	Track	1	275.1	District or Village Roa	d	270214	None	Moderate	Moderate	High	No data	No data	No data	No data
52	56351	38638	Track	1	123.7	District or Village Roa	d	278213	None	Moderate	Moderate	Moderate	No data	No data	No data	No data
53	56352	89638	Track	1	36O.B	District or Village Roa	d	278 13	None	Moderate	Moderate	High	No data	No data	No data	No data
54	56353	38638	Track	1	141.7	District or Village Roa	d	276212	None	Low	Moderate	Moderate	No data	No data	No data	No data
55	56354	38638	Track	1	315.2	District or Village Roa	d	277 12	None	Moderate	Moderate	Moderate	No data	No data	No data	No data
6	56355	39638	Track	1	235.1	District or Village Ros	d	276 12	None	Moderate	Moderate	Moderate	No data	No data	No data	No data
17	56356	38639	Black Topped	4	81.4	District or Village Roa	d	261214	None	Low	Low	Low	No possibility	No possibility	Low	Low
58	56357	39639	Black Topped	4	243.1	District or Village Ros	d	262 14	None	None	None	None	No possibility	No possibility	Low	Low
59	56358	38640	Gravel	4	92.2	District or Village Roa	d	263 14	None	Low	Moderate	Moderate	No data	No data	No data	No data
50	56359	88641	Track	1	36.2	District or Village Ros	d	263215	None	Low	Low	Low	No possibility	No possibility	Low	Low
1	56360	39641	Track	1	35.6	District or Village Ros	d	263 14	None	Low	Moderate	Moderate	No data	No data	No data	No data
12	56361	38642	Gravel	4	48.0	District or Village Roa	d	263215	None	Low	Low	Low	No possibility	No possibility	Low	Low
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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.

A	В	C	D	E	F	G	- 4	A	8	0	D	E	F	G
							1							
							2							
Road	Class 🔻						3	Class	Class					
	 High 	Moderate	Low	None	Blank Tot	al	-4		 High 	Moderate	Low	No possibility	No data	Blank
National Highway (NH)	1,325	3,354	10,653	46,271		61,603	5	National Highway (NH)	7,552	7,927	2,578	317	43,228	
Black Topped	1.325	3,354	10.653	46,271		61.603	6	Black Topped	7,552	7,927	2,578	317	43,228	
Feeder Road Major (FRN)	8,781	35,143	109,308	136,902	2	90,134	7	Feeder Road Major (FRN)	12,799	16,488	9,292	9,010	242,545	
Black Topped	5,147	16,010	71,717	104,398		197,272	8	Black Topped	11,028	12,069	8,185	5,661	160,329	
Earthen	1,288	12,551	32,446	23,526		69,811	9	Earthen	207	2,438	898	3,027	63,241	
Gravel	2,347	6,582	5,145	8,978		23,051	10	Gravel	1,565	1,982	208	322	18,975	
Feeder Road Minor (FRO)	1,035	5,978	39,948	37,689		84,650	11	Feeder Road Minor (FRO)	66	6,151	4,888	2,350	71,195	
Black Topped		33	11,870	25,274		37,177	12	Black Topped	66	3,963	2,350	1,496	29,302	
Earthen	1,035	5,945	18,125	4,268		29,373	13	Earthein		518	281	561	28,013	
Gravel			9,954	8,147		18,100	14	Gravel		1,670	2,258	293	13,880	
■Strategic Urban Road (SUR)	1,563	4,827	22,175	100,420	1	28,985	15	Strategic Urban Road (SUR)	13,550	13,175	7,739	1,767	92,754	
Black Topped	259	694	15,629	89,936		106,518	16	Black Topped	12,366	12,648	7,634	1,767	72,103	
Brick Paved				1.05		105	17	Brick Paved			105			
Earthein		98	2,088	6,187		8,373	18	Earthen	507	317			7,548	
Grave	1,304	4,034	3,788	2,546		11,672	19	Gravel	376	62			11,234	
Stone Paved			396			396	20	Stone Paved	26				370	
Track			275	1,647		1,922	21	Track	275	148			1,499	
District or Village Road	85,802	475,907	1,948,524	2,734,955	5,2	45,189	22	District or Village Road	240,982	409,120	216,162	142,200	4,236,725	
Black Topped	3,048	19,792	192,596	774,150		989,585	23	Black Topped	111,751	136,216	68,488	34,733	638,397	
Brick Paved		166	4,728	36,890		41,783	24	Brick Paved	1,193	3,757	1,763	711	34,359	
Earthein	42,187	227,500	1,032,332	1,084,942	2	386,961	25	Earthen	69,162	146,291	87,908	65,840	2,017,759	
Gravel	8,092	51,928	223,844	345,799		629,663	26	Gravel	33,158	84,470	38,449	22,328	451,257	
PCC	20	102	2,599	3,206		5,927	27	PCC					5,927	
Stone Paved		91	6,399	14,268		20,759	28	Stone Paved	2,288	1,916	295	291	15,968	
Track	32,456	176,329	486,026	475,701	1.	170,512		Track	23,429	36,469	19,259	18,297	1,073,059	
∃ Blank	C	long	failu	Iro				Blank		lia	uofa	oction		
Blank	3	nohe	; ianu	116				Blank		ny	ueld	ICHOIT		
Total	98,506	525,209	2,130,609	3,056,237	5,8	10,561		Total	274,949	452,861	240,658	155,644	4,686,449	
	Aggrog	atod	long	the o	froa	d not	1410	vrk locatod in	oach	noto	ntia			
4	Aggreg	aleu	ieng	uis u	TUa	unei	.vv c	n k iucateu ili	Cauli	μυιε	iitia	ILEVEL		

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;

									(Km)
Road Class		Slope Fa	ilure: High			Liquefac	tion: High		Total Length
11080 01833	WN	CNS-1	CNS-2	CNS-3	WN	CNS-1	CNS-2	CNS-3	Total Length
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 transferred to road network data based on a grid number of road segment as shown in below.

	_				-											
ction Ge	eoprocessing	Customize	Windows He	lp.												
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ble		_						_								
		Roa	nd Net	work Data h	IV SE	gment		Fst	imat	ed da	mag	e huil	ding	numh	ler	
• 昭•																
ad Netw	ork with Dam	age Building I	Number													
	_															
Shape *	OBJECT JD	FID_KV_Roa	SUR_TYPE	ROAD_WIDTH PAVE_TYPE	RW_CAT	LENGTH ROADCLASS	GridCode	Bidg_N2016	WN_DL45	WN_DL345	CS1_DL45	CS1_DL345	CS2_DL45	CS2_DL345	CS3_DL45	CS3_DL345
Polyline	1		D Earthen	2 Unpaved	< 5 m	20.40085 District or Municipal road	217259	78	4.912495	10.040454	16.891436	28.23513	38131152	51 587884	54,464592	6513052
Polyline	2		Earmen	2 Unpaved	< 5 m	00.204 District or Municipal road	217253	100	4,312435	10.040454	21 202470	20,23013	50.007530	00.000076	07.465.007	116 260416
Colution	3		Crevel	2 Unpaved	< 5 m	4 490715 District or Municipal road	217200	170	7 790257	16 272520	07 07 0060	40 7001 01	62 909459	94 707259	92 71 9405	124.005646
Pohine			2 Gravel	2 Unowed	<5 m	10400714 District or Municipal road	201258	167	7.02897	1489471	25 084828	46.296941	61 359046	90153768	90517957	118 502 703
Polytine	6		Black Tonned	6 Paved	225m	70164355 NH	215255	124	2 573511	5 497633	1073841	20.629571	30757918	49.61.009	54 011 018	75 663759
Polyline	7		Black Topped	6 Paved	>=5m	63.01.9838 NH	216255	96	6.076874	12,419161	23179954	37 844961	50.330865	65717104	70108128	82,32506
Polyline	8	1	Black Topped	6 Paved	>=5m	44,034802 NH	215254	109	1.427574	3.056264	6 D0601 3	11.958824	18,391,055	31 873257	35198125	53 334765
Polyline	9	4	4 Black Topped	6 Paved	>=5m	29.1.42.41.3 NH	21 6 2 5 5	96	6.076874	12,419161	23179954	37 8 4 4 9 6 1	50.330865	66717104	70108128	82.32506
Polyline	10		Black Topped	6 Paved	>=5m	100591783 NH	216255	96	6.076874	12.419161	23173954	37.844961	50.330865	66,717104	70108128	82,32506
Polyline	11	6	PCC	3 Paved	< 5 m	68.92811 District or Municipal road	215255	124	2,573511	5,497633	1073841	20.629571	30757918	49.61009	54.011018	75.663759
Polyline	12	6	5 POC	3 Paved	< 5 m	21.544894 District or Municipal road	215254	109	1,427574	3.056264	6.006013	11.958824	18.391.055	31 873257	35198125	53 234765
Polyline	13	2	7 Track	1 Unpaved	< 5 m	53.93691 District or Municipal road	21 5 2 5 5	124	2.573511	5,497633	10,73841	20.523571	30,757918	49.61009	54.011018	75.563753
Polyline	14	8	3 Track	1 Unpaved	<5 m	71 802034 District or Municipal road	21 6 2 5 5	96	6.076874	12,419161	23179954	37 844961	50.330865	66717104	70108128	82,32506
Polyline	15		Gravel	3 Unpaved	< 5 m	103.472838 District or Municipal road	21 6 2 5 5	96	6.076874	12.419161	23179954	37 8 4 4 9 6 1	50.330865	66717104	70108128	82.32506
Polyline	16	10) Earthen	2 Unpaved	< 5 m	77.512818 District or Municipal road	216255	96	6.076874	12,419161	23179954	37 844961	50.330865	66717104	70108128	82.32506
Polyline	17	11	Earthen	2 Unpaved	<5 m	87.615671 District or Municipal road	21 5 2 5 5	124	2.573511	5.497633	1073841	20.529571	30757918	49.61009	54.011018	75.663759
Poryane	18	11	2 Earthen	2 Unpaved	< 0 m	160.038573 District or Municipal road	217255	95	/ 335744	14583065	25.394992	41 2801 43	53813748	03525298	72/56345	83337297
roryane	19	13	000	3 Paved	< 5 mi	1+527636 District of Municipal road	21 4255	71	0.539978	2.011321	3 #55653	7.585776	11.82939	20.545707	22700805	34.480335
Poryline	20	14	S POU	3 Paved	< 5 m	114814143 District or Municipal road	210200	124	25/3511	5,497633	10,73841	20523571	30/5/918	49.51009	54,011018	/5.003/53
COLUMN 1				Lindana d		A 200 YOL LANGE OF MULTIPLE FORD	714755		0.219978	200 1321	4,055553	1 585775		205457071		10,020,035

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".

			Cl	assification o	of Roa	d widtl	h using Ca	lculatio	n Form	I	
	A	В	С	D	E	F	G	н	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 Bid; DL CNS-1
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.

 Width of representative road: Less than 3.5m Rate of road-link blockage (%)=0.9009×Rate of damaged building(%)+19.845
 Width of representative road: 3.5m to < 5.5m Rate of road-link blockage (%)=0.3514×Rate of damaged building(%)+13.189
 Width of representative road: 5.5m to < 13m Rate of road-link blockage (%)= 0.2229 ×Rate of damaged building(%)-1.5026

d	A	В	С	D	E	F	G	н	I	J	0	P	Q	R
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	Damage Bldg No DL 4+5 CNS-2 2016	Damage Bldg No DL 3+4+5 CNS-2 2016	Rate of Damaged Bidg CNS-2 2016	Rate of Road-Link Blockage (%) CNS-2 2016
2	1	0	Earthen	District or Village Road		2	<3.5m	20.4	217259	78	38	52	0.576	71.7
3	2	1	Earthen	District or Village Road		2	<3.5m	17.2	217259	78	38	52	0.576	71.7
4	3	1	Earthen	District or Village Road		2	<3.5m	29.3	217258	139	69	93	0.582	72.3
5	4	2	Gravel	District or Village Road		2	<3.5m	4.5	221259	178	64	95	0.446	60.0
6	5	2	Gravel	District or Village Road		2	<3.5m	30.4	221258	167	61	90	0.454	60.7
7	6	3	Black Topped	National Highway (NH)	Tribhuvan	6	5.5m to <13m	70.2	215255	124	31	50	0.324	5.7
8	7	3	Black Topped	National Highway (NH)	Tribhuvan	6	5.5m to <13m	63.0	216255	96	50	67	610	121

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

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 c	of RLB * segme	length o ent (m)	f road
	A	В	C	D	E	F	G	Н	I	J	AA	AB	AC	AD
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	(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
2	1	0	Earthen	District or Village Road		2	<3.5m	20.4	217259	76	936.5	1,463.1	1,813.9	581.0
3	2	1	Earthein	District or Village Road		2	<3.5m	17.2	217259	78	790.2	1,234.5	1,530.5	490.3
-4	3	1	Earthein	District or Village Road		2	<3.5m	29.3	217258	13	1,373.1	2,119.1	2,613.9	846.
5	4	2	Gravel	District or Village Road		2	<3.5m	4.5	221259	178	175.3	268.9	335.8	116.
6	5	2	Gravel	District or Village Road		2	<3.5m	30.4	221258	167	1,196.8	1,845.7	2,317.3	783.
7	6	3	Black Topped	National Highway (NH)	Tribhuvan	6	5.5m to <13m	70.2	215255	12-	92.4	401.4	712.3	0.0
8	7	3	Black Topped	National Highway (NH)	Tribhuvan	6	5.5m to <13m	63.0	216255	9	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.

d	A	В	C	D	E	F
1						
2						
3	Grid Code	Total Road Length	Total / Rate*Length_CNS-1	Total / Rate*Length_CNS-2	Total / Rate*Length_CNS-3	Total / Rate*Length_WN
4	187261	101.3828188	0	0	0	0
5	188252	122.4658759	0	0	0	0
6	188253	59.75166924	0	0	0	0
7	188261	351.3318329	15048.86448	26442.80199	10741.83444	21239.38942
8	188264	278.7396415	1121.035529	3336.627881	326.3095787	2318.225842
9	188265	182.9235742	722.5869761	2170.204496	215.0528823	1502.860337
10	189251	8.22587976	0	0	0	0
11	189252	862.9860465	0	0	0	0
12	189253	138.7943605	0	0	0	0
13	189261	102.1664649	4369.16368	7679.45049	3118.699616	61 66.761 725
14	189262	221.3825045	9427.91693	16583.35309	6761.929955	13307.60359
15	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);



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)
- 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

9	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.

	Bridge No		Yield In	tensity Calculation Form	
Crid codo to	19	🗢 Select bri	dge No. here		
determine	Grid Code			Date :	
response Acc.	240256	Checked by	:	Date :	
*••••••	Construction Year	Name of Brid	dge :	SN 19 - Dhobi Khola	
	A	Weight of su	iper structure Wu (kN)		4,372.50
vear to		Weight of su	ıbstructure Wp (kN)		797.80
determine	1				0.00
regression			Pier section		0.00
coefficient				r (m)	0.40
•••••••••••••••••••••••••••••••••••••••	÷			No. ()	5.00
		Pier	Height	h (m)	3.08
		-	I (m ⁴) for all piers		0.1005
			Young's modulus of RC p	pier E (N/mm²)	20,000
			Initial stiffness Ky0 (kN/	m), only consider that above pilecap	207,249
		Regression c	coefficient α		0.390
		Yield stiffne	ss ky (kN/m)		80,827
		δ (m) (Disp	placement subjecting to h	orizontal acceleration of 1g)	0.057058
		Ty (s)			0.480126
		Regression c	coefficient β		0.230
		Regression c	coefficient γ		-0.463
		Yield Intensi	ity Khy (dimensionless)		0.323
			Sa (gal) Acceleration res	ponse spectrum	438.150
		CNS-1	µr Response ductility fa	ctor	1.458
		CNIS_2	Sa (gal) Acceleration res	ponse spectrum	620.951
			µr Response ductility fa	ctor	2.424
			Sa (gal) Acceleration res	ponse spectrum	762.215
			μr Response ductility fa	ctor	3.398
		WN	Sa (gal) Acceleration res	ponse spectrum	293.894
			µr Response ductility fa	ctor	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.

	Cal	culation Fo	orm for Sup	erstructu	re and Subs	tructure Weig	ht	
19								
	Calculated by :					Date :	3-May-16	
	Checked by :					Date :		
	Name of Bridge :		SN 19 - Dh	obi Khola				
	Superstructure weight							
	Flement	Width	Thickness	Length	Volume	Unit Weight	Number	Weight
		(m)	(m)	(m)	(m ³)	(kN/m³)		(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							
		Width	Thickness	Length	Volume	Unit Weight	N	Weight
	Element	(m)	(m)	(m)	(m ³)	(kN/m ³)	Number	(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	Time a manifest	Regre	ession coe	efficient
	code	Time period	α	β	γ
А	Linear analysis utilizing response spectra	Before 1980	0.39	0.23	-0.463
В	Non-linear analysis was applied to consider ductile behavior of pier	1980~1990	0.39	0.25	-0.328
с	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.



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.

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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.

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10	400	1930	80 05	Reniben	05-0187	1205	1207	17 Other Surfaces		Bs	Bs	225	276 38.03	57.05	76.07	29.83	215113
3 E	400	1930	80 05	Raniban	05-0187	1205	1207	17 Other Surfaces		Bs	Bs	230	276 38.07	57.11	7615	23.89	31 97320
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11	400	1930	80 05	Lekhnath Sadak	05-0533	687	688	8 Fluxial Surfaces	(modern flood plain surfaces)	tr2	tr2	230	275 39.56	59.27	78.95	3079	4.99286
10	400	1930	80 05	Lekhnath Sadak	05-0532	687	688	8 Fluxial Surfaces	(modern flood plain surfaces)	tr2	tr2	230	275 39.56	59.27	78.95	30.79	2 58616
	400	1930	80 05	Lekhnath Sadak	05-0531	687	688	8 Fluvial Surfaces	(modern flood plain surfaces)	tr2	tr2	230	275 39.56	59.27	78.95	30.79	1111674
10	400	1930	80 05	Lekhnath Sadak	05-0531	1490	1499	1 Fluvial Surfaces	(modern flood plain surfaces)	a	al	230	275 39.56	59.27	78.95	3079	155.83822
10	400	1930	80 05	Lekhnath Sadak	05-0531	1 4 9 0	1499	1 Fluxial Surfaces	(modern flood plain surfaces)	a	al	230	274 45.96	69.18	92.43	35.31	55 27654
10	400	1930	80 05	Lekhnath Sadak	05-0530	1490	1499	1 Fluvial Surfaces	(modern flood plain surfaces)	al	al	230	274 45.95	69.18	92.43	35.31	2,73679
3 F	400	1930	80 05	Lekhnath Sadak	05-0528	1490	1499	1 Fluvial Surfaces	(modern flood plain surfaces)	9	el	230	274 45.96	69.18	92.43	35.31	19.61123
LH	400	1930	80 05	Lekhnath Sadak	05-0528	1 4 9 0	1 499	1 Fluxial Surfaces	(modern flood plain surfaces)	al	al	231	274 45.21	68.18	91.27	3471	5836869
i H	400	1930	80 05	Lexnatt Sedek	05-0528	1 4 9 0	1499	1 Huvial Surfaces	(modern flood plain surfaces)	9		231	2/3 5012	75.26	100.34	3819	13487447
16	400	1930	80 05	Lexinati Sadak	05-0529	1490	1499	Fluxial Surfaces	(modern nood plain surfaces)	(a)	01	230	45.95	69.18	92.43	35.31	1215934
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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)		(C	d)			(0	g)			PC sce eart	6V by enari hqua	/ o ake		S dar by	tand nage segr	ard e rate nent	e t					
	A	В	C	D.	F	F	G	н	Ι	ĸ	L	М	N	0	Р	Q	R	s	Т	U	V	W	×	Y	Z	I
1	NP_ID	PIPE_ID	GridCode	TYPE	Ср	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	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
3	05-027-002	05-0187	230276	SI	0.5	400	0.2	1,930	80	Bs	Bs	0.4	32	38.07	57.11	76.15	29.8	0.355	0.705	1.079	0.216	0.0142	0.0282	0.0432	0.0086	5
4	05-027-002	05-0187	230275	SI	0.5	400	0.2	1,930	80	Bs	Bs	0.4	24	39.56	59.27	78.95	30.7	0.381	0.747	1.135	0.230	0.0153	0.0299	0.0454	0.0092	2
5	05-027-001	05-0186	229276	SI	0.5	400	0.2	1,930	80	Bs	Bs	0.4	9	38.03	57.05	76.07	29.8	0.354	0.704	1.077	0.215	0.0142	0.0282	0.0431	0.0086	ł.
6	05-037-026	05-0535	230275	SI	0.5	400	02	1,930	80	tr2	tr2	1.0	17	39.56	59.27	78.95	30.7	0.381	0.747	1.135	0.230	0.0381	0.0747	0.1135	0.0230	4
/	05-037-026	05-0535	230275	51	0.5	400	02	1,930	80	al	al	1.0	- 11	39.50	59.27	78.95	30.7	0.381	0.747	1.135	0.230	0.0381	0.0747	0.1135	0.0230	4
0	05-037-025	05-0534	230275	51	0.5	400	0.2	1,930	90	tr2	tr2	1.0	4	39.50	59.27	78.95	30.7	0.381	0.747	1.135	0230	0.0381	0.0747	0.1135	0.0230	4
10	05-037-023	05-0532	230275	SI	0.5	400	0.2	1,930	80	tr2	tr2	1.0	2	39.50	59.27	78.95	30.7	0.381	0.747	1 1 35	0230	0.0381	0.0747	01135	0.0230	í
11	05-037-022	05-0531	230275	SI	0.5	400	0.2	1,930	80	tr2	tr2	1.0	11	39.56	59.27	78.95	30.7	0.381	0.747	1.135	0230	0.0381	0.0747	01135	0.0230	ŝ
12	05-037-022	05-0531	230275	SI	0.5	400	0.2	1,930	80	al	al	1.0	155	39.56	59.27	78.95	30.7	0.381	0.747	1.135	0.230	0.0381	0.0747	0.1135	0.0230	5
10	AP 447 444	AF AFA4	00007	-			-	1 000		-		_					-	-				0.0107	0.00.10		0.0007	e.

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.

_														Dam p	age rat ipe seg	e * leng ment (n	th of n)	
vī	N	0	Р	Q	R	S	Т	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	Ē
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	0.001 4	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	
.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	
.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	
.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	
.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	
.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	
.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	
.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	
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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	В	С	D	E	F	G	Н	I	J	K
		Longth	Total /	Total /	Total /	Total /		Grid wise	Grid wise	Grid wise	Grid wise
	GridCode	Length (m)	Rm∗Length	Rm∗Length	Rm∗Length	Rm∗Length		Rm	Rm	Rm	Rm
1		(00)	CNS-1	CNS-2	CNS-3	WN		CNS-1	CNS-2	CNS-3	WN
2	204249	133.2	0.21 04	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.



PVC polyvinyl chloride•		A11	1 0%	2 20/	5 10/	11 20/	24.0%
Ceramic Work Pipe	A-D	ALL	1.076	2.370	5.170	11.570	24.970
Other than above	А	15 <pl< td=""><td>0.6%</td><td>1.3%</td><td>3.0%</td><td>6.5%</td><td>14.4%</td></pl<>	0.6%	1.3%	3.0%	6.5%	14.4%
Other than above	В	5 <pl≦15< td=""><td>0.4%</td><td>1.0%</td><td>2.2%</td><td>4.8%</td><td>10.6%</td></pl≦15<>	0.4%	1.0%	2.2%	4.8%	10.6%
Other than above	С	0 <pl≦5< td=""><td>0.4%</td><td>0.9%</td><td>2.0%</td><td>4.4%</td><td>9.7%</td></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.

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🖃 🥌 Layers	Sewer_Networ	k_with_PGA										
Sewer_Network_with_PGA	FID Shap	e id mea_leng	th sew_sec	sew_mat sw_di	a_dep pave_type	road_width	cons_year	GridCode	PGA_CNS1 P	GA_CNS2 PG	415.12	3A.WN Length
—	1 Polytine	42335 2	1.34 CIRCULAR F	CC(NP2)	0.25 BRICK	2	200	234254	215.23	3177	41512	135.85 21.341 39
	2 Polytine	42336 1	5.29 CIRCULAR R	CONP2)	0.3 ASPHALT	7	200	234254	215.23	317.7	41512	135.85 15.294 02
	3 Polytine	42338 2	4.69 CIPCULAR H	CO(NP2)	0.45 ASPHALT	/	200	234254	215.23	3177	41512	135.85 25.112 39
	5 Pohine	42340 2	013 CIRCULAR R	CONP2)	0.2 ASPHALT	10	200	234254	215.23	317.7	41512	135.85 20191943
	6 Polyline	42296 1	4.54 CIRCULAR R	CONP2)	0.3 STONE	3	200	233255	209.35	30618	395.7	13452 1453 35
	7 Polytine	42345 8	1.32 CIRCULAR F	(CO(NP2)	0.3 ASPHALT	3	200	233253	246.29	344.08	426.56	162.08 47.590 48
	8 Polyline	42345 8	1.32 CIRCULAR F	(CO(NP2)	0.3 ASPHALT	3	200	233252	260.59	365.D1	455.96	158.48 33.531584
	9 Polyline	42346	29.2 CIRCULAR R	CO(NP2)	0.3 ASPHALT	3	200	233252	260.59	365.01	455.96	168.48 29.197 64
	10 Polyline	42349 2	7.51 CIRCULAR R	CO(NP2)	0.3 NA	0	000	233253	246.29	344.08	426.56	162.08 27.507009
	11 Pontine	42350 2	5.76 CIRCULAR R	CONP2)	0.3 ASPHALT		200	233253	246.23	344.08	420.50	162.08 25.755 22
	13 Polyline	42353 1	2.83 CIRCULAR F	(CO(NP2)	0.3 ASPHALT	3	200	233253	246.29	344.08	426.56	162.08 12.825612
	14 Polyline	42355 2	1.53 CIRCULAR F	CC(NP2)	0.3 ASPHALT	3	200	233253	246.29	344.08	426.56	162.08 21.534 49

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.

4	1	S Netv by s	Sewe vork segm	r Data Ient	1	PC sce eart	6A b enar hqu	y io ake		JN sca ba	VA in ale ca ased o	tensi Iculat on PG	ty ed iA	Dar sev	nage wer segn	e rate line l nent	e of by	Da se	amage wer lii segme	e length ne by p ent (km	າ of oipe າ)
1	OBJECT ID	Line ID	Material	Length (km)	Grid Code	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	Damage Rate CNS-1	Damage Rate CNS-2	Damage Rate CNS-3	Damage Rate WN	Total Damage Length per Segment CNS-1 (km)	Total Damage Length per Segment CNS-2 (km)	Total Damage Length per Segment CNS-3 (km)	Totar Damage Length per Segmen WN (km)
432	430	44147	RCC(NP2)	0.013671	237249	255.7	351.8	430.2	164.0	5.1	5.4	5.6	4.	0.9	0.9	1.9	0.4	0.000123	0.000123	0.000260	0.00005
433	431	44198	RCC(NP2)	0.00769	236249	263.6	360.5	442.8	170.8	5.2	5.4	5.6	4,6	0.9	0.9	1.9	0.4	0.000069	0.000069	0.000146	0.00003
434	432	44201	RCC(NP2)	0.044229	236249	263.6	360.5	442.8	170.8	5.2	5.4	5.6	4.	0.9	0.9	1.9	0.4	0.000398	0.000398	0.000840	0.000177
435	433	44203	RCC(NP2)	0.015483	236248	258.0	351.1	424.1	165.7	5.1	5.4	5.6	4.	0.9	0.9	1.9	0.4	0.000139	0.000139	0.000294	0.000062
436	434	44204	RCC(NP2)	0.036394	236249	263.6	360.5	442.8	170.8	52	5.4	5.6	4.	0.9	0.9	1.9	0.4	0.000328	0.000328	0.000691	0.0001 4
437	435	44204 44205	RCC(NP2)	0.020040	230248	258.0	351.1	424.1	160.5	5.1	D.4 E.E.	5.0	4.	0.9	0.9	1.9	0.4	0.000240	0.000240	0.000506	0.000010
430	430	44205	RCC(NP2)	0.02278	235249	266.0	372.5	461.2	168.5	52	5.5	5.7	4	0.9	0.9	1.9	0.4	0.000205	0.000205	0.000176	0.000009
440	438	44208	RCC(NP2)	0.012936	236249	263.6	360.5	442.8	170.8	52	5.4	5.6	4.	0.9	0.9	1.9	0.4	0.000116	0.000116	0.000246	0.00005
441	439	44210	RCC(NP2)	0.030353	236249	263.6	360.5	442.8	170.8	52	5.4	5.6	4.	0.9	0.9	1.9	0.4	0.000273	0.000273	0.000577	0.00012

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);

Gric	I N	umbe	er	Grid-\	wise to length	tal dar (km)	nage
	1	Grid Code	B 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.

Q Demonstration.mxd - ArcMap												
File Edit View Bookmarks Insert Selection Geoprocessing Customic	ze Windows	timate	ed			PGA	vale		Da	maged	l build	ing
●	I 🗊 🖕 🖓 🙀	mber	of	n e	🕁 🗸 🔤	ov sce	nario	/ 🗉 🥫	🗟 🖬 🖬	nber (DL4+5) bv [⊡]
Table Of Contents # ×	Table					.,						/~/
Se 🔍 🧶 🧶 🗉	E - I 碧 - U	tility p	ole		•	earthq	Juake		scer	nario e	arthqı	Jake
🗉 😅 Layers	Power_pole_Dis	tribution_with	n_PGA & Dai	maged_	Building_Nu	umber						
Power_pole_Distribution_with_PGA & Damaged_Building_Number	FID Shape	GridCode	Pole_No	BdgNo	PGA_CNS1	PGA_CNS2	PGA_CNS3	PGA_WN	CNS1_DL45	CNS2_DL45	CNS3_DL45	WN_DL45
	O Polyzon	238311	0	0	106.9	160.35	213.81	116.57	0	0	0	0
	1 Polygon	239311	0	0	106.57	153.85	21313	115.25	0	0	0	0
	3 Polycon	240311	0	4	105.93	158.89	211.85	115.76	0.254264	0.582232	0.960789	0.2091.6
	4 Polyson	242311	0	0	105.63	158.43	211.24	115.45	0	0	0	0
	5 Polygon	243311	0	0	105.28	157.93	210.57	115.15	0	0	0	0
	6 Polygon	264311	0	0	98.99	1 48 49	197.98	1 09.8	0	0	0	0
	7 Polygon	265311	0	2	98,59	1 48.03	197.37	1 09.6	0108522	0.255592	0.428384	0.13773
	8 Polygon	266311	0	0	98.41	147.53	196.84	109.29	0	0	0	0
	3 Porveon	207311	0	0	90.62	147.22	196.29	109.05	0	0	0	0
	11 Polycon	289311	0	0	92.03	138.59	18478	103.94	ő	0	0	, o
	12 Polyton	228310	ŏ	ů.	111.11	166.67	222.22	119.19	ŏ	ŏ	ŏ	ŏ
	13 Polyson	229310	0	0	11078	16616	221.54	118.99	0	0	0	0
	14 Polygon	230310	0	0	110,4	165.61	220.81	118,69	0	0	0	0

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 \Box Gird-wise number of failure poles based on inputted data. All formula necessary for those calculations were already built based on the evaluation method.

	Estimated number of utility pole			PGA vale by scenario earthquake				JMA intensity scale calculated based on PGA					Failure rate due to seismic shaking (%)			
1	A OBJECT ID	B Grid Code	C Pole_No	PGA CNS-1	PGA CNS-2	PGA CNS-3	g PGA WN	Coversion IJMA from PGA CNS-1	Coversion IJMA from PGA CNS-2	Coversion IJMA from PGA CNS-3	K Coversion IJMA from PGA WN	Rs CNS-1	Rs CNS-2	Rs CNS-3	⊖ Rs CNS−4	
98	3299	238277	101	191.4	276.9	357.1	153.0	4,9	5.2	5.4	4.1	0.00005%	0.00005%	0.00005%	0.00005	
99	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	
00	3301	240277	50	184.5	264.7	336.7	148.9	4.8	5.2	5.4	4.	0.00005%	0.00005%	0.00005%	0.00005	
101	3302	241277	57	183.8	262.0	331.6	149.1	4.8	5.1	5.4	4.	0.00005%	0.00005%	0.00005%	0.00005	
02	3303	242277	88	176.3	251.3	317.5	143.5	4.8	5.1	5.3	4.	0.00005%	0.00005%	0.00005%	0.00005	
03	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%	0.000055	
04	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	
05	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	
106	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	
307	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	

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

		Dar nun scen	naged nber (D ario ea	buildir)L4+5) rthqua	ng by ake	Total collapse rate of building (%)				Fail t C	lure ra :o buil ollaps	ate du Iding se (%)	e	Total number of failure poles			
	P Bidg No	C DL4+5 Damaged Bldg No CNS-1	R DL4+5 Damaged Bldg No CNS-2	S DL4+5 Damaged Bldg No CNS-3	DL4+5 Damaged Bidg No WN	Total Collapse Rate of Bldg [%] CNS-1	Total Collapse Rate of Bldg [%] CNS=2	W Collapse Rate of Bidg [%] CNS=3	X Total Collapse Rate of Bldg [%] WN	Rb CNS-1	Rb CNS-2	Rb CNS-3	AB Rb CNS-4	AC Nfp CNS-1	AD Nfp CNS-2	AE Nfp CNS-3	Nfp CNS-4
5%	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
5%	1 4 1	11.65	31.10	51.78	5.91	8.3%	22.1%	36.7%	4.2%	0.01 41 45	0.037747	0.062846	0.007174	1.616548	4.313611	7.245811	0.819888
5%	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
5%	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
5%	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	0.646143	1.85913	3.380713	0.334236
5%	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
5%	219	13.59	32.27	51.34	8.09	6.2%	14.7%	23.4%	3.7%	0.01 0623	0.025222	0.040119	0.006319	0.858534	2.03833	3.242249	0.510691
5%	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
5%	209	13.20	31.06	49.75	7.82	6.3%	14.9%	23.8%	3.7%	0.01 0807	0.025432	0.040741	0.006408	0.769661	1.811186	2.90145	0.45638
5%	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													
ī			PGA			Pred	ominant Period of	Town Town	Bldg Type						
	PGA_Gorkha	PGA_WN	PGA_CNS-1	PGA_CNS-2	PGA_CNS-3	Predo_period	Center	Perimeter	rower_rype	blug_1ypc					
i	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						
i	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					
i	111.65	125.83	230.99	349.87	460.39	1.43	0	1.43	GBT						

(ii) Calculation and output

• Probability of BTS damage

	•	1100a0	muy of D	i S uamag	se						
					Prol BT d	oability of S tower amage		Combined probability of BTS facility, including building and tower			
	PGA: CNS-1										
	Da	amage Ratio o	f Building (<mark>P</mark>	' b)	Damage Ratio	■ Daı	nage Ratio of	$\mathbf{Pbt} = 1 \cdot (1 \cdot \mathbf{Pb}) \times (1 \cdot \mathbf{Pt}))$			
	Non Eng	ineered	Engin	eered	of BTS Tower		Roo				
	Center	Perimeter	Center	Perimeter	(Pt)	Non Eng	gineered	Engin	eered		
Probability of	RC1	RC1	RC2	RC2		Center	Perimeter	Center	Perimeter	Ground	
building	0	0	0	0	0.017919809	0	0	0	0	0.017919809	
damage 🔆	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	

•	Expect	ed numbe		Sum probabil	mation of ities of all	BTS					
	Damage of	fBuilding			Damage of BTS facility						
Non Eng	gineered	Engineered		Damage of BTS		Roo	ftop				
Center	Perimeter	Center	Perimeter	Tower	Non Eng	gineered	Engin	eered	Ground		
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.

🔊 Hur	man casu	alty assessment.xex and the	inside building ratio	n will be set		
	A	l e	for death estimati	on d		E
1		· · · · · · · · · · · · · · · · · · ·		••••		
2		1. Earthquake occurrence scene	**********		Ratio o	of inside building
3		Night	Select Earthquake Occurre	nce Scene		1.00
4						
5		Earthquake occurrence scene	Ratio of inside building			
6		Night	1.00			
7		Weekday Noon	0.90	***		
8		Weekend Afternoon	0.70			Basic information for
9						human casualty
10		2. Death rate				actimation is
11			Masonry	RC frame	and the second	
12		Building damage level 4 and 5	0.02188	0.03895		collectively put in
13						this sheet
14		3. Injured rate			,	
15		Injured rate	3.9163			
16						
17						

BASIC INFO Calculation Sheet

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

Вн	uman casualty assess	ment.xlsx		6	anut nonul	ation of ni	ght and daytime and
	A	В	С	D	iput popui		grit and daytime and
1					ouilding nu	mber here	, the population per
2	Earthquake Occur	rence Scene:		Night	bui	lding will b	e calculated
3					Jui		Je calculated
4							
5					***		
6	Municipality / Ward	Municipality /	Population	Population	No. of Building	people per	
7	wunicipality / waru	Ward	(night)	(daytime)	NO. OF BUILDING	building	
8	Anantalingeshwar	1	43,699.05	29,199.34	8,936.26	4.89	
9	1	0	4,490.96	3,000.82	527.19	8.52	
10	2	0	3,425.10	2,288.62	1,002.67	3.42	
11	3	0	3,505.78	2,342.53	988.46	3.55	
12	4	0	2,026.99	1,354.42	330.33	6.14	
13	5	0	5,799.40	3,875.11	747.64	7.76	

Human casualty assessment.xlsx												
	G	Н	I	J	К	L	ιηρυτ οι	lilding dan	nage of Elv	15 DL345 T	or :	
1							each structure type, estimated from					
2								1.11	/ - /			
3							ומ	iliding dan	nage asses	sment		
1							· · · · · · · · · · · · · · · · · · ·		•••••	•••••	••••	
5												
	CNS-3: Estimated Dmare Building Number for DL345											
6				CNS-3: Est	timated Dmage B	uilding Number f	or DL345				1-1-1	
6	Adobe	SMM	BMM 1	CNS-3: Est BMM 2	timated Dmage B BMM 3	uilding Number f SCM	or DL345 BCM	RC N Eng	RC Eng	Others	total	
6 7 8	Adobe 260.32	SMM 130.05	BMM 1 410.71	CNS-3: Est BMM 2 299.55	timated Dmage B BMM 3 117.58	uilding Number f SCM 17.11	or DL345 BCM 1,656.21	RC N Eng 2,654.36	RC Eng 427.48	Others 150.62	total 6,123.99	
6 7 8 9	Adobe 260.32 4.97	SMM 130.05 2.53	BMM 1 410.71 19.46	CNS-3: Est BMM 2 299.55 8.93	timated Dmage B BMM 3 117.58 5.90	uilding Number f SCM 17.11 0.49	or DL345 BCM 1,656.21 90.94	RC N Eng 2,654.36 179.55	RC Eng 427.48 22.73	Others 150.62 5.72	total 6,123.99 341.23	
6 7 8 9 10	Adobe 260.32 4.97 10.10	SMM 130.05 2.53 5.34	BMM 1 410.71 19.46 32.31	CNS-3: Est BMM 2 299.55 8.93 19.05	timated Dmage B BMM 3 117.58 5.90 10.33	uilding Number f SCM 17.11 0.49 1.13	or DL345 BCM 1,656.21 90.94 155.50	RC N Eng 2,654.36 179.55 346.22	RC Eng 427.48 22.73 54.99	Others 150.62 5.72 11.95	total 6,123.99 341.23 646.92	
6 7 8 9 10 11	Adobe 260.32 4.97 10.10 9.28	SMM 130.05 2.53 5.34 4.81	BMM 1 410.71 19.46 32.31 31.58	CNS-3: Est BMM 2 299.55 8.93 19.05 17.88	timated Dmage B BMM 3 117.58 5.90 10.33 10.12	uilding Number f SCM 17.11 0.49 1.13 1.03	or DL345 BCM 1,656.21 90.94 155.50 154.71	RC N Eng 2,654.36 179.55 346.22 344.56	RC Eng 427.48 22.73 54.99 52.25	Others 150.62 5.72 11.95 11.46	total 6,123.99 341.23 646.92 637.67	
6 7 8 9 10 11 12	Adobe 260.32 4.97 10.10 9.28 6.89	SMM 130.05 2.53 5.34 4.81 3.86	BMM 1 410.71 19.46 32.31 31.58 15.66	CNS-3: Est BMM 2 299.55 8.93 19.05 17.88 10.07	timated Dmage B BMM 3 117.58 5.90 10.33 10.12 4.50	uilding Number f SCM 17.11 0.49 1.13 1.03 0.65	or DL345 BCM 1,656.21 90.94 155.50 154.71 62.59	RC N Eng 2,654.36 179.55 346.22 344.56 97.10	RC Eng 427.48 22.73 54.99 52.25 16.03	Others 150.62 5.72 11.95 11.46 5.10	total 6,123.99 341.23 646.92 637.67 222.46	

N) F	uman casualty	assessment.xls	x							
	R	S	Т	U	V	W	× mb	ut bullair	ig damage	
1							е	ach struct	ure type.	estimated
2								buildin	g damage	assessmer
4							` •••••••			•••••
5										
6				CNS-3: Es	timated Dmage	Building Number	for DL45			
7	Adobe	SMM	BMM_1	BMM_2	BMM_3	SCM	BCM	RC_N_Eng	RC_Eng	Others
8	252.0200	119.8627	380.6567	256.9337	101.4057	13.7615	1339.1722	1903.3062	277.4539	120.9024
9	4.8620	2.3791	18.0817	7.7144	5.0632	0.3989	72.0697	124.5520	14.1591	4.5521
10	9.858	4.9843	29.9494	16.3718	8.8341	0.9015	123.2221	241.3887	34.3865	9.5165
11	9.0668	4.5080	29.4016	15.4461	8.7227	0.8332	124.0290	243.0318	33.1497	9.1700
12	6.738	3.6259	14.5726	8.7584	3.8785	0.5281	50.2744	68.0288	10.0828	4.1369
	E 6011	2 05/2	20.8478	11 8518	6 6124	0.6545	08 1363	223 8373	35,0366	7 25///

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🔊 н	luman casualty	assessment.xl	sx		Ca	lculation			Ecti	imated recu	lts of dooth
	AB				AFCON	aitions a	re	AI	AU ESU	inaleu resu	its of ueath,
1			Masonry	RC frame	shc	wing he	re i		in	jured and e	vacuee are
2		Death rate	0.02188	0.03895						ovnrosso	d horo
3		Injured rate	3.9163	3.9163						expresse	unere
4		Inside ratio	1.0000	1.0000							
5	-						·				
6	Τα	ital	De	ath	Inju	red			Results		
7	Masonry	RC	Masonry	RC	Masonry	RC		Death	Injured	Evacuee	
8	2,584.71	2,180.76	276.55	415.37	1,083.06	1,626.71		591.92	2,709.77	29,255	
9	115.12	138.71	21.46	46.03	84.03	180.25		67.48	264.28	2,839	
10	203.64	275.78	15.22	36.69	59.61	143.70	i –	51.91	203.31	2,158	
11	201.18	276.18	15.61	38.15	61.14	149.42	1	53.76	210.56	2,208	
12	92.51	78.11	12.42	18.67	48.64	73.11		31.09	121.76	1,334	
13	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 Retrofitting Guidelines

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.



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.



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,









Ground model



Heavily Damaged Building Ratio



LDCRP Technical Guideline and DCR Plan



NBC 205 : 1994

MANDATORY RULES OF THUMB REINFORCED CONCRETE BUILDINGS

He Illipsety's Coverviewt of Nepal Ministry of Physical Planning and Works Department of Urban Development and Building Construction

Is your house strong enough against earthquake?

Majority of existing buildings are vulnerable to

earthquake. Seismic diagnosis and retrofitting of

the existing structures should be carried to ensure

Seismic Strengthening of Existing Building:

NEPAL NATIONAL BUILDIN NDC 105: 1994

> SEISMIC DESIGN OF BUILDINGS IN NEPAL

His Maxedy's Government of Hepal Ministry of Physical Plenning and Works Department of Urben Development and Building Construction Bilde Maide, Kathwak, NSPAL

afety of your house.

बस्ती विकास, सहरी योजना तथा भवन निर्माण सम्बन्धी

नेपल सावल सडरी विकास मन्द्रासम विवरणमा, साउमाडी

Images of NBC, Byelay

आधारभूत निर्माण मापदण्ड, २०७२

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.





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







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

ERAKV

The Project for Assessment of

EARTHQUAKE DISASTER RISK

for the Kathmandu Valley in Nepal



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.



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.



SCENARIO EARTHQUAKES

Three scenario earthquakes: Far-Mid Western Nepal, Western Nepal and Central Nepal South, are proposed for the purpose seismicity, tectonics and active faults.



and lifeline.

Scenario Earthquakes	PGA Range (gal)	Strength		Comparison with Gorkha Eq shaking level	
Far-Mid Western Nepal(71-216	V	weak	Very Small comparing with other scenarios	
Western Nepal (WN) (M=	91-303			Approximately same	
	CNS-1	91-519			Approximately 1.5 times
Central Nepal South	CNS-2	136-777			Approximately 2 times
[CNS] (M=7.8]	CNS-3	181-1055	5	Strong	Approximately 2.75 times



Earthquake Occurrence Mechanism

DAMAGE ESTIMATE FOR KATHMANDU VALLEY [Case CNS-2]

BUILDING

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



🕨 विपद् जोखित न्यूनीकरण

के तपाई नयाँ घर निर्माण गर्दै हुनुहुन्छ ?

भवन संहिता तथा सापदण्ड पालना गरौ

राष्ट्रिय भवन संहिता, सापदण्ड तथा उचित निर्साण 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।

NEPAL NATIONAL BUILDING CODE NOC 165: 1854	NEPAL NATIONAL BUILDING CODE NEC351 1994	वस्ती दिकास, सहरी सोजना तथा मवन निर्माण सम्बन्धी आधारमूत निर्माण मापदण्ड, २८७२
		8
STESMIC DESIGN OF BUILDINGS IN NEPAL	MANDATORY RULES OF THUMB REINFORCE DONCETTE BUILDINGS WITHOUT MASONRY INITIL	वेचन सामार सडगी विकास मन्द्रावय विकारण, साल्पनी
His Massin's Generatori of Hond Manasy of Physical Raming and Webs Department of Uken Devicement and Building Construction Mar Mail, Laborato, VBNL 2010	No Reputy Construct of Repd Beneficially of Physical Terrority and Works Department of USAD Physical Terrority October Res Mail Science (1974)	484 1041

अधिकांश निर्तित अवनहरू भूकम्प सङ्कटासन्न रहेको अवस्था छ। विद्यतान

भवन संरचनाहरूको नियमित भूकम्पीय विश्लेषण र प्रबलीकरण गरी

के तपाईको घर भूकम्प प्रतिरोधी छ ?

वेद्यसान घरहरूको भूकक्पीय प्रबलीकरण गर्ने :

हाक्रो जीवनको सुरक्षा सुनिश्चित गर्न अपरिहार्य छ।

कू-उपयोग नकूना नक्सा



भकक्पीय प्रबलीकरण निर्देशिका

के तपाईले घर उचित स्थानमा बनाउनु भरको छ ?

भू-उपयोग नीति तथा योजना अनुसार संरचना निर्माण गरौ : प्रकोपोन्तुख क्षेत्रता कुनै पनि संरचना निर्ताण 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।



विपद्को अवस्थामा तपाईले आफ्नो समुदायलाई कसरी सहयोग पुऱ्याउनु हुन्छ ?

विपद् जोखित जनचेतना र व्यवस्थापनः

कुनै पनि समुदायमा त्यहाँका बासिन्दा विपद् जोखिम र त्यसको न्यूनीकरण तथा व्यवस्थापनका तरिकाहरूको बारेता 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 |

भूकक्प गरको अवस्थामा तपाई कहाँ जानुहुन्छ ? खुला स्थलहरुको संरक्षण

भूकम्प गरको समय र भूकम्प पश्चातको समय दुवैमा खुला स्थलहरुको धेरै सहत्व हुन्छ । अनुकूलित आश्रय स्थलको सुनिश्चितताको लागि खुला स्थलहरुको संरक्षण तथा संवर्द्भनलाई प्रोत्साहन गर्नपर्दछ।



🕨 परियोजनाको रूपरेखा र उपलव्धि

"काठमाडौ उपत्यका भूकम्प विपत्ति जोखिम मूल्याङ्रन परियोजना" JICA को सहयोगमा कार्यान्वयन भएको परियोजना हो | विपद् जोखित विश्लेषणको आधारता प्रभावकारी तथा दिगो उपायहरू प्रयोग गरी विपद् जोखित न्यूनीकरण गर्नु यसको तुख्य उद्देश्य रहेको छ | ३ वर्ष सत्तयावधि रहेको यस परियोजनाको प्रारक्त २०७२ वैशाखता क्षरको थियो क्षने २०७५ वैशाखता सतापन 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 सुख्य लक्ष्य रहेको छ।

यस परियोजनाको नेपाल सरकारका तर्फबाट प्रमुख समकक्षीको रूपमा सहरी विकास मन्त्रालय, गृह तन्त्रालय , संघीय तातिला तथा स्थानीय विकास तन्त्रालय र खानी तथा क्रूगर्भ विभाग रहेका छन् भने ललितपुर महानगरपालिका , भक्तपुर नगरपालिका र बुढानिलकण्ठ नगरपालिका परियोजनाको पाइलट गतिविधिका लागि लक्षित ३ वटा पाइलट नगरपालिका हुन् । यस परियोजनाका मूख्य उपलव्धिहरू निक्नानुसार छन्

- काठमाडौ उपत्यकाको भूकम्पीय प्रकोप मूल्याङ्कन
- काठताडौ उपत्यकाको भूकत्म्पीय जोखित सूल्याङ्कल

♦ ३ वटा पाइलट नगरपालिकाहरूको लागि "अक्त रात्रो र बलियो (Build Back Better – BBB] पुनर्निर्काण योजना", "स्थानीय विपद् तथा जलवायु उत्थानशील योजना", "आधारभूत कार्यसञ्चालन विधि" को तर्जुमा र "समुदायमा आधारित विपद् जोखिम न्यूनीकरण तथा व्यवस्थापन गतिविधिहरु" सञ्चालन

 नेपालको सक्पूर्ण स्थानीय निकायहरुको लागि स्थानीय विपद् तथा जलवायु उत्थानशील योजनाको प्राविधिक निर्देशिकाको तर्जुमा



परियोजनाको अध्ययन क्षेत्र











स्थानीय विपद् तथा जलवायु उत्थानशील योजना तथा प्राविधिक निर्देशिका



परियोजनाका बिषयबस्तुहरु





काठमाण्डौ उपत्यका भूकम्प विपत्ति जोखिम मूल्याङ्कन परियोजना



विपद् जोखित्तबारे बुकाइ, दिगो विकासका लागि विपद् जोखिम न्यूनीकरप





सहरी विकास तन्त्रालय गृह तन्त्रालय संघीय मामिला तथा स्थानीय विकास मन्त्रालय खानी तथा भूगर्भ विभाग



नापान अन्तर्राष्ट्रिय सहयोग नियोग (जाइका)

काठमाण्डौ उपत्यका भूकम्प विपत्ति जोखित तूल्याङ्रन परियोजना

ERAKV Koral Japan

> भुकक्पः इतिहास, वर्ततान र भविष्य

हिमालय श्रंखलाको आसपासमा रहेको नेपालको अधिकांश भूभाग भूकम्प प्रकोपजन्य क्षेत्रमा पर्दछ | शेतिहासिक लेख, शिलापत्र र पछिल्लो समयको विभिन्न अध्ययन अनुसन्धान अनुसार यस क्षेत्रता इतिहासको वित्तिन्न कालखण्डता भुकक्प गरको देखिन्छ।



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

नेपालको भुभाग दक्षिणमा इण्डियन प्लेट र उत्तरतर्फ तिब्बतीय प्लेट माथि अवस्थित छ । इन्डियन प्लेट कमिक रुपमा तिब्ब्तीय प्लेटमा घम्रिदै जाँदा सञ्चित हुने शक्ति उत्सर्ग हुँदा यस भुभागमा भुकम्प जान्छ । यसरी शक्ति सञ्चयको अवधि जति लामो समयसम्म हुन्छ त्यति नै ठूलो क्याञिनच्युडको र विनाशकारी भुकक्प जाल्छ |



🕨 परिदृश्य भूकक्पहरू

पश्चिम नेपाल र मध्य दक्षिण नेपाल नामका तीन परिदृश्य भूकम्पहरू प्रस्ताव गरिस्को छ।



जोखित न्यूनीकरणको लागि CNS-2 को अनुतान प्रयोग गर्ने सल्लाह दिइएको छ।

परिदृश्य भूकम्पहरू	PGA वितरण (gal)	हल्लाइको अवस्था		ञोरर्खा भूकक्पको तूलनामा जमीनको हल्लाइको तह	
सूदूर-मध्य पश्चिम नेपाल परिदृश [M=C.&]	ଜଟ-୧୩३		कताजोर	अन्य परिदृश्यहरू भन्दा निकै सानो	
पश्चित नेपाल परिदृश्य (WN) (M	60-303			लगभग उतिकै	
	CNS-1	୧ঀ–ୢ୳ঀ୧			लञभग १.५ गुणा बढी
त्तध्य दक्षिण नेपाल (CNS)	CNS-2	୧३୧ – ୦୦୦			लगभग २ गुणा बढी
[M=७.८]	CNS-3	ዓႠ৭-ዓоႸႸ		शक्तिशाली	লসমস ২.७५ সুणा ৰढी



गोरखा भूकक्पसँग परिदृश्य भूकक्पको तुलना

उपलव्ध तथ्याङ्गहरू र पूर्वधारणाका आधारता अनुत्तानित क्षति प्रस्तुत गरिस्को छ । तसर्थ, यथार्थ क्षति अनुतानित क्षतिबत्तोजित नहन सक्छ ।