Seismic Screening of Large Water Pipelines for TWC's Seismic Improvement Program

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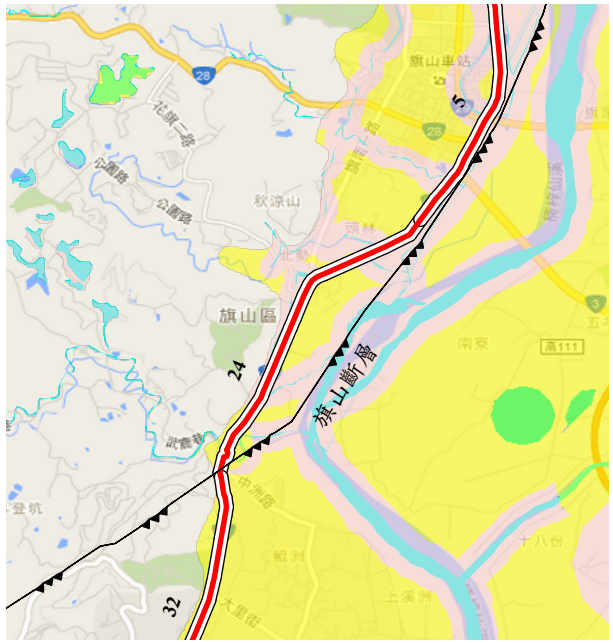
Target pipelines

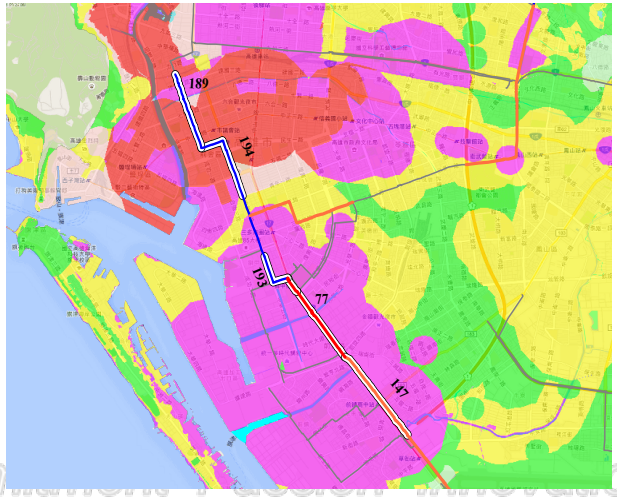
- All with a diameter of 800mm or larger
  - 2,229km
  - in terms of 6,500 plus GIS objects

- Re-organized into 1,687 "**pipeline evaluation units**"

Seismic exposure

- Number of fault crossings
  - 61 (3.6%)
- Number of fault vicinities
  - 42 (2.5%)
- Pipelines in liquefiable areas ($P_L \geq 20$)
  - 314.9km (14.1%)





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Goals and methodology

- **Goal: seismic screening**
  - Sorting according to importance
  - Ranking according to seismic risk

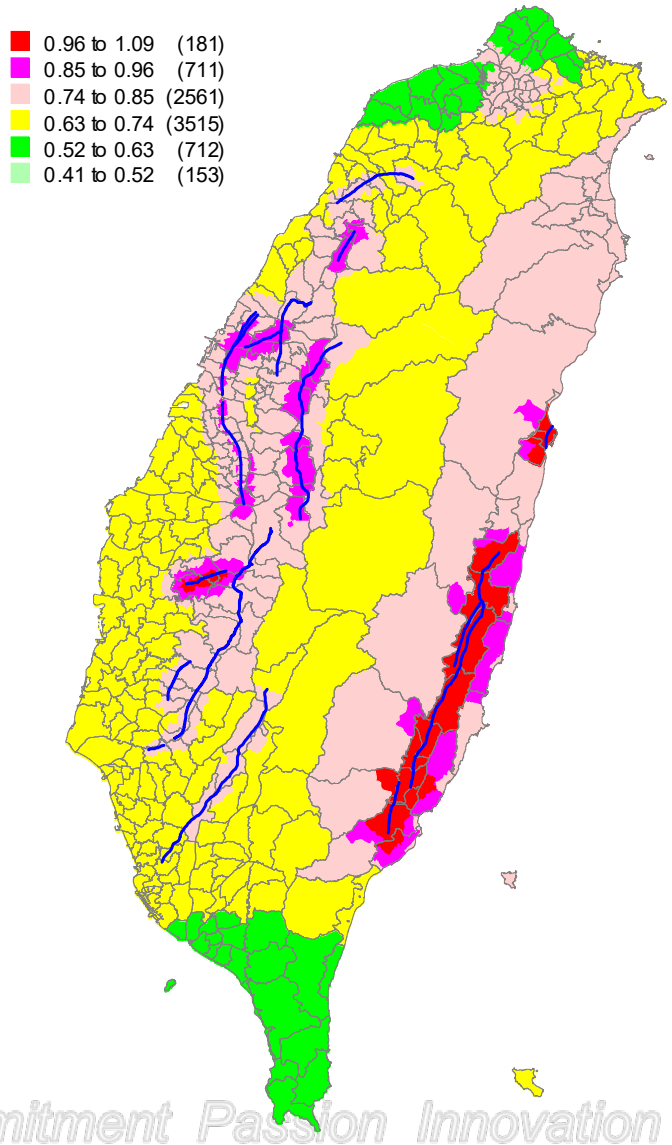
- **Methodology**
  - Hazard and vulnerability of pipelines
    - Independent and quantifiable
  - Risk
    - A combination of hazard and vulnerability
  - Risk-importance matrix

Importance of pipelines

- Four classes of pipeline importance
  - Very important
    - Very large flow, no redundancy, …
  - Important
    - …
  - Normal
    - …
  - Low
    - Low flow, one or more redundancies

Hazard maps (1), ground shaking

- *PGV* of design earthquake (a 10% chance of exceedance in 50 years)
- Derived from designed code-specified S_{D1} (spectral acceleration at $T = 1.0s$)
  - site amplification effect: medium site condition throughout
  - near fault effects considered except that from Chelungpu fault



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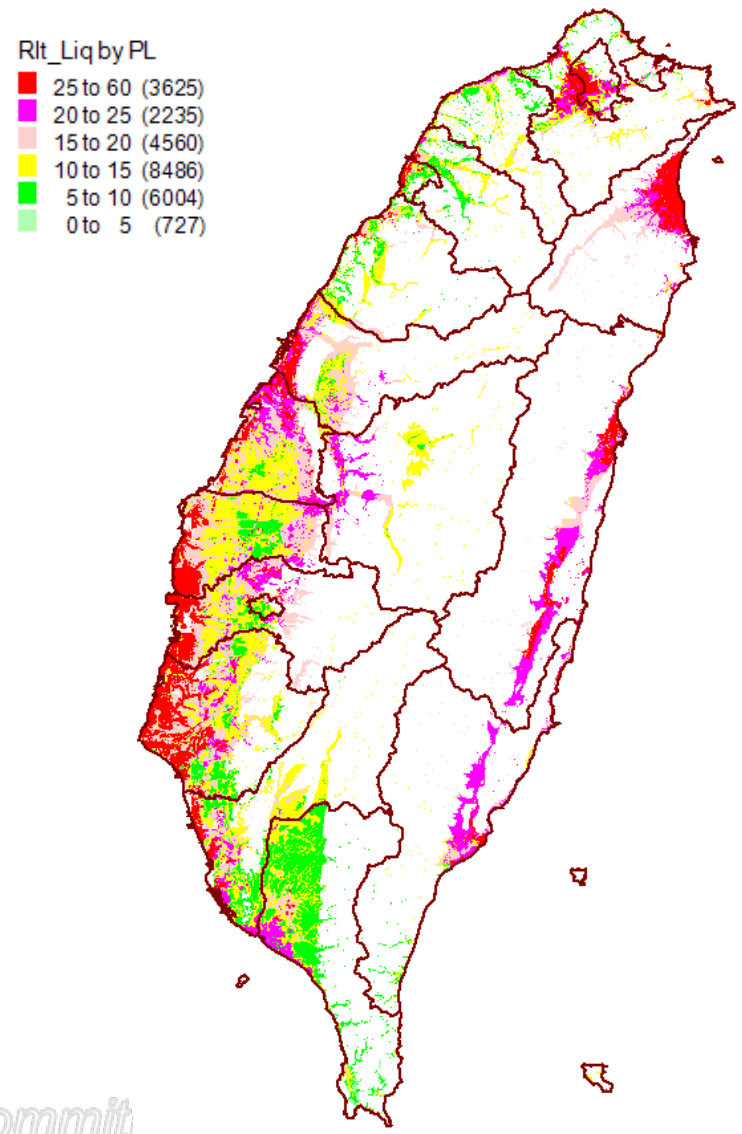
Hazard maps (2), soil liquefaction

- P_L (liquefaction potential index) of design earthquake (a 10% chance of exceedance in 50 years)
  - 10 liquefaction susceptibility categories by Yeh (2015)
  - design code-specified PGA and earthquake magnitude
  - ground water level not considered



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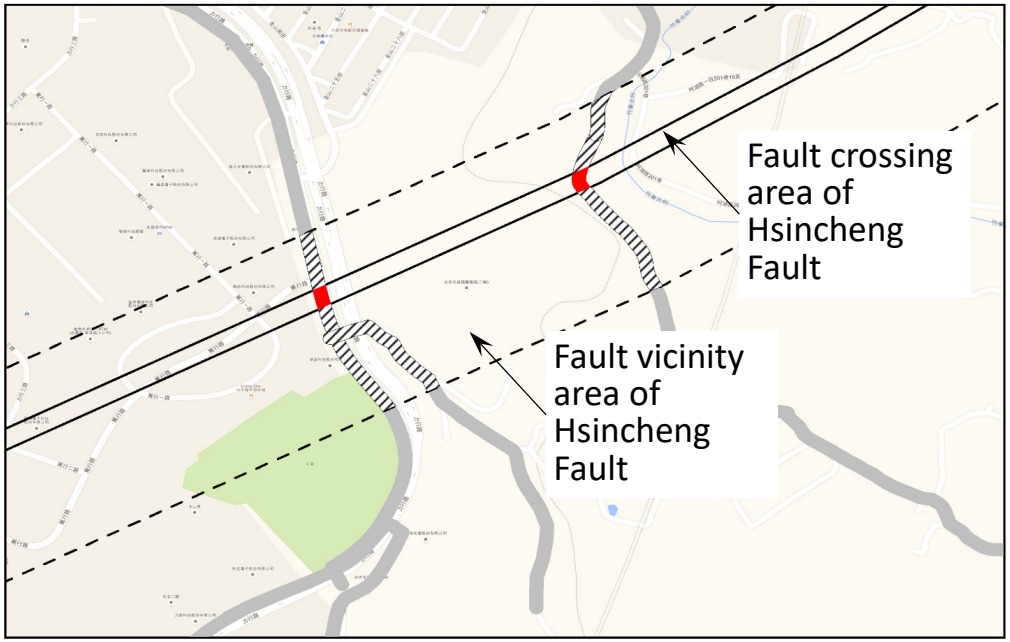
Hazard maps (3), fault rupture

- L_c and L_v, effective lengths of a unit encountered with fault crossing and fault vicinity
  - Active fault map of Taiwan, with Chelungpu fault excluded
  - Different areas in hanging walls and footwalls for different types of faults



Fault vicinity area
Fault crossing area
Buffer region of a pipe evaluation unit
Area of fault crossing of a pipe evaluation unit
Area of fault vicinity of a pipe evaluation unit

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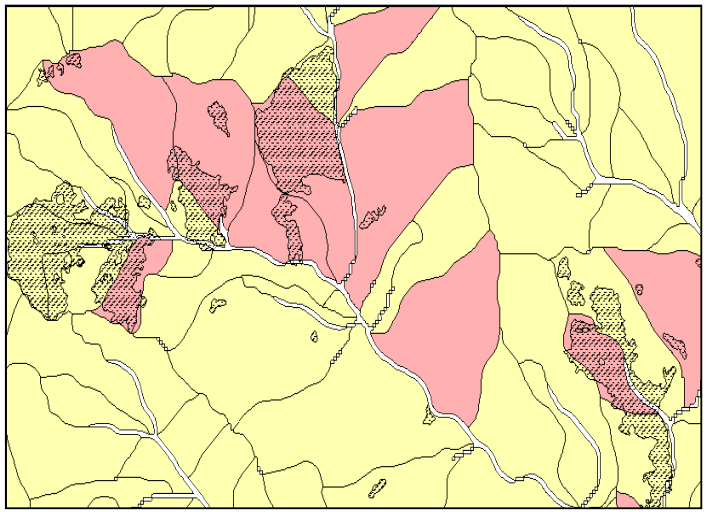
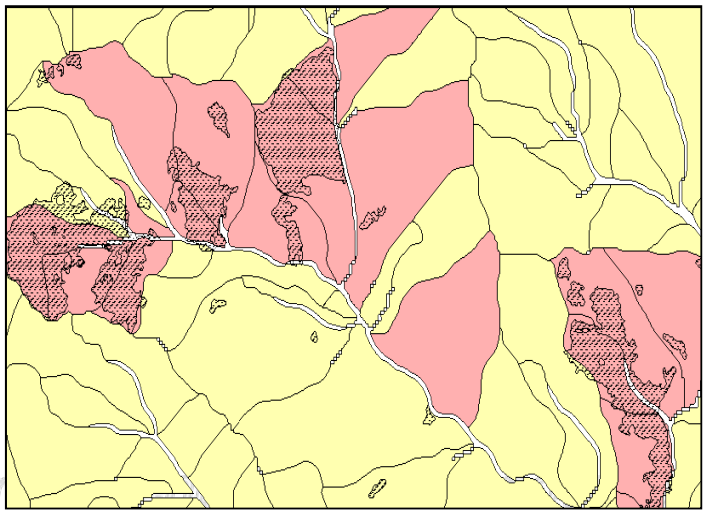
Hazard maps (4), landslide

- Landslide score
  - landslide potential map by Central Geological Survey, MOEA





High Score = 3

Medium Score = 1

Low Score = 0

Landslide occurred before

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Quantified the hazards to a "unit"

Ground shaking

$$H_{GM} = \left(\overline{PGV} - 15\right)^{1.14} - (30-15)^{1.14}$$
$$= \left(\overline{PGV} - 15\right)^{1.14} - 21.915$$

$$\overline{PGV} = \sum_j \frac{A_j}{A} \cdot PGV_j$$

Fault rupture

$$H_F = \min\left(10L_c + L_n, 600\right) \cdot \overline{D} \cdot f$$

$$\overline{D} = \begin{cases} D & D < 1.0 \\ 1.0 & D \geq 1.0 \end{cases}$$

(D: mean offset)

$$f = \begin{cases} 1 & R \geq 500 \\ 2 - \dfrac{R-200}{300} & 200 < R < 500 \\ 2 & R \leq 200 \end{cases}$$

(R: return period)

Soil liquefaction

$$H_{LQF} = \overline{PL} \cdot \log_{10} L$$

$$P_L = \sum_j \left(\frac{A_j}{A} \cdot P_{L,j} \right)$$

$$\overline{PL} = \begin{cases} 0 & P_L < 10 \\ P_L - 10 & 10 \leq P_L < 30 \\ 20 & P_L \geq 30 \end{cases}$$

Landslide

$$H_{LS} = \sum_{j=1}^{4} \frac{A_j}{A} \cdot LS_j$$

$$LS = \begin{cases} 0 & \text{Non} \\ 0 & \text{Low} \\ 1 & \text{Medium} \\ 3 & \text{High} \end{cases}$$

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Diverse "hazards" to the pipelines

- **Ground shaking**
  - $PGV = 43.3 \sim 105.4$ cm/s
- **Soil liquefaction**
  - $P_L = 0 \sim 43.15$
- **Fault rupture**
  - $L_c = 0 \sim 539$m $L_n = 0 \sim 1{,}833$m
- **Landslide**
  - Score = 0 ~ 2.15

How to combine them into a single Hazard value for each unit?

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Combined hazards to a "unit"

- **Order points**
  - For each type of hazard, sort all units according to the hazard value from low to high
  - Give the order point of a type of hazard to each unit

$$\bar{H}_{GM}(i) = r\left(\frac{i}{1687}\right) \quad i = 1,\ldots,1687$$

$$\bar{H}_{F}(i) = \begin{cases} 0 & i = 1,\ldots,1584 \\ r\left(\frac{i}{1687}\right) & i = 1585,\ldots,1687 \end{cases}$$

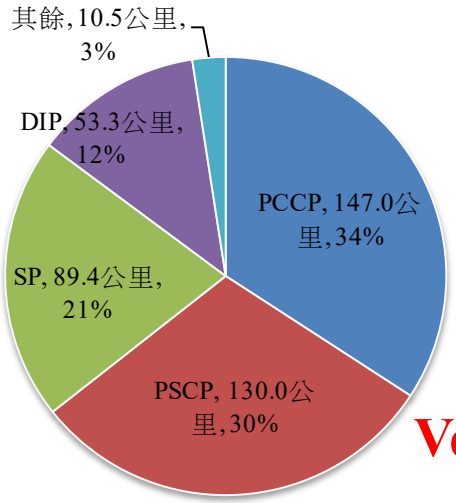
$$\bar{H}_{LQF}(i) = \begin{cases} 0 & i = 1,\ldots,606 \\ r\left(\frac{i}{1687}\right) & i = 607,\ldots,1687 \end{cases}$$

$$\bar{H}_{LS}(i) = \begin{cases} 0 & i = 1,\ldots,1469 \\ r\left(\frac{i}{1687}\right) & i = 1470,\ldots,1687 \end{cases}$$

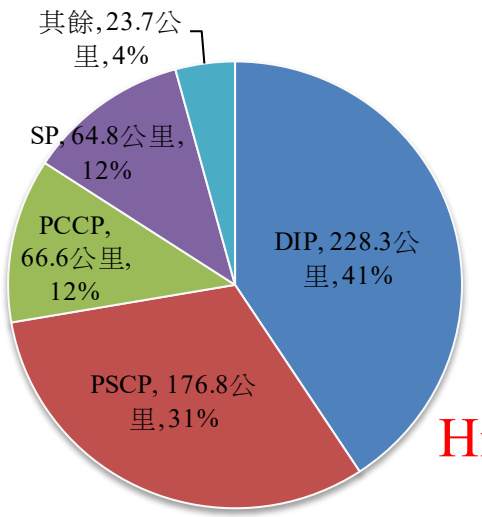
- **Normalized hazard to a unit**

$$\bar{H} = 0.45\bar{H}_{GM} + 0.45\bar{H}_{LQF} + 0.08\bar{H}_{F} + 0.02\bar{H}_{LS}$$

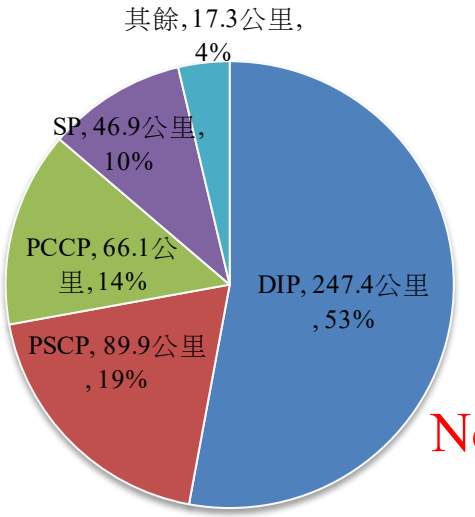
Pipelines of different importance



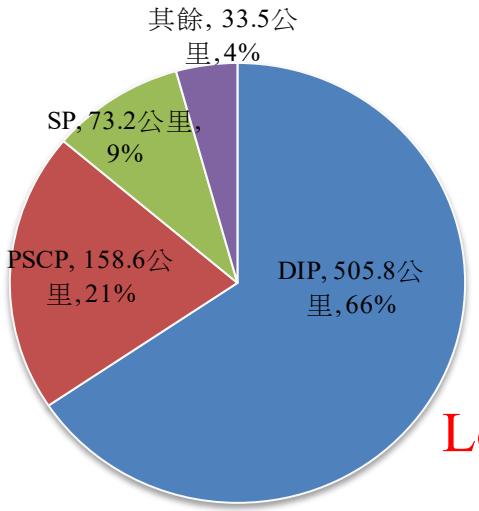
Very high (19.30%)



High (25.13%)



Normal (20.98%)



Low (34.59%)

Vulnerability of pipelines

- **Of a pipe**

$$V = \log_{10}\left(10 \cdot C_p\right) \times \left(\frac{800}{\phi}\right)^{0.125}$$

- **Of a pipeline evaluation unit**

$$V = \sum_k \frac{L_k}{L} \cdot V_k$$

- **Normalized into [0, 1]**

$$\overline{V} = \frac{V - V_{\min}}{V_{\max} - V_{\min}}$$

C_p : **Pipe type (joint)** correction factor to the repair rate equation by Miyajima (2013)

ϕ : **pipe diameter** in mm

Risk and risk groups

- Of a pipeline evaluation unit

$$R = \left(\overline{H} + 1\right) \cdot \left(\overline{V} + 1\right)$$

- Sorting all pipeline evaluation units into 10 "**risk groups**" from high to low

Risk-importance matrix

Risk Group	Very High	High	Normal	Low	Sum
R1	29	51	38	51	169
R2	53	33	40	43	169
R3	46	38	34	51	169
R4	20	56	28	65	169
R5	34	55	30	50	169
R6	18	45	47	59	169
R7	22	35	57	55	169
R8	24	34	44	67	169
R9	41	27	31	70	169
R10	6	48	26	86	166
Total	293	422	375	597	1,687

Priorities of units to for enhancement

- First priority: 29 + 53 = 82
- Second priority: 51 + 46 = 97
- Third priority: 33 + 20 = 53

Priority	Order	Combination	No. units
First	1	(Very high, R1)	29
	2	(Very high, R2)	53
Second	3	(High, R1)	51
	4	(Very high, R3)	46
Third	5	(High, R2)	33
	6	(Very high, R4)	20

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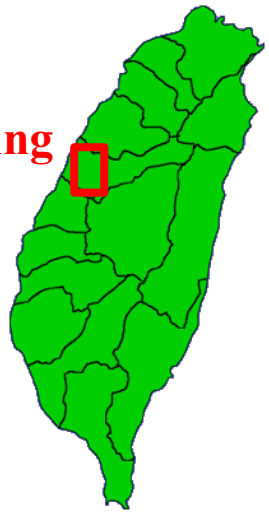
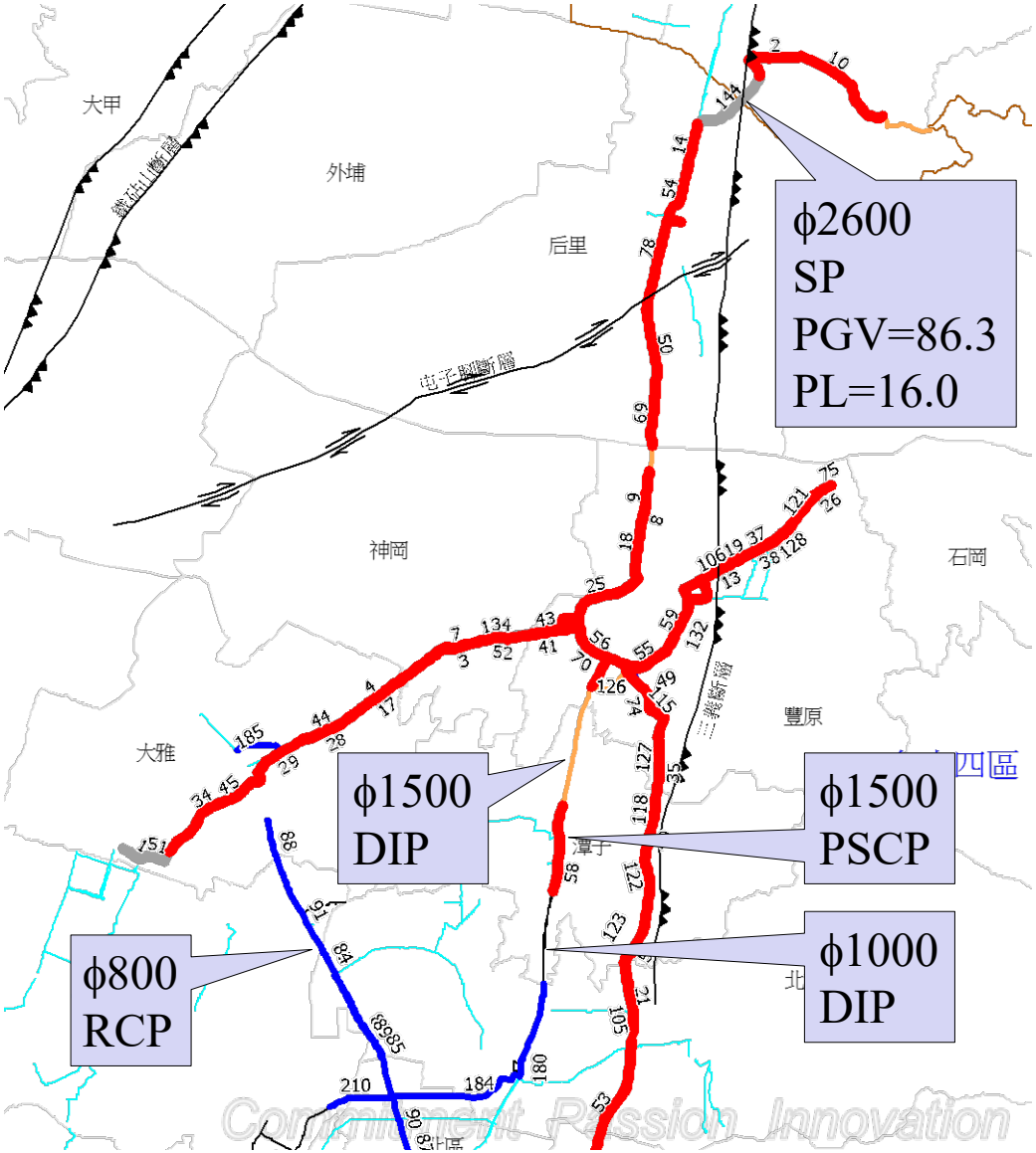
The suggested units from 4th Branch



No. of evaluation units	
	47
	3
	24

- Very high importance, risk groups R1 and R2
- Very high importance, risk groups R3 and R4
- High importance, risk groups R1 and R2
- Very high importance, risk groups R5 to R10
- High importance, risk groups R3 to R10
- Normal and low importance, all risk groups



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Concluding remarks

- First step: screening
  - Hazard maps-based
  - 232 pipeline evaluation units (13.7%) suggested for seismic enhancements
    - First priority: 4.9%
    - Second priority: 5.7%
    - Third priority: 3.1%
- Second step: assessment
  - Site investigation-based
- Third step: implementation
  - Seismic objectives and strategy of TWC

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Thanks for your attention!