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Japan Water Research Center

Review of an Equation to Estimate Seismic Damage to Water Mains in Light of the 2016 Kumamoto Earthquake

Yuko TSURUDA

Japan Water Research Center

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Damage prediction equation

JWRC Made

The equation to estimate (predict) the number of pipe failures in earthquakes

Analysis

1995 Kobe earthquake
2004 Chūetsu earthquake
2007 Chūetsu offshore earthquake
2011 Great East Japan Earthquake

Damage prediction equation

Purpose of the equation

- To Predict pipe damage **easily and accurately**
- To help utilities prioritize seismic improvement of pipelines

Damage prediction equation

If there is no information available on liquefaction or there is no possibility that liquefaction occurs	If there is an information available on liquefaction and there is a possibility that liquefaction may occur
$$R_m = C_p \times C_d \times C_g \times R(v)$$	$$R_m = C_p \times C_d \times R_L$$
R_m: Estimated damage rate [locations/km] C_p: Correction factor for pipe and joint type C_d: Correction factor for pipe diameter C_g: Correction factor for microtopography R(v): Reference damage rate [locations/km] $R(v)=9.92\times10^{-3}\times(v-15)^{1.14}$ v: Peak ground velocity (**PGV**) (cm/s) $(15\leqq v<120)$	R_m: Predicted damage rate [locations/km] C_p: Correction factor for pipe and joint type C_d: Correction factor for pipe diameter R_L: Average damage rate of liquefaction area [locations/km], R_L = 5.5

Correction factor

Pipe and joint type	C_p
DIP(A)	1.0
DIP(K)	0.5
DIP(T)	0.8
DIP(disengagement prevention)	0
CIP	2.5
VP(TS)	2.5
VP(RR)	0.8
SP(welding)	0.5/ 0
SP(non-welding)	2.5
ACP	7.5
PE(electrofusion)	-

Diameter (mm)	C_d
Φ50 - 80	2.0
Φ100 - 150	1.0
Φ200 - 250	0.4
Φ300 - 450	0.2
Φ500 - 900	0.1

Microtopography where pipes are installed	C_g
Mountain, mountain foot, hill, volcanic area, volcanic mountain foot, volcanic hill	0.4
Gravel upland, loam upland	0.8
Valley lowland, alluvial fan,humid lowland plain, delta, coastal lowland	1.0
Natural levee, former river channel, sandbar, gravel bar, dune	2.5
Reclaimed land, drained land, lakes and marshes	5.0

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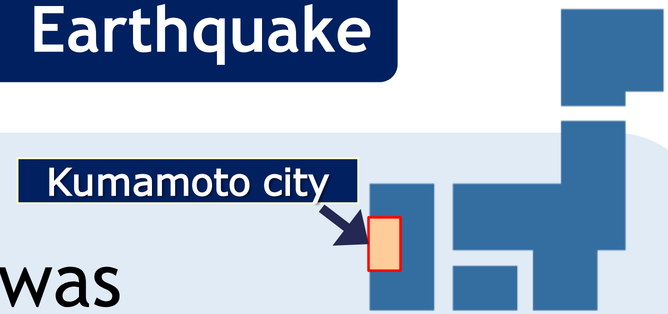
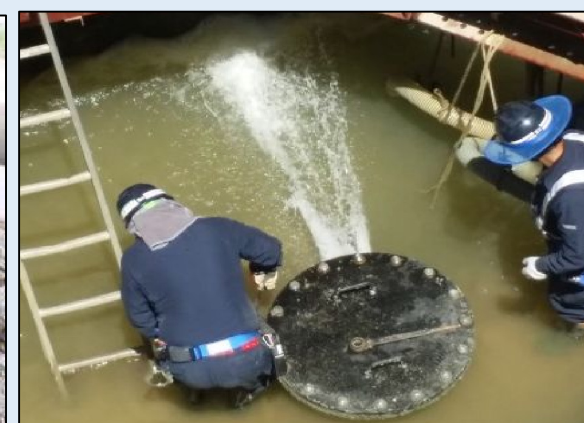
Purpose

In April 2016, the Kumamoto Earthquake



The Kumamoto Region of Japan was hit directly by **two earthquakes** of magnitude greater **than Mw 6.0** that occurred consecutively over a three-day period.



Source: Ministry of Health, Labour and Welfare

Purpose

In the wake of the Kumamoto Earthquake

☞**Reviewed the equation to see if it would need a further update to improve its accuracy of damage estimation.**

Review Process

Develop a database on pipe damage

↓

Analyze and compare the data with pipe damage of other major earthquakes

↓

Compare the estimation result and the actual damage

↓

Evaluate the validity of the equation

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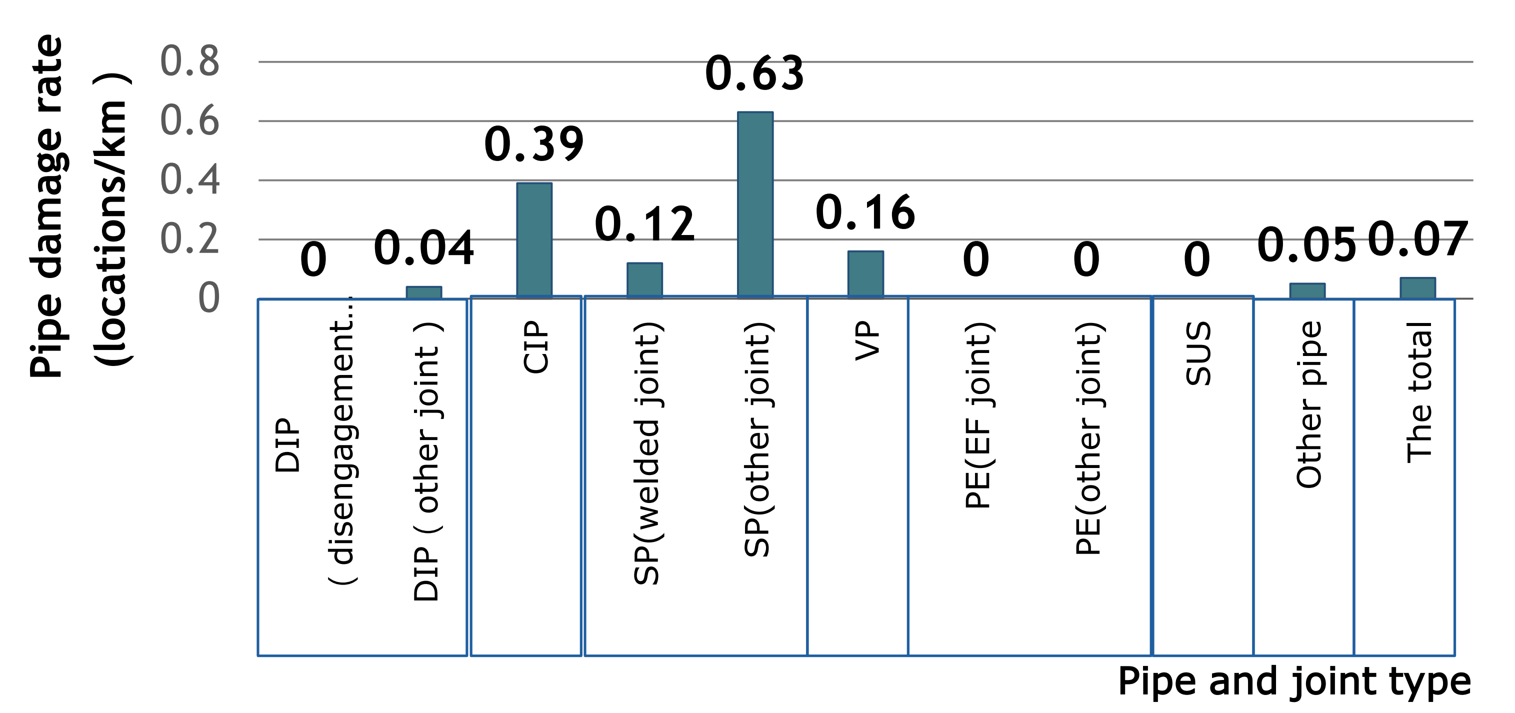
Pipe Damage in Kumamoto City

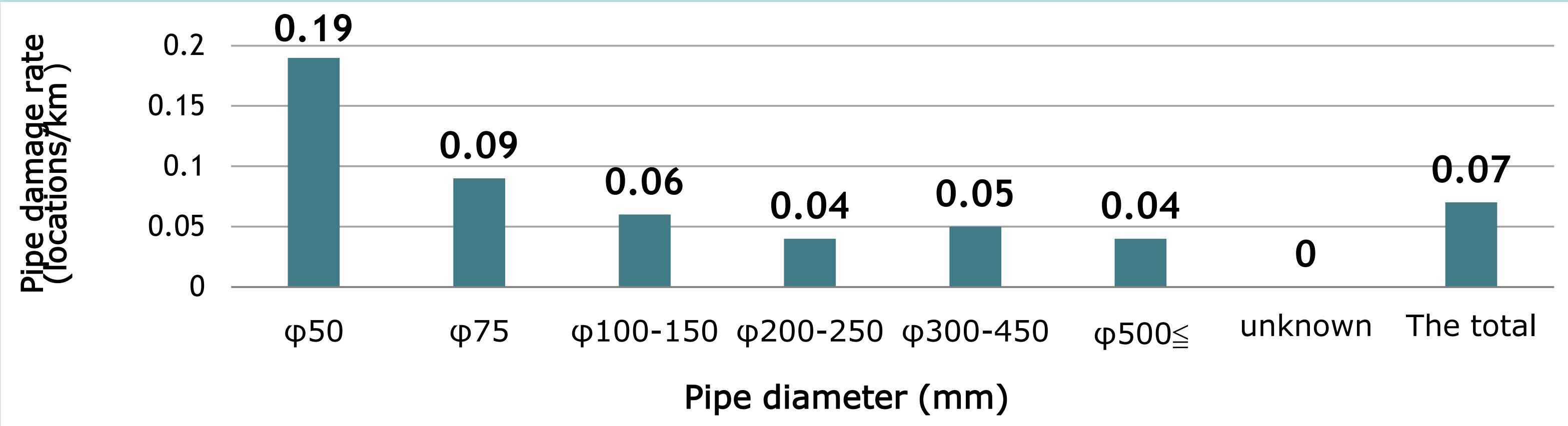
- Analyzed : Pipelines length **3,238 km**
  Number of pipe damages **233 locations**
  *Covers only mains with over 50 mm diameter
- Pipe damage rate : **0.07 locations/km**

Pipe damage rate by pipe material

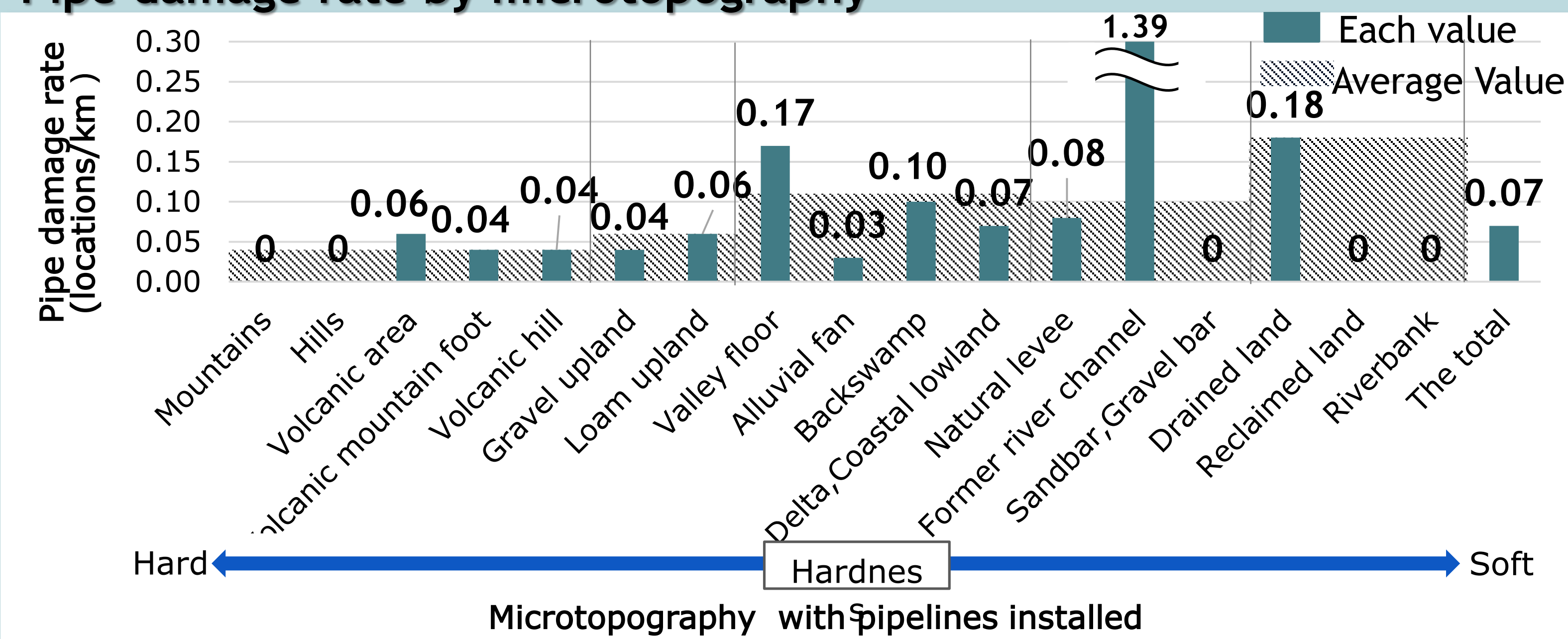


Pipe Damage in Kumamoto City

Pipe damage rate by pipe diameter

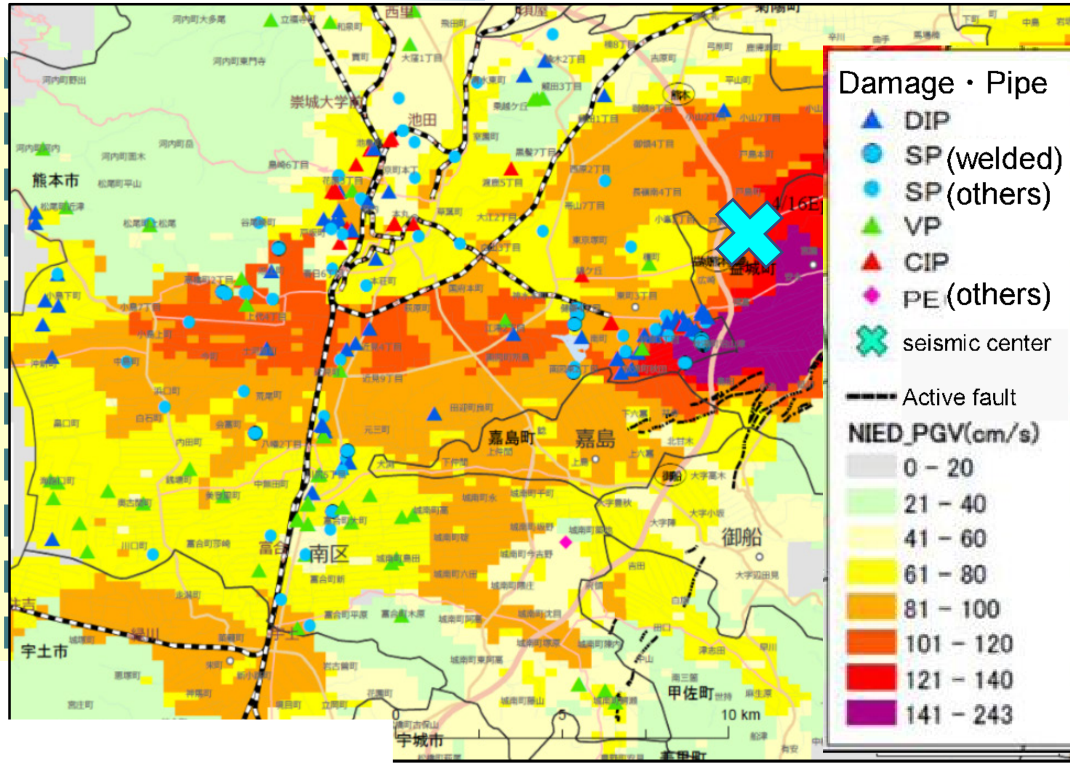


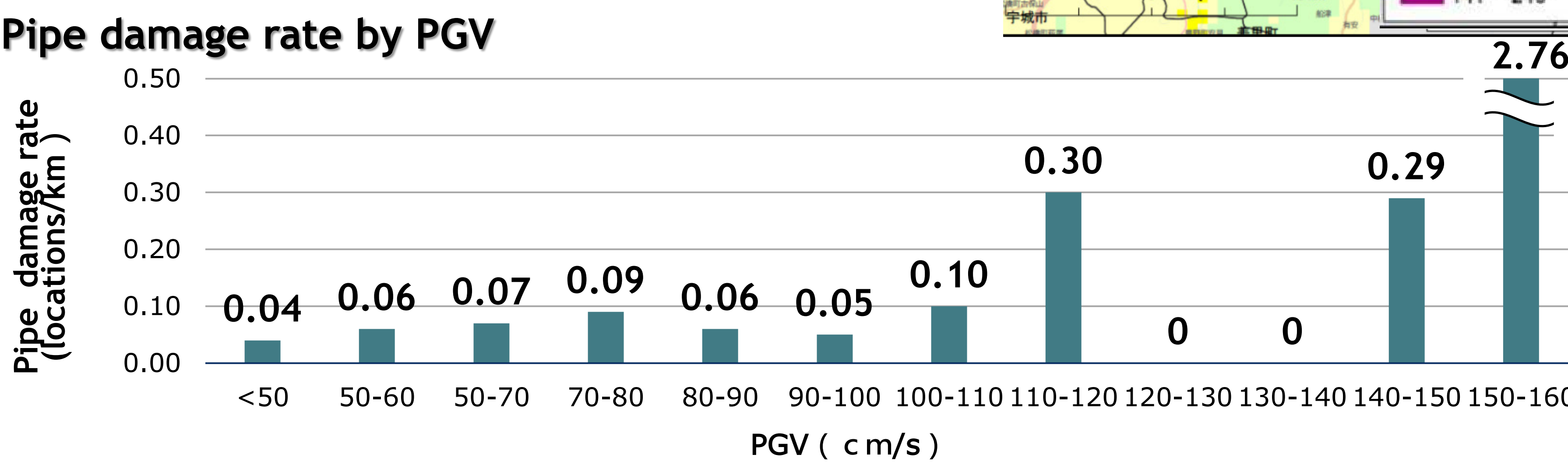
Pipe damage rate by microtopography



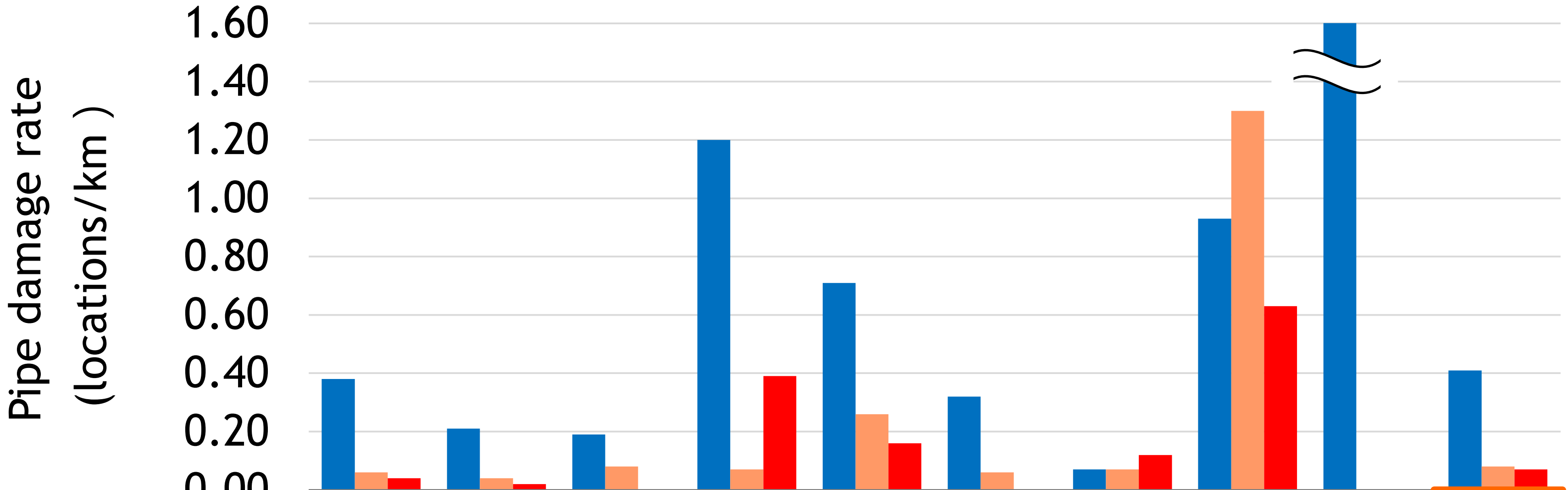
Pipe Damage Rate by peak ground velocity(PGV)

- The pipe damage rates are larger where PGVs are greater.
- This tendency is the same as the current reference damage rate curve of the equation.





Comparison with Other Major Earthquakes



	DIP (A)	DIP(K)	DIP(T)	CIP	VP (TS)	VP(RR)	SP(welded)	SP(other)	ACP	The total
Hyogo pref and Nigata pref	0.38	0.21	0.19	1.20	0.71	0.32	0.07	0.93	4.86	0.41
Sendai city	0.06	0.04	0.08	0.07	0.26	0.06	0.07	1.30	—	0.08
Kumamoto city	0.04	0.02	—	0.39	0.16	—	0.12	0.63	—	0.07

Comparison of Pipe damage rate

- Hyogo Pref※1. and Niigata Pref※2. **0.41** locations/km ⇒ **About 1/10**
- Sendai city※3 **0.08** locations/km ⇒ **About the same**

※1 : 1995 Kobe earthquake
※2 : 2004 Chūetsu earthquake, 2007 Chūetsu offshore earthquake
※3 : 2011 Great East Japan Earthquake

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Evaluation of Validity of the Correction Factors

< Verification method >

◆ For each correction factor…

The ratio of the damage rate of other pipe material/joint, diameter, and microtopography to the damage rate of the reference pipe material/joint, diameter, and microtopography is the value corresponding to the correction factor.

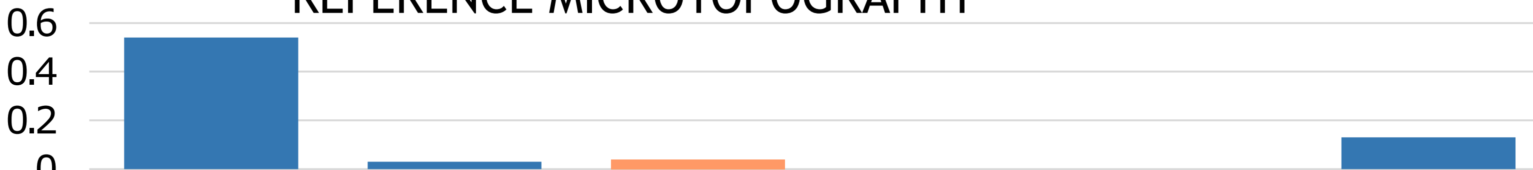
There fore → **Assessed the accuracy of the correction factors by comparing the damage rate of each reference item & other items in the Kumamoto Earthquake**

The reference factor・・・

- **The reference pipe material/joint・・・DIP（A）**
- **The reference diameter・・・・・・・・・・・・・・Φ100-150**
- **The reference microtopography・・・・・・valley lowland, alluvial fan, humid lowland plain, delta, or coastal lowland**

Evaluation Result of the Correction Factors

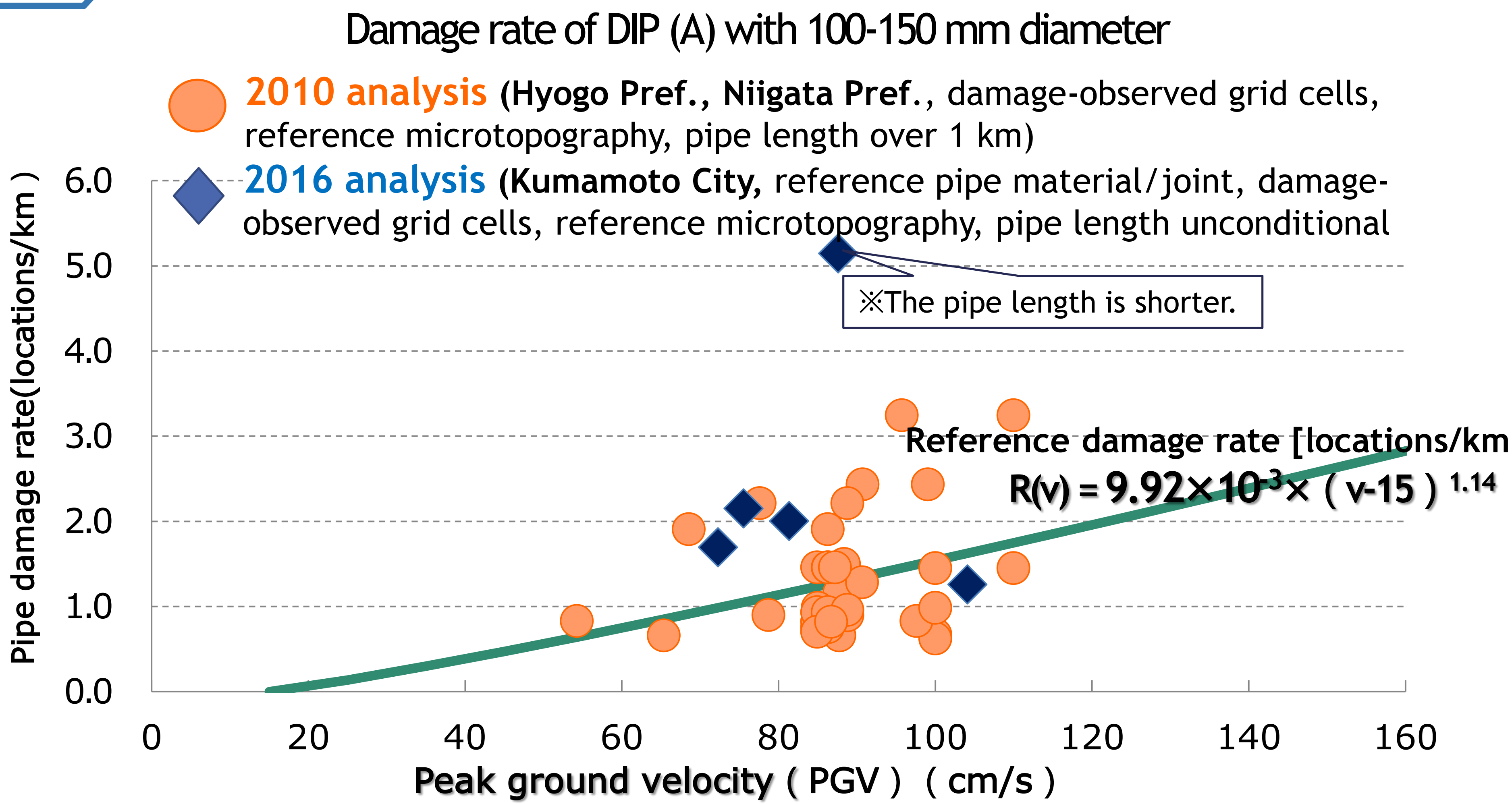
DAMAGE RATE BY PIPE MATERIAL/JOINT FOR THE REFERENCE DIAMETER AND REFERENCE MICROTOPOGRAPHY



	CIP	DIP(K)	DIP(A)	SP (welded)	SP (other)	VP
Pipeline length(m)	26,124	211,508	515,753	3,981	1,664	63,678
Pipe damage (no. of locations)	14	7	22	1	10	8
Pipe damage rate (locations/km)	0.536	0.033	0.043	—	—	0.126
Ratio to the damage rate of DIP (A)	12.5	0.8	1.0	—	—	2.9
			Comparison			
Correction factor(Cp)	2.5	0.5	1.0	0.8/0	2.5	2.5

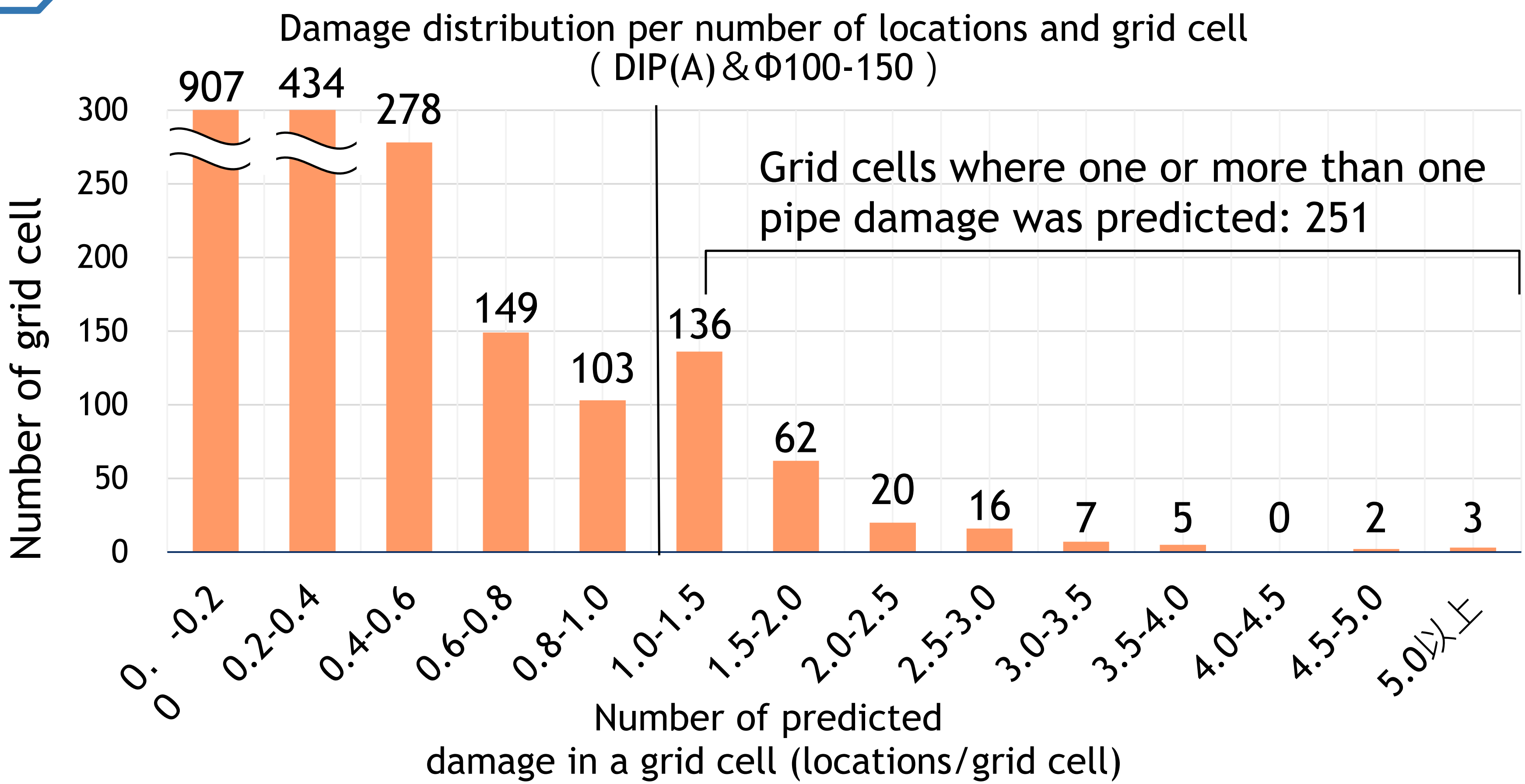
- **DIP (K) and VP, their actual damage rates in relation to DIP (A) are close to the correction factors.**
- **We consider CIP's damage rate was more susceptible to the number of pipe damages than other pipes since its installation length is shorter.**

Assessment of reference damage rate



The distribution of pipe damage rate is similar between the Kumamoto Earthquake and the other earthquakes

Assessment of Pipe Damage Prediction Accuracy



- **The number of grid cells with more than 1 damage predicted was 251**
- **Actual damage 19 grid cells**
- **Actual damage < Predicted damage = Prediction on the safe side**

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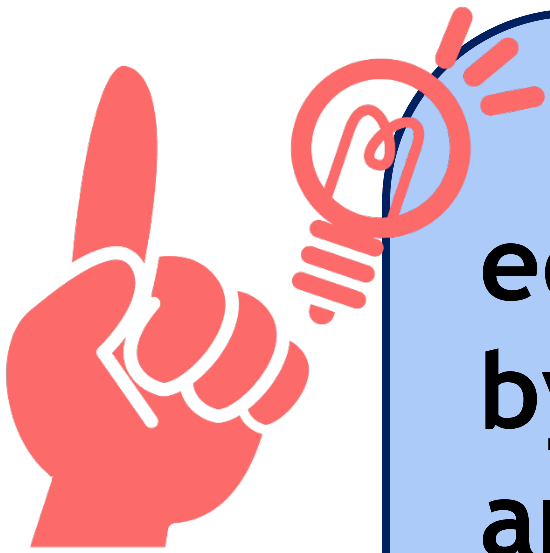
Conclusions

Tendencies of the correction factors and reference damage rates are consistent with the past analysis.

- **No immediate modification is being planned at the moment**

However, the equation might have predicted a little too far on the safe side as it provided a number of damage a few times larger than the actual one. Therefore, this aspect would need further improvement in future.

Conclusions



We expect this equation will be utilized by more utilities to help an effective pipe renewal and replacement for an improved preparedness against future seismic risks!!

We would like to extend our gratitude to the Kumamoto City Water and Sewerage Waterworks Bureau for their data provision as well as to the water utilities and private companies that participated in this review process.

Thank you very much for your kind attention

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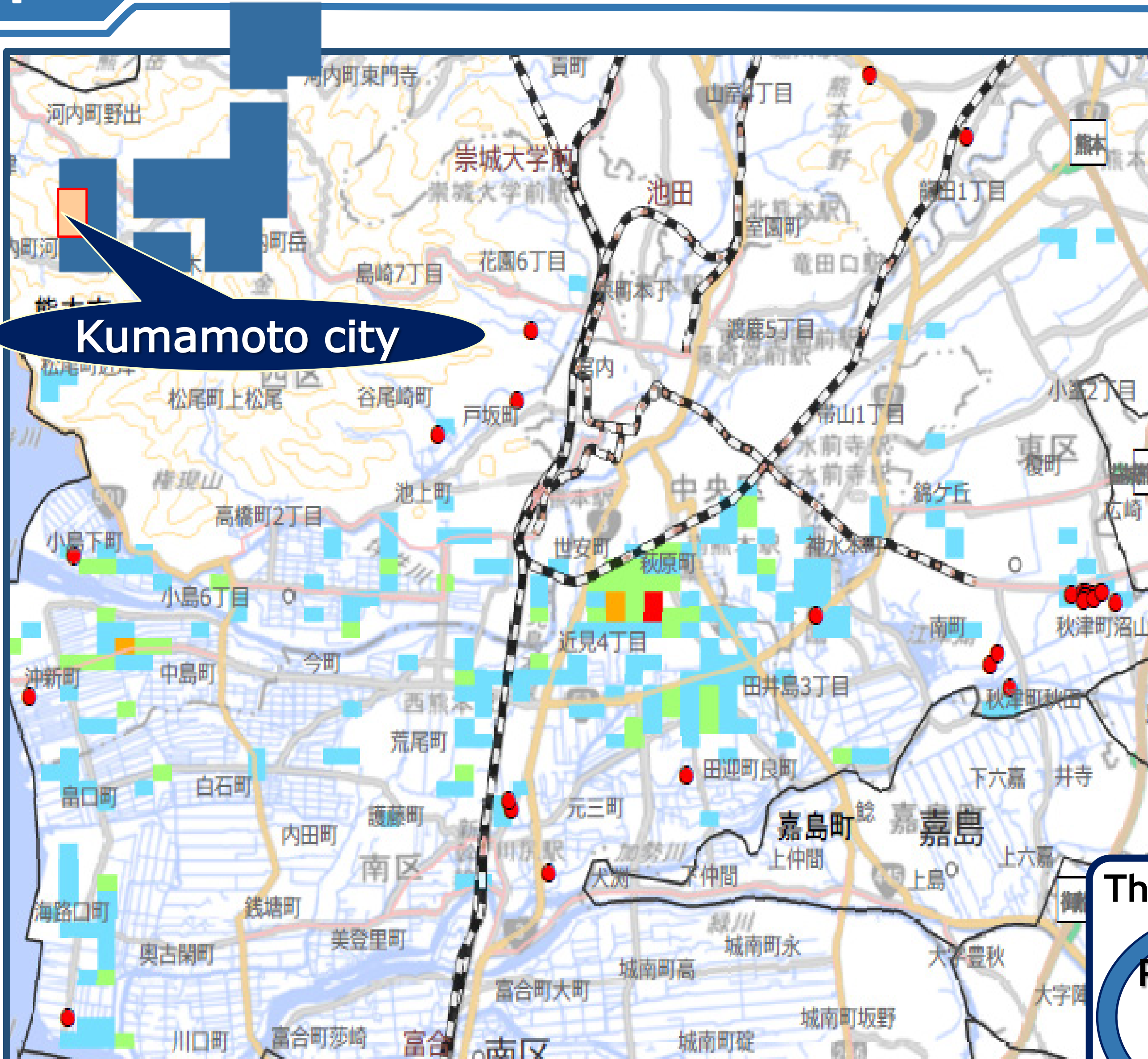
Assessment of Pipe Damage Prediction Accuracy



No. actual damage: 30

● DIP（A） 100–150

No. of predicted damage

- 1.0–2.0
- 2.0–4.0
- 4.0–6.0
- 6.0–8.0
- 8.0<

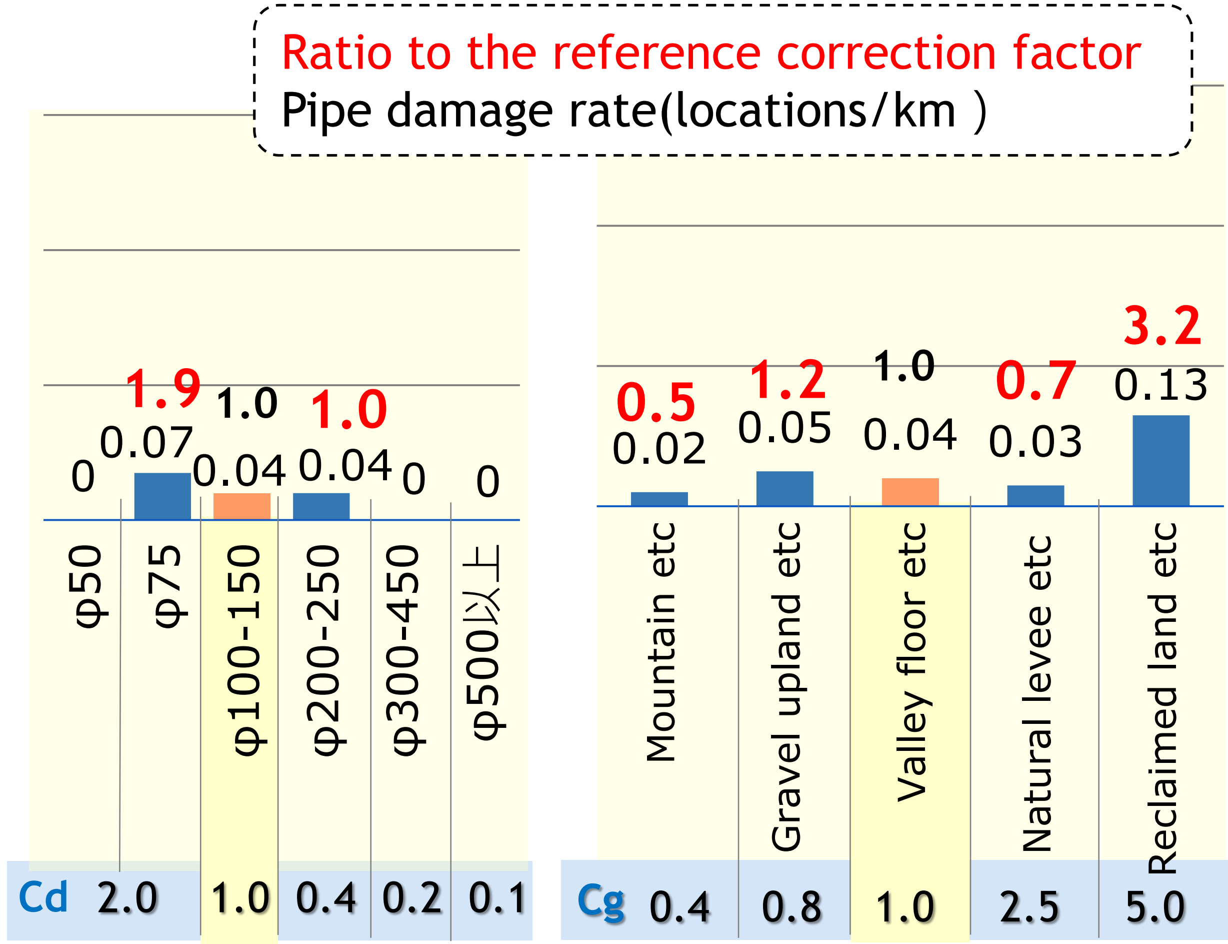
- Predicted damage
  251 grid cells
- Actual damage
  19 grid cells

Prediction made on the safe side not to underestimate damage

The total number of pipe damage

Predicted 957 locations — **4.1** times — **Actual** 233 locations

Evaluation Result of the Correction Factors



DAMAGE RATE BY PIPE DIAMETER FOR THE REFERENCE MATERIAL/JOINT

DAMAGE RATE OF THE REFERENCE MATERIAL/JOINT WITH THE REFERENCE DIAMETER BY MICROTOPOGRAPHY